Research for promoting SUSTAINABLE FARMING SYSTEMS in arid and semi-arid areas of Morocco

Challenges, achievements and future prospects

ICARDA
Science for resilient livelihoods in dry areas

المعهد الوطني للبحث الزراعي
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This book has been written within the framework of the Moroccan Collaborative Grants Program (MCGP) between ICARDA and the National Institute for Agricultural Research (INRA Morocco). This program was established to provide the support needed to develop synergies between INRA and ICARDA scientists.

This book is a summary of the work carried out within the framework of MCGP programs and Aridoculture program.

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Foreword

Prof. Mohammed Sadiki
Minister of Agriculture, Maritime Fisheries, Rural Development and Water and Forests

Dryland farming relies on the unpredictability of weather, particularly precipitation and temperature. It encompasses all aspects of land use in arid and semi-arid conditions, where annual precipitation is only about 20–35% of potential evaporation, severely limiting crop yields. Water conservation is emphasized throughout the growing season in these regions.

In Morocco, semi-arid areas account for 87% of arable land and are home to over 50% of the population, contributing to 55% of the country's crop production. To effectively address the challenges posed by adverse climatic conditions, it is crucial to leverage knowledge gained from research and innovation. Over the last decades, INRA and ICARDA, under the Moroccan Collaborative Grant Program (MCGP), has developed technologies, knowledge, and methodologies tailored to the delicate nature of dryland farming systems and the constraints of natural resources, ultimately enhancing resilience, and better managing the negative impacts of climate change.

Crop production objectives in these drought-prone regions are to improve, stabilize and sustain yields through selection of species, and cultivars and cultural practices that will reduce yield fluctuations and permit stable production. The emphasis should be placed on the inter relationships of environment, soil and crop management factors on crop productivity, which are limited not only by low and uncertain rainfall, but also by high extreme temperatures and shallow soils.

Research thrusts comprise agro-ecological and socio-economic environments characterization, natural resources conservation, including soil, water, and genetics; efficient use of agricultural inputs; development of low input technologies; release of resistant germplasm to biotic and abiotic stresses; conception of alternative and flexible cropping systems; integration of crop and livestock; social and economic aspects of technology development; and implementation of appropriate approaches for technology transfer, impact assessment, and information dissemination.

Results outlined in this review clearly indicate the importance of agricultural research and technology transfer for preservation of natural resources, and achievement of sustainable agriculture that will feed future generations. It also presents prospects for building resilience to improve the livelihoods of Moroccan rural communities.

The key component of this book introduces research axis results that aim conserving natural resources, improving the efficiency of resource use, and research schemes to developing crop varieties that can improve productivity by increasing yield, reducing the crop cycle to mature, increasing tolerance to stresses such as drought, salinity, pests, and disease, and improving technological quality of crops, in all, solutions on the ground that farmers can adopt to enhance positive effects towards greater adaptive capacity.

Finaly, we are very satisfied to observe that several research outcomes obtained within this program are in perfect agreement with the objectives of the Generation Green Strategy (2020-2030) which aim to make the agriculture more resilient and sustainable in Morocco.

TABLE OF CONTENTS

PART I
BIOPHYSICAL AND SOCIO-ECONOMIC FEATURES OF ARID AND SEMI-ARID AREAS OF MOROCCO

PART II
SUSTAINABLE FARMING SYSTEMS

PART III
WATER USE AND WATER USE EFFICIENCY

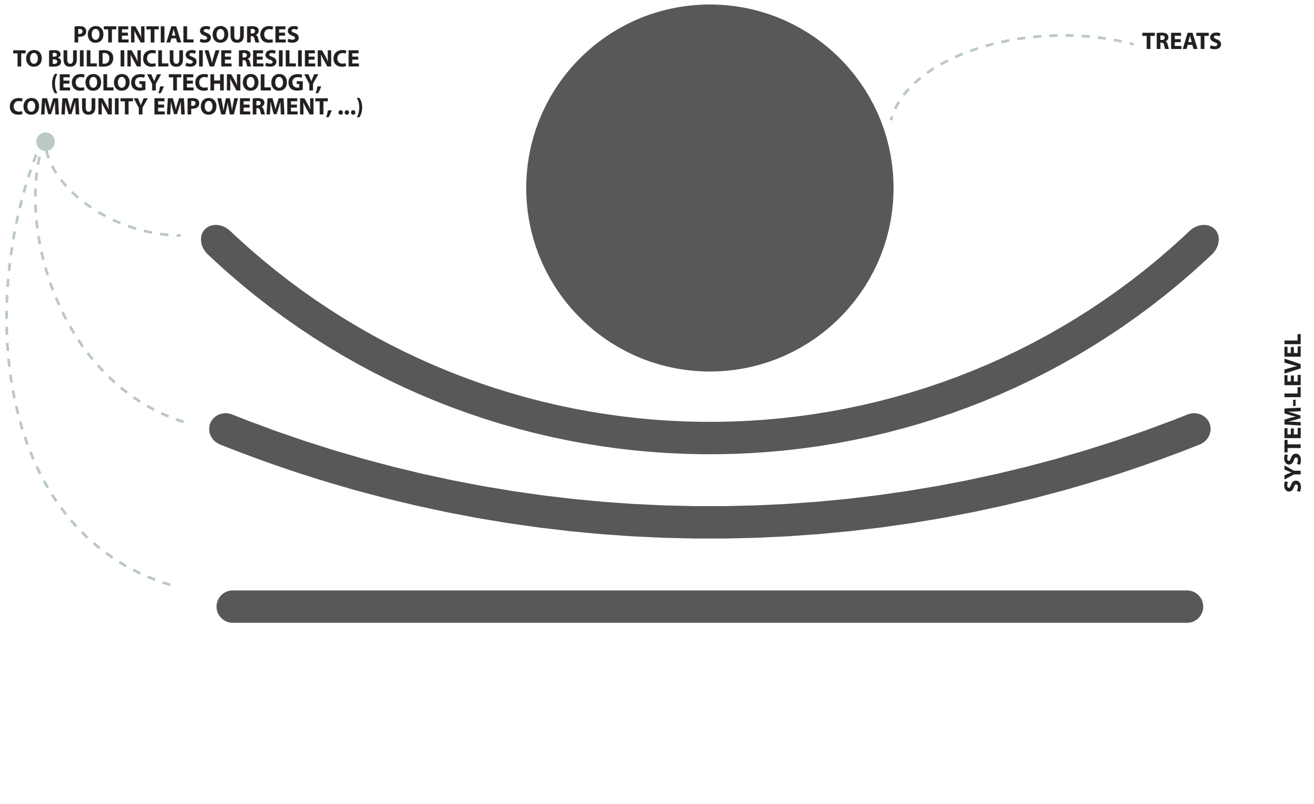
PART IV
SOIL FERTILITY AND NUTRIENT MANAGEMENT

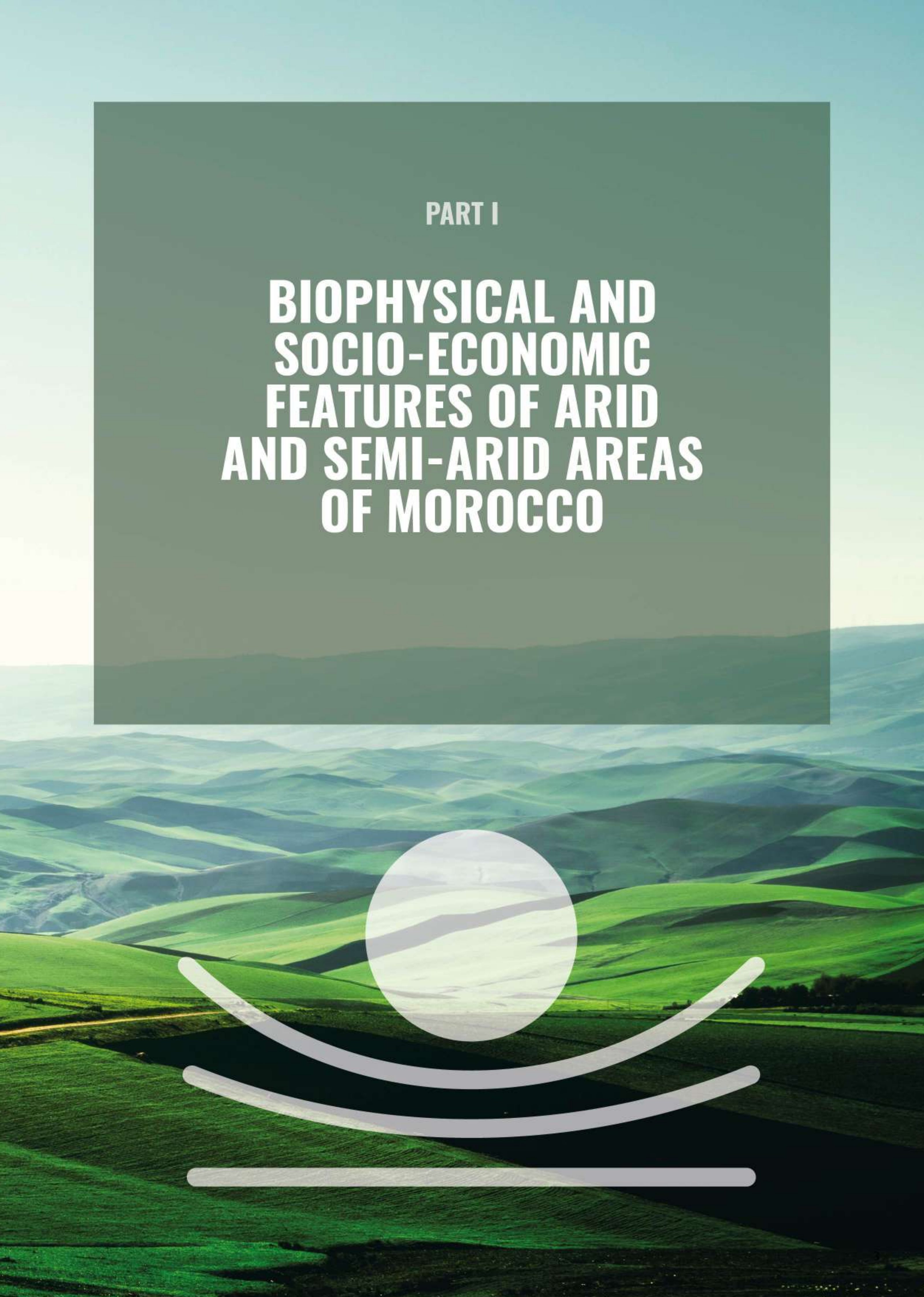
PART V
CROP GENETIC IMPROVEMENT

PART VI
DISEASE AND WEED CONTROL

List of tables

List of figures


POTENTIAL SOURCES
TO BUILD INCLUSIVE RESILIENCE
(ECOLOGY, TECHNOLOGY,
COMMUNITY EMPOWERMENT, ...)
TREATS
SYSTEM-LEVEL



PART I

BIOPHYSICAL AND SOCIO-ECONOMIC FEATURES OF ARID AND SEMI-ARID AREAS OF MOROCCO

AGRO-ECOLOGICAL CHARACTERIZATION AND MODELLING: TOOLS FOR DECISION SUPPORT IN AGRICULTURE AND CROP PRODUCTION MANAGEMENT

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SYNOPSIS

In rainfed agriculture, low and highly variable available water is the major constraint to crop production. Managing risks associated with increasingly variable and unpredictable climate is the key to successfully adapting agriculture while reducing the vulnerability and dependence brought about by climate-related adversities.

Simulation models and cereal yield forecasting have been developed, tested, and validated; and baseline data on climate, soils, and crops has been generated. Results of this research are outlined, and prospects are suggested.

I. PROBLEMS OF WATER DEFICITS IN MOROCCO

The main adverse condition in rainfed agriculture in Morocco is water limitation, aggravated by irregular rainfall, high temperatures, poor and eroded soils, diseases, and insects in addition to constraints imposed by the socio-economic environment. The long and severe droughts that particularly struck Morocco during the eighties and nineties had dramatic effects on Moroccan agriculture. Furthermore, during the 20th century, the country experienced more than ten major dry periods (Driouech *et al.*, 1997), whose extent was more or less widespread over most of the country and of moderate to severe intensity. However, the most severe are those of 1904-05, 1931-34, 1944-45, 1982-84, 1994-95 and 1999-2000. The year 1994-95 is the driest of the century.

The frequency of drought, which was 1 year out of 5 before the 1990s, became 1 in 2 in the last decade of the 20th century (Karrou, 2006). The duration of two droughts has never exceeded 13 years and all decades have had at least one dry year. Similarly, the persistence of the drought can last up to 6 years (cases of 1930-35 and 1980-85). Changes in rainfall evolution and trends in Morocco over the past 45 years show (Driouech, 2006): (i) significant downward trends in cumulative precipitation from the rainy season to the northwest and spring rainfall National level; (ii) a significant increase in intra-annual drought periods, especially in February-March-April; An important period for national agriculture; and (iii) a decrease in the total annual number of rainy days. There is no clear cyclic phenomenon and rainy and dry years. However, dry years are becoming more and more common. In Settat region for example (Benaouda *et al.*, 2010), the variability in rainfall is very high with a coefficient of variation of 33% (Figure 1).

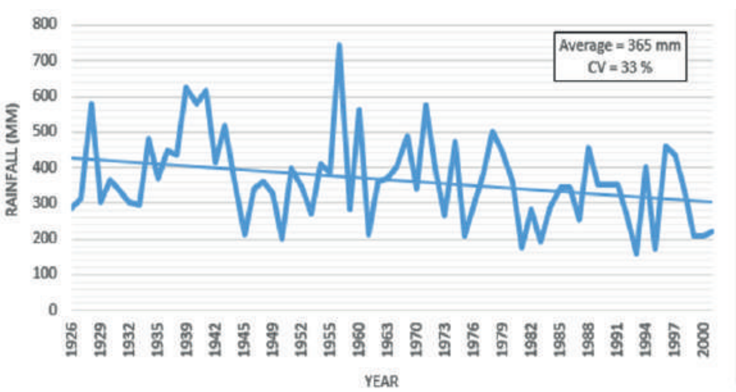

Figure 1: Rainfall evolution at Settat Region

As for future projections of climate change, according to the latest IPCC report, Morocco will be exposed to: (i) an increase in average temperature; (ii) a decrease, according to certain models, of precipitation; and (iii) a reduction in soil moisture. These projected climate trends and changes will definitely have negative impacts on natural resources and the sustainability of Moroccan agriculture (Karrou, 2006).

The high variability of water availability for rainfed crops in Morocco (10 to 25 km^3/year) (Ambroggi, 1988; Driouech, 2006; Karrou, 2006) has led INRA to develop appropriate methodological tools to understand this diversity. The first step in this path is good knowledge of the physical environment, its variability and its effects on agricultural production.

This approach was revealed in studies of frequencies of the precipitation regime, evapotranspiration and climatic deficit (El Mourid and Watts, 1993; El Mourid 1991; Ameziane *et al.*, 1990). In addition, climate and yield relations have been carried out on several crops and in several regions of Morocco (Ameziane *et al.*, 1990); however, the lack of climatic data over long series (over 30 years) was a major constraint to conventional climate studies. To alleviate this constraint, mathematical modeling was used based on agro climatic models of growth and plant development (El Mourid, 1988; Ameziane *et al.*, 1990). Research, on agro characterization, has been carried out by the National Institute of Agronomic Research (INRA-MOROCCO), along with the National Meteorological Directorate (DMN), ICARDA, and EU since 1990. The developed and validated models and results are outlined in this review.

II. SPATIAL DATA GENERATOR (SWG)

Swg allows the generation of long series of climatic data essential to agricultural production. It was developed at ICARDA (Goebel, 1990) and validated in Morocco (Zeggaf *et al.*, 1994). It consists of three parts designed to (i) parametric estimation which consists of reducing the original climate data of each weather station into a set of statistical coefficients (ii) the stochastic reproduction of the synthetic climatic data sequences from the previous coefficients, and (iii) spatial interpolation of coefficients between meteorological stations. Thus, synthetic data on rainfall, maximum and minimum temperatures and solar radiation can be generated for any locality in the study area where there is a lack of climatic data (El Mourid *et al.*, 1996).

III. MODELLING APPROACH AS A BASIS FOR PLANNING AND MANAGING CROP PRODUCTION

Crop management is complex due to the interaction of different agricultural, agronomic and environmental factors (Soil, radiation, wind speed, etc.), and more particularly, with climatic conditions. The choice of appropriate management for a given region characterized by a given climate may require years of field experiments and heavy spending. The major problem of this conventional approach is the complex interaction of the factors mentioned above, which determine the yield of the crops. Furthermore, the extrapolation of the results obtained from a limited number of environmental combinations to other environments is difficult, or misleading. The choice of modelling in this context is crucial and complementary, it can help to evaluate the interaction between soil and climate by combining long climatic series. Modeling techniques applied to agriculture can be useful to define research priorities and understanding the basic interactions of the soil-plant-atmosphere system.

III.1. THE GRAIN GROWTH AND DEVELOPMENT MODEL (SIMTAG)

The model Simtag has been validated in Morocco (El Mourid, 1988). It is designed to simulate the growth, development, yield and its components of bread wheat as well as the evolution of water reserves and their uses by plants. It simulates the potential conditions where mineral nutrition is optimal and in the absence of weeds and diseases under varying conditions of water supply and different types of soil and crop varieties. Simtag also allows generating series of crop yields over a long period for a given region, a series that is lacking in the majority of cases (El Mourid, 1991). Simtag was linked directly to Swg to get Simtagwg (El Mourid *et al.*, 1996).

El Mourid (1988) evaluated SIMTAG in the semi-arid region of Morocco by comparing model outputs to field experiment results for several crop attributes, namely, (i) crop yield and yield components; (ii) crop growth through leaf area and dry matter accumulation; (iii) crop phenology; and (iv) soil moisture availability. Results showed that the model is very sensitive to varying environments, agronomic practices, and genotypes. The model simulated yields in the range from 500 kg ha^{-1} to 5800 kg ha^{-1}, and in better conditions it can simulate yields of 8000 kg ha^{-1}, whereas the observed data ranged from 300 kg ha^{-1} to 5200 kg ha^{-1}. In bread wheat, the comparison of simulated results over 21 years showed that WUE of grains is reduced by about 25% from an irrigated to a dry regime (0.88 dry) versus 1.16 g m^{-2} mm^{-1} Under irrigated conditions) (Lamine, 1991).

Grain yield, total above ground dry matter, and dry matter at anthesis were predicted with 3%, 12%, and 7% average bias, respectively, over two growing seasons. However, yield components were predicted with larger deviations from observed data, usually greater than 20%. Spikes number m^2 had the highest deviation even though standard deviations were similar for observed and estimated values. Maximum green area was overestimated, and discrepancies between observed and estimated values were very large. Soil moisture and phenological stages were reasonably estimated. Kernel weight and green area had the largest discrepancies between observed and estimated values.

SIMTAG can be used to test new research hypotheses and determine knowledge gaps in wheat production under Moroccan semi-arid conditions. In addition, it can help derive programs and possibilities for improving wheat yield in the region.

To know critical crop development stages occurrence and how the environment affects them, phenology characterization showed that irrigation increases life cycle duration for all the studied species, especially the grain filling period. Differences were noticed among species, and varieties within each species (El Hafid *et al*. 1996).

Comparison of observed and simulated data revealed that irrigation reduced the gap between the two types of values. Indeed, Simtag model was more accurate in predicting heading, anthesis and physiological maturity stages. Results showed that irrigation tends to reduce the difference between the simulated values and those observed. On the other hand, this difference depends in part on the genotype but especially on the phenological stage. In this respect, the prediction tends to diminish while moving towards the stages of development. As a result, the accuracy of the model is more efficient for phenological stages of heading, flowering, and physiological maturity. Thus, in the case of flowering and maturity, the mean absolute error does not exceed, in the majority of cases, two weeks. The standard deviations for these two stages are the lowest; the model is therefore more precise in the prediction of flowering and maturity stages (El Hafid *et al*., 1996).

Lamine *et al.* (1993) used SIMTAG to simulate the effect of water regime on bread wheat productivity over several years. Results showed that the timing of supplemental irrigation varies from one year to another and between types of soils. Irrigation at tillering or at heading produces the best results in deep soils. On shallow soils, irrigation applied at heading is better than that applied at tillering or at anthesis.

Indeed, on deep soil and in terms of average of years and varieties, irrigation at the beginning of tillering and that applied at the beginning of the heading produced the best yield (4950 and 4880 kg ha^{-1} respectively). On shallow soil, irrigation limited at the beginning of heading gives the most substantial results (3760 kg ha^{-1}). Concerning the inter-annual variability of yields, it is more pronounced in the case of a low soil water reserve. The date of supply of water allowing the best stability is that of the beginning tillering on the deep soil and that of the beginning of heading on the shallow soil.

For both types of soil, the dates of supplemental irrigation that provide the best performance improvements at the same time yield the best water use efficiencies. This is mainly done by improving the ratio of transpiration to evapotranspiration.

III.2. SIMULATOR OF YIELD DISTRIBUTIONS (MULTISIM)

The method consists in characterizing the distribution of yields over time for a given soil and a given rotation. It is based on surveys of experienced farmers. The means, the variance and the covariance were used as inputs of Multisim which will generate a series of crop yields following a normal distribution. This normal distribution is obtained using the Box-Muller approximation. The Box-Muller method (Box and Muller, 1958) consists in generating pairs of random numbers with reduced normal center distribution from a source of random numbers of uniform distribution.

The comparison of the yields estimated by Multisim and those simulated by Simtag makes it possible to quantify the difference in yield to be gained by an appropriate transfer of technology or the development of an adequate technology (Boughlala *et al*., 1996; Nordblom *et al*., 1994).

III.3. CROPSYST MODEL

Cropsyst model using data from the on-farm trials at Ouled Zemam and Bradia communities in the Tadla region was evaluated to simulate planting date, variety, and deficit irrigation trials. Simulated and observed yield and evapotranspiration were compared (Oweis *et al*., 2007). Results showed that yield is increasing with early planting dates in both simulated and observed simulations. Indeed, the grain yield can be increased by more than one ton when planting date is advanced to October. Observed and simulated grain yield and evapotranspiration were highly correlated, which was not the case for variety and deficit irrigation simulations (Oweis *et al*., 2007).

Prediction of the impact of drought on wheat yields to adapt cropping management to the semi-arid climate is important. In this regard, WOFOST and CropSyst models were adapted to local agro-climatic conditions in Morocco (Bregaglio, 2015; Confalonieri *et al*., 2013). Results showed that both models achieved good estimations, with an R^2 always higher than 0.91. Results of spatially distributed simulations were then analysed for the whole country in terms of different response to drought. The spatially distributed application of the models confirmed their ability in differentiating the response to different degrees of drought. Despite the similar performances shown by the two models during field-level calibration and evaluation, their application to the whole Moroccan wheat cropped area highlighted the different behavior of the two models when applied to seasons differing for the degree of drought, because of the different approaches used to reproduce key processes involved with wheat growth. Hence, this work encourages the implementation of CropSyst and WOFOST in multi-model, operational crop yield forecasting systems capable of reproducing the impact of drought in the semi-arid regions. Such system would provide an effective support to Moroccan stakeholders, via timely wheat production forecasts able to properly manage policies aimed at satisfying internal demand.

III.4. GENOTYPE-BY-ENVIRONMENT INTERACTION ON CROP GROWTH SIMULATOR (GECROS)

The crop growth model GECROS (Genotype-by-Environment interaction on CROp growth Simulator) developed in Wageningen by Yin and van Laar (2005) can be used to assess the yield responses of cereals to environmental conditions, genotypic characteristics, and genotype by environment interactions. The model summarises various physiological processes taking into account the current knowledge of physiological mechanisms and their interaction at plant and crop levels (Yin and van Laar, 2005).

Comparing the simulated versus observed data, the statistical analysis showed that the model output turned out to be satisfactory for estimating grain yield and aboveground biomass at anthesis and maturity. However, estimates of nitrogen concentration in storage organs and yield components such as the number of grain/m^2 and grain weight (TKW) need further improvement.

III.5. AGRICULTURAL PRODUCTION SYSTEM SIMULATOR (APSIM)

In another study, Agricultural Production System simulator (APSIM) has been used to simulate climatic and soil management effects on crop growth and crop yield.

A key feature of APSIM is the central position of the soil rather than the crops; changes in the status of the soil state variables are simulated continuously in response to weather and management. Thus, the APSIM model seems to be appropriate to simulate the impact of different soil management option in conservation agriculture practices.

The regression of observed and and APSIM simulated grain yield and biomass, across farmers and 2 years of the experiments showed an R^2 of 0.94 and 0.95 for grain yield and biomass, respectively. This suggests a deviation of less than 5% between the simulated and the observed yield and biomass.

The calibrated APSIM model may be used under similar (soil and climatic) conditions in rainfed semi-arid areas in Morocco for decision support in nitrogen fertilizer recommendation, weed completion, WUE using different rotations, or to simulate appropriate wheat planting dates and possible impact and prediction of climatic changes in wheat production in semi-arid areas of Morocco.

IV. EDAPHIC DATABASE

A synthesis of the existing soil maps resulted in the elaboration of a schematic map at 1/500,000 of the main soil types (El Oumri *et al*., 1994). This map was digitized using the Idrissi software to create raster images of the soil units. In parallel to the digitization of the map, analytical data from about 50 soil profiles representative of each soil unit were prepared according to the requirements of the Simtag growth model.

V. AGRONOMIC DATABASE

An agronomic database of the genetic characteristics of varieties grown in Morocco and the technical patterns was compiled from more than 10 years of field experiments (Bennani *et al*., 1993; El Hafid *et al*., 1996). The data validated the models used for agro-ecological characterization. Series of yields over periods ranging from 5 to 10 years have been collected for areas where Multisim has been validated. The mathematical simulation tools developed have been tested and validated mainly in the arid and semi- arid zones of western central Morocco and partly in the Saïss.

VI. CLIMATE MAP INDICES

The study was carried out in a test zone between Casablanca-Settat-Benguerir-Chemaia and Safi (32 ° 00' N to 33 ° 30' N and 7 ° 30' W to 9 ° 30 W). The precipitation simulation results confirmed the existence of a double, north-south and west-east rainfall gradient and that all regions experienced high inter-annual fluctuations with coefficients of variation oscillating from 33.7% to 35.7%.

The variation in temperature is less important; although the temperature difference between the hottest month and the coldest month oscillates between 9 and 18 ° C as we move away from the sea. The absence of too low temperatures in these regions allows for continuous crop growth and development in winter.

The crop establishment in autumn is faced with lack of substantial rainfall. In addition, the probabilities of sowing dates were established and the quantities of significant first rains were measured (El Mourid and Watts 1989). Indeed, in arid and semi-arid areas in Morocco, sowing date is perhaps the most crucial step in crop establishment and crop production. If it is done correctly and on time, it will lead to good production in winter sown cereals. However, deciding on planting time is not an easy task, especially under limiting and erratic conditions of rainfall.

Any delay in plating date can affect crop yield negatively. Any significant delay exposes the crop to late season water stress and high temperature. The first significant rain (FSR) can be considered a dependable tool for deciding on the best planting time. The FSR is defined as the period after October 1 during which there is enough rain to ensure crop germination and stand establishment.

Analysis of the FSR in Settat and Berrechid regions (central part of Morocco) is shown in Figure 2. The 25 mm rain is enough to allow successful planting (this amount differs depending on soil type and depth). The figure shows that in the wetter region (Berrechid) farmers can start planting their cereal crop earlier from 1 November, whereas in Settat they have to wait until 10 November. FSR can be used to set planting time in areas where no demonstration trials have been conducted (Benaouda *et al.*, 2010).

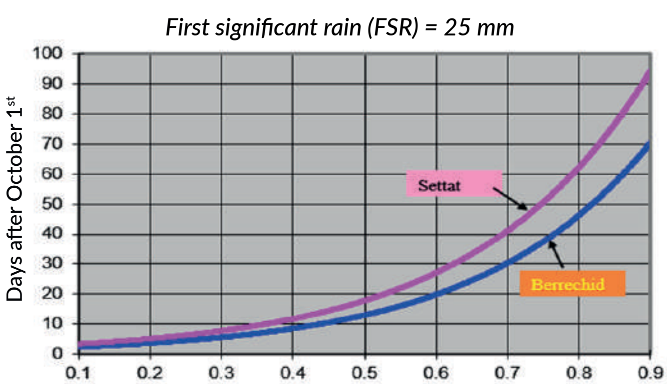

Figure 2. First significant rain in Settat and Berrechid (Benaouda *et al.*, 2010)

Early seeding from early November to 30 November was the best in 70% of the time. However, crops face early-cycle droughts after surveys (November-January) (defined drought-like the probability of having 30 days with less than 30 mm). The risk of drought at the beginning of the cycle is ranging from 30 to 90% essentially following the west-east rainfall gradient. Thus, one year out of three (1/3) would be considered dry in the Doukkala, West of Abda, Chaouia, while the Rehamna and Hmar would experience a quasi-systematic dryness of beginning of the growing season (70 to 90%).

The Swg/Simtag was also used to characterize the production environment and the risk assessment of spring drought (severe water deficit in March-April). In the study area, the analysis shows that the end-of-cycle drought risks are also common and range from 20% to 90%. Thus, the Atlantic coast and the upper Chaouia would have a risk of one year in five (20%); Chaouia, Doukkala, Abda, one in three (30%), whereas this risk is systematic in the Rehamna and Hmar (90%).

VII. RAINFALL PROBABILITY AND VARIABILITY ANALYSIS

Deciles are one of the statistics used to provide an indication of the spread of data in a data set (e.g. a collection of rainfall observations at a site). This is a method developed by Gibbs and Maher (1967). It is based on the arrangement of rainfall data in deciles called d1, d2, d3, d4, d5, d6, d7, d8 and d9 Corresponding respectively to the values 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 of the Cumulative probability. The group of the lowest 20% (d1, d2) is much lower than normal. The deciles d3 and d4 correspond to the situation of the 20% which are below normal. The next 20% (d5, d6) is close to normal. As superior to normal, they represent, respectively, Groups of deciles (d7, d8) and (d9, d10). This formula has the advantage of being based on a Simple calculation method; it is more precise and allows uniformity in the Classifications of drought. Its major disadvantage is that it requires a lot of Precipitation data to arrive at accurate calculations.

In Figure 3 using Sidi El Aidi Experimental Station as an example, the 1998-1999 growing season (blue curve) was dry between October and Mid-November, wet between Mid-November and January, but dry again in February and April.

The 1999-2000 cropping season was wet early in the season. But, a period of drought occurred from January to Mid-March. Rain resumed at the end of the growing season (Figure 4).

Figure 5 shows a different behavior. However, the season was wet from the end of November, but it has experienced a period of drought from Mid-January to the end of April.

INRA Morocco used the method of deciles calculated over several years and the growth model of wheat SIMTAG to make scenarios of wheat production in the region of Chaouia. It is clear that the combination of the information generated by the tools described

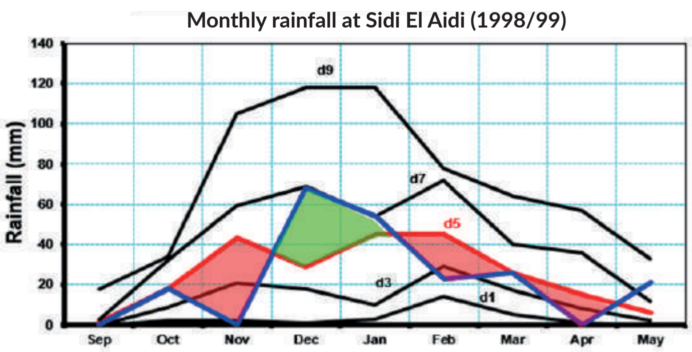

Figure 3. Annual rainfall probability at Sidi El Aidi Experimental Station during 1998- 1999 cropping season

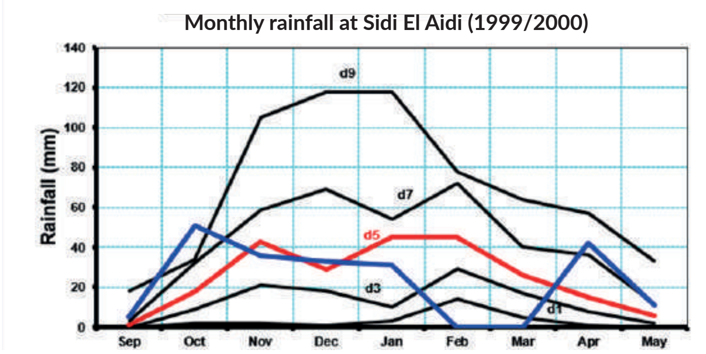

Figure 4. Annual rainfall probability at Sidi El Aidi Experimental Station during 1999- 2000 cropping season. cropping season

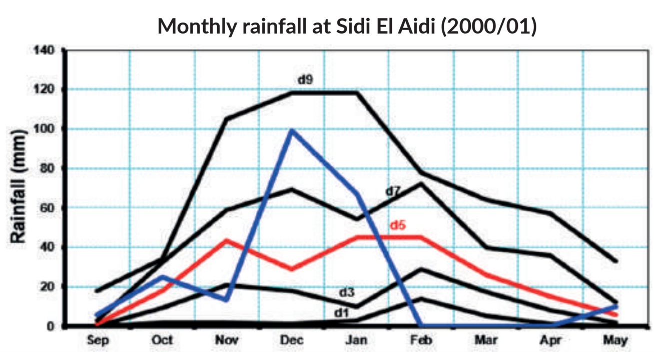

Figure 5. Annual rainfall probability at Sidi El Aidi Experimental Station during 2000- 2001 cropping season.

above, including the seasonal forecasting tools developed by Morocco, whose rainfall success scores sometimes exceed 60% depending on the region and the timetable considered, can help to better identify early warning of drought.

The disadvantage of the index is that it compares the rainfall deficit in the current month with rainfall for the same month in the history of the station and does not consider the cumulative effect of rainfall deficit.

VIII. STANDARDIZED PRECIPITATION INDEX (SPI)

This index is developed by McKee *et al.* (1993). It is used to quantify the Precipitation at different time scales. Soil moisture conditions respond Precipitation anomalies on relatively short scales; On the other hand, Groundwater flows, surface run-offs and in the storage of water in Reservoirs are related to long-term precipitation anomalies.

The procedure for determining the SPI involves the following steps: The procedure for determining the SPI involves the following steps: (i) Determination of the probability function of a long series of precipitation at a Time scale; (ii) Calculation of the cumulative probability of the series in question; and (iii) Normalization of precipitation so that SPI values follow a normal distribution centered with an average of 0 and a standard deviation of 1. Positive values Precipitation above the median and those below the Median values have negative values.

SPI is calculated using the following formula:

$$SPI = (Pi-Pm) / \sigma$$

Pi = Precipitation of year (i) at a given time scale (1 month, 3 months, 6 months, 12 months),
Pm = Average precipitation of a long series of data
σ = Standard deviation.

The classes of drought severity according to SPI are presented in the table 1:

Table 1. Drought severity classes according to SPI

SPI value	Class
> +2.0	Extremely wet
+1.5 to +1.99	Very humid
+1.0 to +1.49	Moderately moist
-0.99 to +0.99	Close to normal
-1.0 to –1.49	Moderately dry
-1.5 to -1.99	Severely dry
< -2.0	Extremely dry

Neither the Percent of Normal nor the Decile drought indices are able to assist decision- makers with the assessment of the cumulative effect of reduced rainfall over various periods. Neither of these indices can describe the magnitude of the drought compared with other drought events. The Standardized Precipitation Index can alleviate both of these principal shortcomings of the other indices, while at the same time being less complex to calculate than some of the other drought indices.

Drought occurs when SPI is negative. Drought is moderate for SPI -1.5 to 0, severe for -2 to -1.5 and extreme for values lower than -2. Figure 6 shows that there have been many drought episodes since 1970's in Morocco.

At sidi El Aidi region, the SPI has been calculated for two periods of the growing season: October-December (cereal crop establishment) and January-March (main growth period). Figure 7 shows that during the

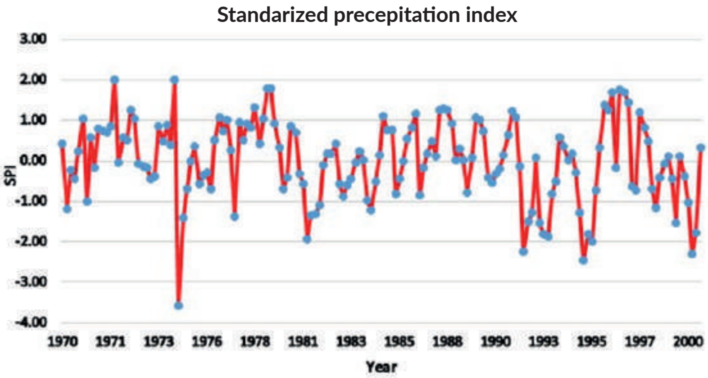

Figure 6. The standardized precipitation index at Sidi El Aidi, Morocco

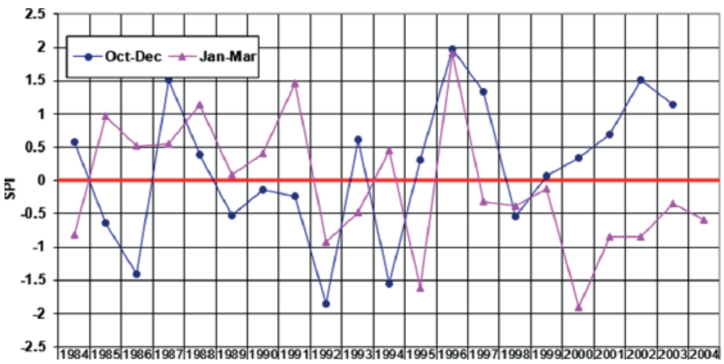

Figure 7. The standardized precipitation index at Sidi El Aidi, for two periods of the growing season

last four years, the first period has been wetter than the second. When, previously it was more often drier during crop establishment. The pattern if it continues, and the grain growth period becomes relatively even drier and shorter will require changes in the management of the crops in this region.

The SPI was chosen because of its simplicity, the possibility to describe drought on different time scales, and its standardization, which guarantees independence from the geographical position of the measuring stations. (Pashiardis and Michaelides, 2008). The SPI is calculated from the monthly precipitation data. It was developed to quantify the precipitation deficit for multiple time scales that reflect the impact of drought on the availability of the different water resources, including rainfall. The SPI was selected because precipitation is not normally distributed; therefore, absolute rainfall values are usually more poorly correlated with yields than when the rainfall values are standardized (Teigen and Thomas, 1995). The objective in relating SPI as a function of yield is to advise farmers on how to adjust their cropping plans ahead of time to maximize returns or reduce costs.

Karrou and Oweis (2014) assessed drought severity in the main cereal production areas of Morocco and evaluated its effects on grain yield. Also, the authors evaluated if the standardized precipitation index (SPI) may be used as a tool to predict drought and crop yield early in the season. Data analysis revealed that for the period 1988 to 2008, yields fluctuated from 150 to 3000 kg/ha with a coefficient of variation oscillating between 30 and 50% in the north and 60 and 70% in the south. Based on the SPI, the regions studied experienced, on average, a drought once every 2.6 years. However, very severe droughts were observed only once in 7 years. The SPIs computed for the periods October to June and January to March were highly correlated. Furthermore, there was a high positive correlation between the yield and the SPI calculated for the period January to March. The coefficients of determination varied between around 0.20 and 0.62 for bread and durum wheats, and between 0.28 and 0.69 for barley. The authors concluded that soil moisture levels during the tillering and stem elongation periods of the cereals are the most important determinants of yield. Hence an SPI computed for the period January to March can be used to predict drought severity and yields early in the season.

IX. LENGTH OF THE GROWING PERIOD (LGP)

LGP is defined as the period during the year when prevailing temperatures trigger crop growth and precipitation moisture stored in the soil profile exceed half the potential evapotranspiration (ETP). Sufficient soil moisture should be accumulated in the soil profile, on a daily basis, to permit seed germination. The estimation of the growing period is based on water balance model, which compares rainfall (P) with potential evapotranspiration (PET). In case of the growth is not limited by temperature, the ratio (P/PET) determines the start and the end of the growing period.

The analysis of LGP in Khouribga region (central part of Morocco) shows a shift of the start of the period from October in 1960-65 to November in 1995-2000 (Figure 8). The whole period is also shortened from 180 days to 110 days because the end season moved from early March to Late April. By knowing the LGP of different regions at the national level, we can reliably recommend suitable species, varieties and crop management approaches for farmers to use in advance (Benaouda *et al.*, 2010).

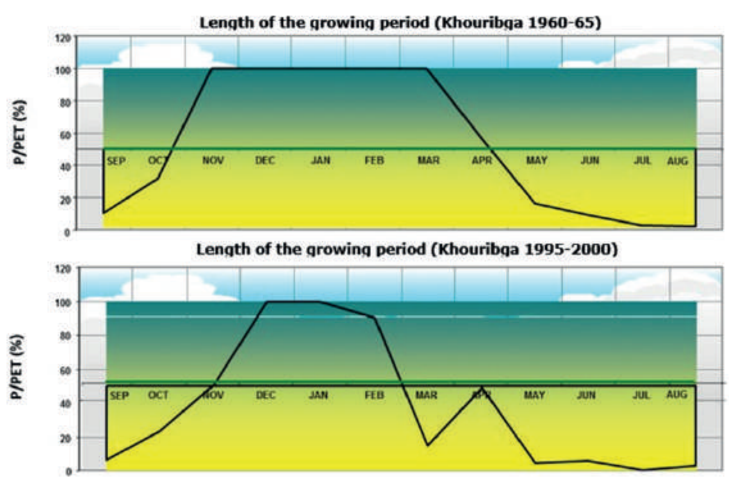

Figure 8. The length of the growing period during 1960-65 and 1995-2000 in Khouribga, Morocco.

X. CEREAL YIELD FORECASTING IN MOROCCO

Usually, cereal productions are estimated based on a sampling technique nearly weeks before harvest, every year, by the Ministry of Agriculture, Maritime Fisheries, Rural Development, and Forestry (MAPM) through the Direction of Strategy and Statistics (DSS). It is a direct method, precise, and applied directly before harvest, but requires consequent human and financial resources. The need to elaborate an indirect method to early forecast yields that is fast and economical. In 1995, INRA-Morocco urged by the severe drought of that particular season, which was described as the worst dry season of the 20th century in Morocco. Neither the classical frequency analyses of the climate used to identify seasons of close similarity to 1994-1995 season, nor the available mechanistic models for crop forecasting used in developed countries, have been able to monitor crop development during that season and even more so predict the disastrous harvest of 1995. Therefore, it became necessary to come up with a new approach for forecasting cereal yields using an innovative methodology, which combines realistic and statistical approaches with agronomic and meteorological expertise (Boughlala *et al*., 2013).

Primary research focused on the interaction between the climate and the cereal crops behaviors, particularly the analysis of both climatic and crop cycles in a series of long- term data (Balaghi *et al*., 2010; Balaghi *et al*., 2013). This study was originally undertaken for Meknes region and extended later to other regions of Morocco. Primary results indicated for the first time in Morocco that inter-annual variation of cereals yields could be explained by variation in the amount of rainfall cumulated during the cropping period, with a relatively high exactness. The relationship could further be improved by partitioning the season into three or more phases.

In collaboration with the University of Liège (ULg, Belgium) and later with the Joint Research Centre of the European Commission (JRC), a new indicator was identified as highly correlated to cereal yields, which is the Normalized Difference Vegetation Index (NDVI) derived from satellite images. Different from many European countries, this index was highly correlated to cereal yields in Morocco, mainly due to the aridity of Moroccan climate and the predominating coverage of cereals of agricultural areas. NDVI is correlated with cereal yields as long as cropping season rainfall did not exceed 550 mm, which explains the insignificance of NDVI to forecast crop yields in Northern Europe (Balaghi *et al*., 2013). The combination of both rainfall and NDVI allowed forecasting of cereal yields as early as March, three months before harvest, and at a low cost, with a level of accuracy comparable to the one of the direct sampling methods used at crop maturity by DSS.

These unforeseen results and outcomes have led INRA to publish for the first time in Morocco many crop forecasting bulletins since 2009, in collaboration with JRC (Figure 9). In these bulletins, an approach combining four individual approaches was used: (i) similarity approach using rainfall and/or NDVI as criteria of comparison, (ii) regression models using rainfall and NDVI as predictors of cereal yields, and (iii) the JRC approach which is based on a simulation model of crop growth called WOFOST (WOrld FOod STudies). The deterministic model WOFOST is now being adapted to the Moroccan agro-climatic context and incorporated in an operational forecasting system.

WOFOST is a mechanistic model that explains crop growth on the basis of the underlying processes, such as photosynthesis, respiration and how these processes are influenced by environmental conditions. With WOFOST, you can calculate attainable crop production, biomass, water use, etc. for a location given knowledge about soil type, crop type, weather data and crop management factors (e.g. sowing date). WOFOST has been used by many researchers over the World and has been applied for many crops over a large range of climatic and management conditions. Moreover, WOFOST is implemented in the Crop Growth Monitoring System, which is used operationally to monitor arable crops in Europe and to make crop yield forecasts for the current growing season (Bregaglio *et al*., 2015).

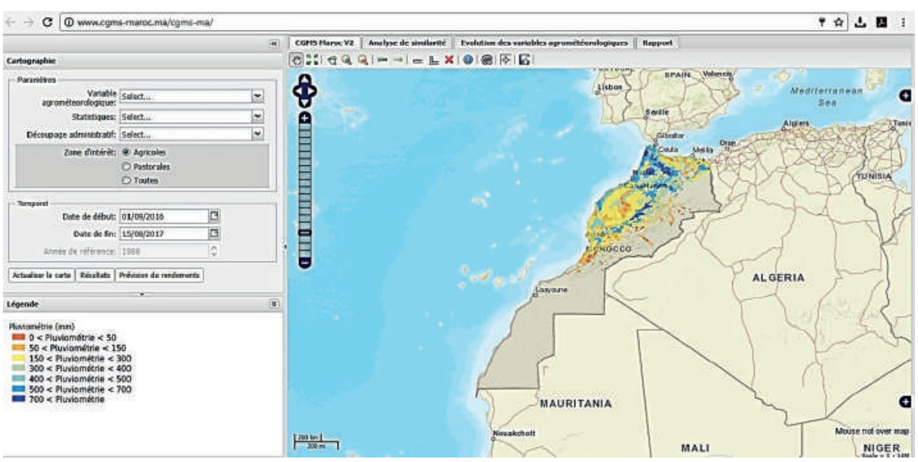

Figure 9. Portal of the agro-meteorological monitoring of crops and forecasting of cereal crop yields (www.cgms-maroc.ma).

Cereal yields can be forecasted based on combined approaches, which relies on a simultaneous use of four methods (the non-parametric approach, the similarity analysis, the regression models, and the simulation approach models) and various types of predictors (rainfall, temperature, NDVI). The combined approach for cereal yield forecasting has been automated in an operational forecasting system, in order to forecast cereal yields in Morocco, called "CGMS-MAROC" (www.gms-maroc.ma). CGMS-MAROC has the same architecture than the European CGMS but has been enriched, since it includes statistical models for forecasting crop yields developed at INRA. Also, CGMS-MAROC runs with spatialized weather data on finer climate grids of 10x10 km resolution. CGMS-MAROC can currently forecast cereal yields at the level of the country, agro-ecological zone and province levels. It is operated by INRA and managed in collaboration with DMN and DSS, in the basis of an official partnership. It is intended to support DSS, as this administration is officially mandated to provide crop statistics and forecasts. CGMS-MAROC is installed on a central server at DMN, which is responsible for updating and delivering the weather grid. A Web viewer installed at INRA was specifically developed for checking data and making preliminary analysis concerning the season. CGMS-MAROC is the first operational agrometeorological crop forecasting system available in Morocco, institutionalized by a strategic partnership which permits its development and sustainability (Balaghi *et al.*, 2013).

XI. CONCLUSIONS AND OUTLOOKS

XI.1. YIELD POTENTIAL OF WHEAT

Simulations of wheat yields showed great variability in potential yields between regions and between years. Thus, potential yields range from 5 qx/ha in Rehamna and 60 qx/ha in the Chaouia with the risks of obtaining zero yield, 2 years out of 10 in Jemaa Shaim (Lamine *et al.*, 1993, El Mourid 1991). The coefficient of variation of potential yields in the study area varies from 40% to 200% and according to climatic gradients. Research trials of farmers in these areas confirm this variability. This implies the need to review agricultural production strategies in these regions in order to, better exploit their potential.

XI.2. ADAPTATION OF EARLY GENOTYPES TO DROUGHT STRESS

The choice of variety is an essential element in the farmers' production strategy. Therefore, determining the type of cereal variety to be recommended to farmers in arid and semi-arid areas has always been a priority of agronomic research. The simulations carried out with Simtag (Lamine *et al.*, 1993, Yacoubi *et al.*, 1994) comparing three different genotypes: early (Potam), semi-early (Nasma) and late (Keyperounda) showed the interest of using early varieties and semi-early in the Moroccan arid and semi-arid zones. Indeed, early-to-early varieties when combined with appropriate cropping techniques (early seeding, early weed control, semi- adequate dose) reduce yield fluctuations and stabilize agricultural production.

XI.3. ESTIMATING THE GAPS BETWEEN ACTUAL AND POTENTIAL YIELD

The comparison of the potential yield simulated by Simtag and the actual yields of the farmers estimated by Multisim make it possible to evaluate the yield gap to be made up at the level of a region or a farmer. Thus, the studies carried out in the Chaouia, Abda and Saiss make it possible to identify the important gains. These yields can be achieved by targeting technology transfer (Nordblom *et al.*, 1994, Boughlala *et al.*, 1994). Gains of more than 30 qx/ha are possible with current technologies.

XI.4. RESEARCH AND DEVELOPMENT

The implications of this research for development are manifold. The most important of these are the primary interest in climate knowledge for the rehabilitation of all development and research activities in the Moroccan zones. A greater integration of national meteorological services with agricultural research and extension would be necessary to make use of available climatic data and to develop networks (El Mourid *et al.*, 1996).

The reliability of the statistical indicator to be used to inform the researcher, extension services and farmers about the climatic conditions of production are vital. Indeed, given the predominant irregularity of precipitation, the use of probabilities (frequency analysis) to characterize the climate of a region would better reflect the reality of rainfall distributions than using averages.

The heterogeneous character of the arid and semi-arid zones should be taken into account in any planning and development decision. In fact, the extent of the differences, which characterize each region, should involve different strategies in terms of development and also consider these areas as clearly differentiated areas of research networks (El Mourid *et al.*, 1996).

Optimization of crop management at tactical and strategic levels is complex due to the fact that crop response to different practices (e.g., sowing date, sowing rate, fertilization, etc.) interacts with other agronomic factors, and with soil type, genotype and particularly weather. The generation of management guidelines for a particular region from experiments may require many experiments in several years and sites, at a high cost of time and money. A major inconvenience of using conventional experimentation is that interactions between cultivar, climate and soil management practices frequently have a greater impact on yield than their individual effects. Therefore, extrapolating the results obtained from a limited number of environmental combinations to other environments is not only difficult but may be misleading. Development and validation of models are powerful tools that integrate soil, plant and climate and thus, allowing to evaluate the results of research, testing new ideas and measuring the region's yield potentials. They also measure the risk that farmers face in applying a new technology. These tools can facilitate decision-making and save time and research costs.

XI.5. YIELD FORECASTING

CGMS-MAROC system is currently being improved to overcome some accuracy limitations encountered in some specific cases, such as prediction of yield under relatively high rainfall growing seasons coupled with severe drought in the middle of the crop cycle like in 1996-1997; High rainfall growing seasons, like those of 2008-2009 and 2010-2011; Low temperature growing seasons like the 2011-2012.

These limitations of the system could be overcome by taking into account phenological stages of the crop during periods of forecasting and during periods of drought, excess water or cold.

Methods for forecasting yields can be developed for other annual crops similar to cereals, since one of the modules of the WOFOST model provides parameters for many other crops, particularly corn, sugar beet, potato, bean, rapeseed, sunflower...

CGMS-MAROC allows not only to instantly forecast grain yields two to three months before harvest, but can also be adapted to other uses, through additional improvements, like drought insurance, agricultural warning, mapping potential of land and land use, seasonal forecasting of crop yields and impact of climate change on agricultural productivity.

CGMS-MAROC can be improved and used in agricultural early warning, by incorporating modules for forecasting short-term weather events (rain, drought, heat waves and cold) and biotic hazards (diseases, insects). These products can be generated directly from local weather stations, national networks of weather stations or numerical models of spatial interpolation of climate data. This suggests a consorted effort in local data collection, transmission, processing and dissemination of agrometeorological information to farmers and extension services.

CGMS-MAROC can also be adapted for forecasting cereal yields in countries with similar climate to that of Morocco, such as the Mediterranean countries. In these countries, behavior of cereals crops to weather and crop management are similar.

Satellite imagery data, NDVI in particular, has been proven to be relevant in forecasting cereal yields for Morocco. Based on this result, the possibility of estimating cereal areas, and yield gaps, using satellite imagery data can be postulated.

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LAND SUITABILITY EVALUATION TO WHEAT AND BARLEY UNDER MODERATE AND DRY CLIMATE SCENARIOS IN MOROCCO

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SYNOPSIS

This study was carried out to spatially evaluate land suitability for wheat (T. aestivum L.) and Barley (Hordeum vulgare L.) crops in Morocco, based on biophysical approach as developed in FAO guidelines. Geographical Information System (GIS) was used to develop land suitability map. Land characteristics (LC) and cropland use requirements (LUR) used as criteria for crop suitability analysis were soil properties (pH, depth, texture.) and climate factor (length of the growing period index: LGP).

Crop suitability map was made by matching reclassified LC with crop LUR using expert knowledge and GIS modeling. To study the effect of climate variability, two LGP scenarios were used (dry and average climatic year).

The results indicated that regions with high and moderate suitability to wheat are of the order of 4.8 million hectares in a normal climatic year. However, in a dry year, 57 % of this aptitude becomes rather marginal. Concerning barley, this study shows that about 6 million Ha are highly to moderately suitable for this crop in medium climatic year. In dry year, 32 % of this high-moderate aptitude becomes marginal. This analysis clearly demonstrated potential use of the suitability approach in delineating the vulnerable zones vs climate scenarios. This study can be further improved with an additional input from socio-economic and ecological aspects.

I. INTRODUCTION

The agricultural sector plays an important role in the growth of the Moroccan economy and constitutes a strong support to the development of the country since it represents 20% of the gross domestic product and employs about 40% of the working population (Akesbi, 2006). The agricultural area in Morocco represents approximately 9.2 million of which 65% is grown in cereal crops. This area occupied by cereal must be reduced by 22% while increasing its production by 44% by 2020 as planned under the new agricultural strategy (Green Morocco Plan) (Badraoui and Dahan, 2010).

Concerning the cereal production, in the 1960s, Morocco was largely self-sufficient producing more than 80% of its total wheat demand. After a decade, the share of domestic wheat production drastically dropped to 62% while imports increased to 38%. In the first decade of 2000, domestic wheat production met on the average only 60% of the total domestic demand (FAOSTAT, 2015). The Moroccan population more than doubled from the 1960s, reaching about 33.5 million in 2015. Per capita supply of wheat remarkably increased from 138 kg/person in the 1960s to an average of 243 kg/person for the period 2001-2011 (FAOSTAT, 2015). In light of population increase and shifts in consumption habits, wheat became a major component of food security.

Wheat yields in Morocco remained low at about 0.9 tons per ha until the seventies. With the introduction of improved wheat varieties in the 1980's, significant increases in yields were observed which, after the new millennium, reached a 10-year average of about 1.5 tons/ha for durum wheat and 1.6 tons/ha for bread wheat. However, these yield levels are far below both the global average of over 3 tons/ha and the African average of 2.3 tons/ha.

These low yields are often explained by misuse of the soil in areas of cereal intensification and non-rational extension to unsuitable soil. Thus, after decades of intensification use of cereal, the soil is degraded and devoid of its organic matter and easily transported by water erosion. This was confirmed by FAO, which carried out a comprehensive inventory of all the land in the country and estimated that 9 million hectares of all the soils in Morocco require conservation measures (Ouassou *et al*., 2006).

In fact, soil degradation is becoming a major challenge in Morocco not only for increasing cereal crop productivity but also for maintaining soil resource base for the future generation. Accordingly, the potential of the land for cereal production to satisfy the ever-increasing food demand of the increasing population is declining because of severe soil degradation.

To meet the increasing demand for cereal, farmers have to produce more. On the other hand, land is limited, and successful agriculture requires the sustainable use of soils that significantly determine the cereal potential of an area. Under present situation, where land is a limiting factor, it is important to use suitable soil for cereal cultivation and keep the unsuitable one for other crops to satisfy the ever-growing food demand (Fischer *et al*., 2002). Hence, it is essential to understand their nature and properties in order to preserve soils for future generations and for their most efficient use (FAO, 1998). In fact, the proper understanding of the nature and properties of the soils and their management based on their potentials and constraints is crucial for optimization of cereal production to the potential levels.

To cope with this situation, the Ministry of Agriculture in Morocco has commissioned INRA since the 2000s to launch studies on the suitability of maps to identify areas that have an accepted suitability to cereal and to reserve the rest of the land for further speculation. In fact, the suitability is a function of crop requirements, climate and soil characteristics and it is a measure of how the qualities of land unit will matches the requirements of a particular form of land use. The land suitability analysis is to achieve optimum utilization of available land resource for agricultural production in a sustainable manner. The suitability analysis often adopted the qualitative as well quantitative evaluation of land parameters to determine various degree of suitability to given set of the criteria. For the broader extent, similarity mapping based on the matching factors derived from the area of interest (AOI) or a pilot site is very useful approach as it allows integrating biophysical information (e.g. climate, land use, topography and soils properties) to predict or delineate set of the similarity index across the extrapolation zones (e.g., regional scales). The similar approach has been used in suitability modelling as a decision support for identify the suitable area for cereal or other crops (Dixon *et al*., 2001; Fischer *et al*., 2000; Hopkins, 1977, Moussadek *et al*., 2015). Unfortunately, most of those suitability models require many legacy data (soil, climate, crop requirement, etc.).

Enormous efforts are underway throughout Morocco to gather natural resources data (soil, climate), information on crops and other related agricultural resources. However, there is lack of the existing and open access data and information which reflect the impact of the climate variability that are often affecting the cereal suitability at national level (Driouech *et al*., 2010) and therefor fail to capture the vulnerability of cereal agro-ecosystems in Morocco to propose alternative crop management (Moussadek *et al*., 2015).

II. OBJECTIVES

The main results of this suitability study will be discussed by showing the effect of climatic scenarios (dry or normal year) to delineate scientifically the cereal production basins in Morocco. Hence, the objective of this paper is to present the main result of the suitability study for cereal-based system (wheat and barley) under two climatic scenarios (normal and dry year).

This study will allow delineating areas and producing potential land suitability maps of Morocco that will allow growing wheat and barley at the right zone for optimum yield to increase the food security in Morocco.

III. METHODS

Land suitability for cereal (wheat and barley) was evaluated using FAO (1976, 1998) guidelines. The evaluation criteria used to address the suitability of the selected crop land utilization types (LUTs) in the study zones were soil characteristics (pH, depth...), slope and climatic factors (length of the growing period [LGP]). Digital data of land characteristics (LCs) of major soil types and classified look up tables for cereal requirements (LURs) were properly encoded as database file to be used in Arc GIS for spatial analysis. Point data of the selected LCs generated from soil profiles were spatially interpolated using Kriging tool in Arc GIS. In addition, the LCs was reclassified based on crop LURs. Hence a 'homogeneous' land unit was defined by the particular climatic, topographic, and estimated soil characteristics used to match the properties of land to the agronomic crop requirements.

In this study, the factors were selected based on agronomic knowledge of local research experts and reviews of existing literatures such as FAO framework for land evaluation (FAO, 1998). The LGP calculated during dry and normal rainfall season was used to highlight the effect of climate variability.

The crop requirements were expressed by means of a set of critical threshold values, which determine the limits between the land suitability classes. None or slight limitations define the S1 level (very suitable), moderate limitations the S2 level (moderately suitable), and severe limitations the S3 level (marginally suitable to unsuitable). Very severe limitations result in a non-suitable (N) class.

The final suitability map was compared with integrated grids calculate the spatial stats and percentage of crop potential to the different suitability classes.

Finally, cereal land suitability evaluation at dry and normal climatic scenarios was then made in entire Morocco by matching between reclassified LCs of major soil types with crop LURs using GIS model builder. The model builder uses maximum limitation method so that the most limiting climatic or soil parameter dictates the final level of suitability (Sys *et al*., 1991; Van Diepen *et al*., 1999).

IV. RESULTS AND DISCUSSION

IV.1. WHEAT SUITABILITY UNDER TWO CLIMATIC SCENARIOS

From the maps obtained, it can be seen that the biophysical zones with a high and moderate suitability to wheat are of the order of 4.8 million hectares in a normal climatic year. However, in a dry year, 57% of this aptitude becomes rather marginal (Figure 10 & 11).

This national analysis provided the broad scale biophysical suitability, which has been further analyzed with wheat system to identify the vulnerable region to climate variability.

This study shows that in the dry year the main wheat production areas such as Chaouia and Abda in the Central Morocco are affected. Unfortunately, 50% of farmers of this region are smallholders with up to five ha of cultivated land, which increases the climate vulnerability in Central Morocco.

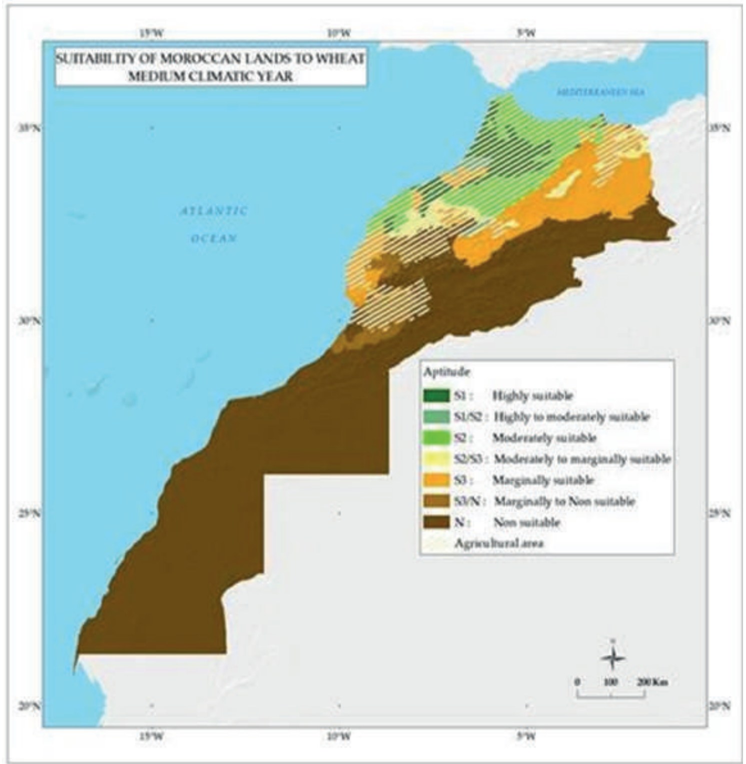

Figure 10. Land suitability to wheat in medium climatic year

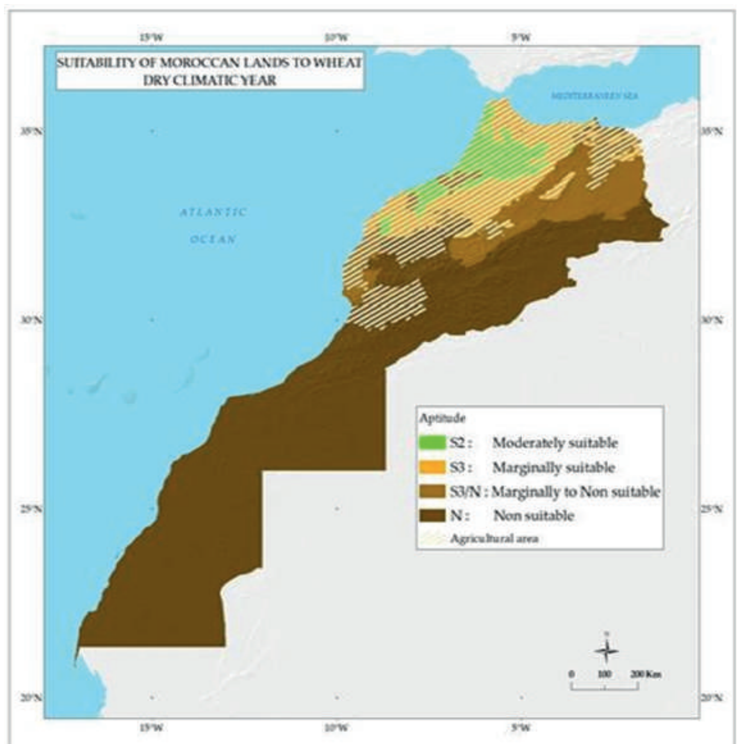

Figure 11. Land suitability to wheat in dry year

This study shows that in the dry year the main wheat production areas such as Chaouia and Abda in the Central Morocco are affected. Unfortunately, 50% of farmers of this region are smallholders with up to five ha of cultivated land, which increases the climate vulnerability in Central Morocco.

In fact, the following Figure 12 shows that during unfavorable climatic year, there is deterioration in the land use of wheat and 56% of land with a high to medium- suitability to wheat becomes rather marginal to unsuitable.

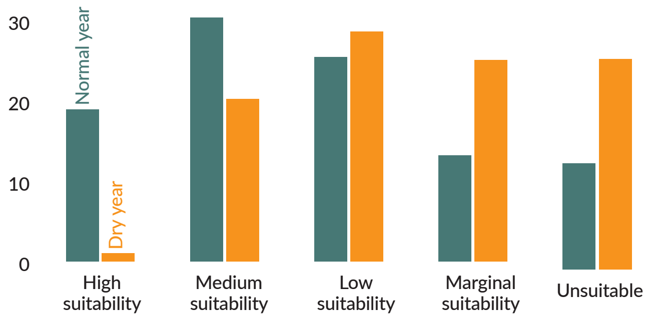

Figure 12. Percentage of land suitability classes in a normal and dry climatic year for wheat

IV.2. BARLEY SUITABILITY UNDER TWO CLIMATIC SCENARIOS

According to maps (Figure 13 & 14), about 7 million ha have a high to moderate suitability to barley in a normal climatic year.

Detail analysis of the suitable agricultural land areas for barley in Morocco shows that about 6 million ha are highly to moderately suitable for this crop in medium climatic year which mainly distributed in the North Central part of Morocco, and more than 3 Million Ha are marginal suitable (Figures 13 & 14).

In dry year, the highly and moderately suitable areas were decreased by more than 32 % compared to normal year (Figure 15).

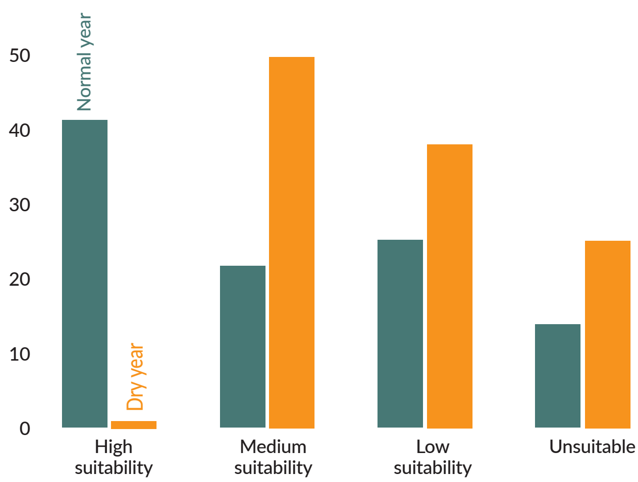

Figure 13. Percentage of land suitability classes in a normal and dry climatic year for barley

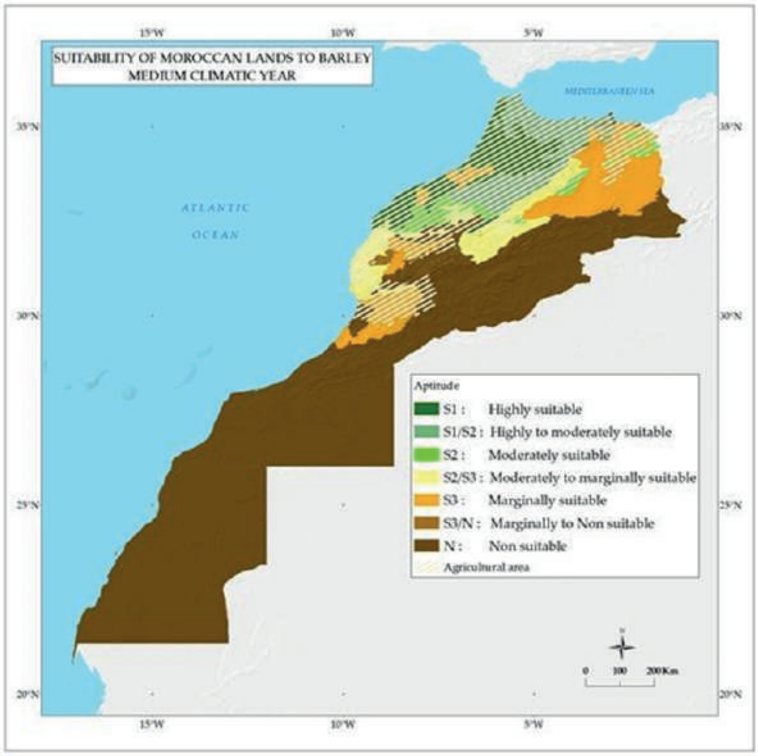

Figure 14. Land suitability to barley in medium climatic year

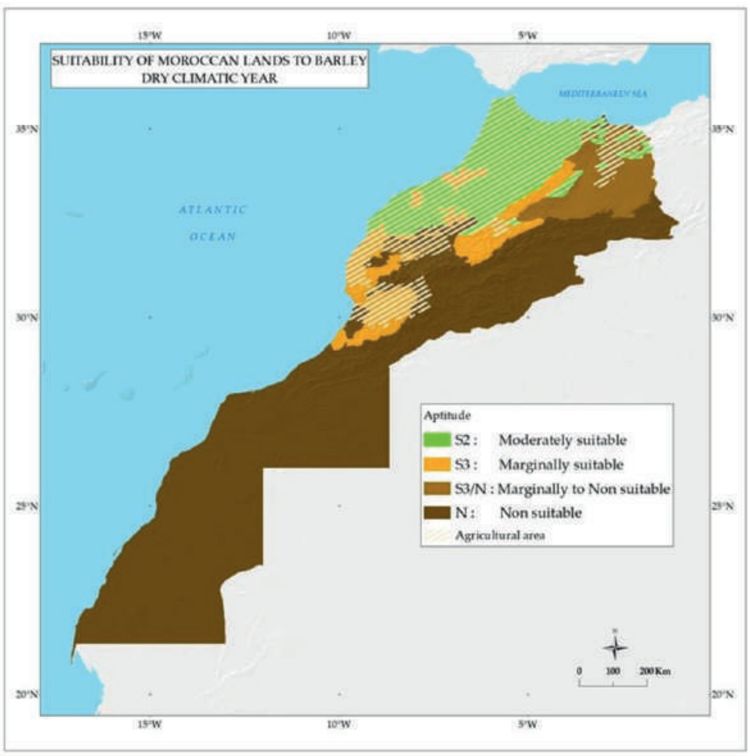

Figure 15. Land suitability to barley in dry year

This study clearly demonstrated potential use of the suitability approach in delineating the vulnerable zones vs climate scenarios. This study can be further enchased with an additional input from socio-economic and ecological aspects to quantify the impact of climate change and variability on crop production.

V. CONCLUSION

This study shows the vulnerability of cereal based system in Morocco to climate variability, mainly in rainfed areas of central Morocco and it provides information about the areas suitable for the main cereal crops (wheat and barley) taking into account the impact of the climate variability. The spatial information provided in GIS offers the decision maker with reasonable suitability maps. The GIS based land evaluation approach can provide thematic layers that enable the formulation of dynamic scenarios for integrating land information.

The study has delineated areas and produced potential land suitability map of the watershed that will allow growing the right cereal crops at the right site for optimum yield. Based on the finding of this study, it was clear that the climate index used in this study (LGP) shows a high variability from medium to dry year. However, suitability for growing crop is not only limited by the selected edaphic and agro-climatic constraints but also socioeconomic factors, which should be lunched for further study.

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AGRICULTURAL ECONOMICS AND RURAL SOCIOLOGY RESEARCH IN ARID AND SEMI-ARID AREAS OF MOROCCO

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SYNOPSIS

The following bibliography contains more than 60 citations and covering different topics. The bibliography includes the literature review of the most relevant results of research carried out on farming system and farm typology, production costs, technical and economic efficiency, risk and farmer's behavior, impact assessment, and gender studies. It provides an overview of research efforts since the establishment of the socioeconomic research program.

I. INTRODUCTION

Chronologically research program on economics and rural sociology was initiated by USAID/INRA Aridoculture Project. Research topics enclosed cover the main issues related to the development and adoption of appropriate technologies in agriculture, production costs in Abda and Chaouia, risk analysis and risk management, technical and economic efficiency, assessment of new technologies generated by the, economic modeling and policy issues, agricultural policy and energy. In addition to this research, other components related to training and prioritizing research were targeted.

Rural sociology research program was launched under MIAC-DDR contract (Conjuncture Center), and the first study was on marketing strategies in aridoculture. Since 1983, research on sociology has diversified its program by introducing new aspects such small mechanization, chickpeas varieties, barley, and soft wheat. Thus, research teams in economics and sociology have conducted several research issues in collaboration with ICARDA, IPGRI, CIMMYT, World Bank, IDRC, FAO and others.

This research has contributed to the improvement of different approaches such production system, community-based approach, on-farm trials, innovation plate-from and participatory research approaches. In 1989, the concept of multidisciplinary, and community research were introduced in the case of Saada variety assessment.

Finally, it should be noted that all this work could not have taken place without the human and financial resources available to the socio-economic research program since the launch of the aridoculture project and other projects in collaboration with ICARDA, CIMMYT, IPGRI, IDRC, the European Union and special programs with public institutions.

The following literature review will target the following aspects: (i) Production system and farm typology; (ii) Production cost of wheat and food legumes; (iii) Technical and economic efficiency; (iv) Risk analysis and farmers' behavior; (v) Impact assessment of improved technologies; (vi) Gender issues; and (vii) Agricultural policies and energy

II. PRODUCTION SYSTEM AND FARM TYPOLOGY

Farming systems in arid and semi-arid regions exist across a wide variety of cultures and landscapes. The biophysical, institutional, social and economic variety between contexts, are resulting in different responses of farmers and communities between and within areas. It is important to notice that farms are in different development stages, and farmers have different skills and ambitions. Over time, these differences are the drivers of temporal and spatial variability between and within farming systems. The existing farming systems variability is challenging to comprehend, leading to partial representation of reality. Various tools and methods (e.g., wealth rankings, farm typologies, and cropping system, clustering) have been developed to understand and deal with farming systems diversity. When using these tools and methods, a trade-off is made between the quality of representing reality and the level of detail required. An often-used methodology to deal with variability and diversity is typology construction, i.e., the grouping of farms/households. Different studies were conducted by the aridoculture program for different purposes.

In agriculture, there is a diversity of farms according to assets and activities. Literature has given more importance to land and livestock. These variables affect farmers' decisions. Although, livestock is considered as a pillar of the production system. In general, farmers try to make appropriate adjustment according to the size of the available area. These two criteria are important in farm classification (Laamari, 1993, Moore *et al*., 1993). In 1985, the first work on farm typology was launched by the aridoculture program. The transect approach was used to classify systems according to a climatic gradient and the importance of wheat. This classification was used by the program to evaluate different technologies (on-farm trials). The approach was simple and useful in capturing production system diversity and farmer's behavior.

In 1991, the program has launched Aridoculture baseline study and farming system typology (Moore *et al*., 1993). The typology was developed in order to target investigation and dialog with farmers, within clearly defined and homogeneous research domains. The foundation of these farming systems is in cereal production combined with livestock enterprises. Despite many similarities across these mixed bined with livestock enterprises. Despite many similarities across these mixed farming systems, important differences emerge. Socio-economic characteristics provide the basis for this differentiation. Particularly significant are the size of the household labor force, the number of hectares operated, off-farm employment, land tenure status, the hiring of full-time laborers, and non-agricultural investments. The analysis of these characteristics emphasizes the need to distinguish recurrent features of the population as a whole from the specific roles those characteristics play in sustaining any particular farming system.

The diversification of productive and income-generating activities is the core element in all aridoculture farming system strategies. The implementation of these strategies, however, is dependent on two interrelated conditions. Overall resource levels limit the range of activities it is possible to pursue. The nature and quality of those resources, combined with farm household objectives, determines the form in which resources are integrated.

All these resources are mobilized to achieve farm household objectives. The goal of crop production varies among household consumption, market sales, and livestock feed. These variations are reflected in the allocation and intensity of household labor (or use of mechanization) in crop production, as well as in the use of inputs. Of the six categories of farming systems, the market-oriented hired labor, medium scale, and small-scale farming systems are relatively more mechanized and purchased-input intensive than off-farm employment dependent, marginal and resource deficient farming systems which tend to consume more of their production.

Finally, the baseline data set and farming system typology constitute an information system, which serves multiple and interrelated purposes such as: (i) Develop comprehensive understanding of the existing farming systems; (ii) Provide a common frame of reference for dialog between researchers, farmers, extension, and policy makers; (iii) Identify conditions which constrain the improvement of existing systems; (iv) Plan a strategy of technology development and policy implementation for the transformation of farming systems into more productive entities; (v) Target technologies and messages; (vi) Target monitoring and impact evaluation; and (vii) Determine the level of impact at the regional level.

Other farm typologies were developed at different contexts and for different purposes. Estimation of production cost by different categories (Rafsnider *et al.*, 1988; 1989) was important in presenting technical and economic coefficient by small, medium, and large farms. This presentation of results has contributed to present farmer's economic performances by category and identify the most efficient group. Farm clustering using SPSS was used in farm typology for developing community model (Bendaoud *et al.*, 1995). The approach was based on using farm assets such as land, livestock size, and other factors to identify the different categories of crop/livestock integrated farming systems. The same approach was used in identifying farm types in Chaouia for economic modeling activities (Laamari, 1992; 1998 and 2009).

A comprehensive baseline study was conducted in Taourirt Taforalt region by INRA-Settat team, in collaboration with colleagues from Oujda DPA (PRDTT project). The purpose of this study was to conduct specific studies during the period 1998-2000, and the most important one was the diversification analysis of the production system. The objective of this study was the analysis of the production system economic performances diversity according to raw production, income (livestock and crops), area, flock size and complex indicators such livestock production by area, net income by flock size, etc... This typology was used in targeting technology transfer program of PRDTT project, particularly for livestock production. A cluster analysis was used for 140 case studies and for 13 rural communities. Five major farm types were identified. Five representative douars or villages were selected from each type and used by PRDTT project extension program.

Other studies were conducted within Benchmark project and TRITIMED (Laamari *et al.*, 2009; 2014 and 2015) to model the representative farms and analyze the impact of adopting durum wheat varieties or water economic productivity. The data set collected by Benchmark project was used in analyzing the Green Morocco Plan in Tadla (Saadan; 2014) and Risk aversion farmer's behavior (Laamari; 2015). The two studies have used the farm typology developed based on farm size, wheat income, flock size and other indicators. The six types identified from principal component analysis was representative of the major level of water used.

The diversity of production system studies has enabled the use of several statistical methods and appropriate applications. The development of computer tools has contributed significantly to the perfection of the analysis. It has also been shown that the production system typology is an appropriate tool for targeting agricultural advice and technology transfer programs.

III. PRODUCTION COST

The first studies carried out by the Aridoculture program during 1986-1990 concerned Abda and Chaouia and focused mainly on production costs and labor analysis. The database of 154 and 136 farms, respectively in Abda and Chaouia and for the main cereals and food legume producers (BW, DW, barley, maize, lentil, bean, peas and chickpeas) was developed. The production generated from this first typical study was presented for three groups of farmers (large, medium, and small) given the size of the farm and tractor use. In addition to the estimation of the production cost, it was an opportunity to establish enterprise budgets by crops and farm categories. The way of presenting enterprise budget has contributed to help assessing the economic and technical impact of the adoption-improved technologies. In the context of Aridoculture program, the enterprise budgets for cereal and food legume crops were largely used by technology transfer program.

In the case of cereals (Rafsnider *et al.*, 1987; 1988; 1990), the analysis of production costs as derived from enterprise budgets show that the average operational costs differ from one region to another and from one group of farmers to another. In the Chaouia, small farmers and medium spend more on fertilization and weeding (26% to 70% of the total cost). However, for large farmers, the costs of tillage and fertilizing operations are the highest share (20% to 60% of the total cost). In the Abda region, the costs of sowing and harvesting are highest for the three groups (25% to 53% of the total cost).

In the case of pulses, the costs of sowing, weeding and harvest are the highest (50% to 80% of the total cost). For the same crops, production costs in Abda-Hmar, Chaouia- Ouardigha, Rabat-Azemmour, Tadla-Azilal and Meknes-Tounate regions for a sample of 500 farms (Laamari *et al.*, 2014) were estimated. Generated technical coefficients provide information on the diversity of situations taking into account platforms and farmers. Yield, production, and income will be used to develop indicators for impact assessment and project monitoring.

In the case of Benchmark project, wheat production cost was estimated in order to establish enterprise budgets and estimate indicators for water allocation and water productivity (Laamari *et al.*, 2013; Boughlala *et al.*,2014). In collaboration with a German organization focused on the application of the participatory approach in estimating production costs based on workshops involving different groups, it was possible to introduce new tool and concept for estima ting production costs for milk and wheat (Boughlala, 2013). This approach has the advantage of being rapid, not expensive and confronting different opinions. An average situation can be established for large, medium, and small farms. However, the approach is very limited because of the absence of the variability in the management. However, it is largely used in North Africa and Asian countries for comparative purpose.

In the case of CRP-DS, in system vulnerability research activities, production cost for wheat, barley, bean, potato and onion were established in the perspective to investigate the performances of the production systems in the Sais region (Laamari *et al.*, 2015).

Cost-of-production studies show that the research programs should be tailored according to the physical and / or biological efficiency of the production systems, which are specific to each region and each category of farmer. In arid and semi-arid regions technology improvement program has to target low production cost technology with a high production potential. However, most of data bases used are obsolete and must be updated giving the dynamics of production systems and the changes in agriculture in Morocco.

Finally, between 1988 and 1989 (in collaboration with ENAM), the program developed guides for the estimation of crop production costs, livestock production and evaluation of agricultural innovations (Driouchi and Laamari, 1988). These guides were widely used by colleagues from different department (DPAE), researchers and students of ENAM and IAV Hassan II. In addition, training was provided for CT and ORMVAD staff. The two guides give the detailed procedures to estimate each component of the production costs and income.

IV. TECHNICAL EFFICIENCY

The growing food gap in cereal and food legume productions have always been attributed to the poor performance of the agricultural sector. In an effort to boost agricultural productivity, policy makers have placed substantial emphasis on new technologies and their adoption by farmers. This effort was coupled with a policy reform program to reduce the pressure on agriculture, to liberalize markets and to devalue the currency. The aim was to attain food self-sufficiency through increased use of improved agricultural production technologies.

Various incentives have been used to induce farmers to achieve a high rate of adoption of the chosen modern technologies (use of fertilizer, improved varieties, and chemical inputs), little has been achieved in terms of appropriate application and more efficient use of farmers' limited resources. This is mainly attributed to the wrong hypothesis that farmers may not be able to select appropriate technologies but can operate technology efficiently when chosen for them. In a dynamic technological and policy environment, it is believed that farmers encounter considerable inefficiencies before realizing the intended gains from technological progress.

New technologies demand a new set of skills and knowledge if their productivity- enhancing potentials are to be fully exploited. Deviations of farmers' practices from technical recommendations, coupled with socioeconomic constraints, will ultimately lead to technical inefficiencies. Knowledge of the extent of such inefficiencies and the underlying farm-level as well as system level constraints will help guide policy makers to increase agricultural production by enhancing technical efficiency in using improved technologies and farm resources.

The method for measuring the productive efficiency of a farm relative to other farms was first suggested by Farrell in 1957 using a production frontier. A production frontier is specified to represent the maximum output for a given set of inputs and existing production technology. Failure to attain the frontier output implies the existence of technical inefficiency. Farrell's proposed methodology was, however, deterministic, attributing all deviations from this "best practice" level of production to inefficiency. The approach as initiated by Farrell and enriched by other contributions was largely used in our context. This approach makes it possible to test several functional forms of the production function and allows the incorporation of certain variables having an effect on the technology. This approach has the advantage of offering the possibility of statistically testing differences in efficiencies between different groups or types of farms.

Early works on the efficiency of cereal and food legume producers in the Dryland agricultural program started in 1988. In collaboration with the University of Nebraska, Tamehmachet (1988) has studied technical efficiency using the profit function approach (Cobb-Douglas) on a sample of 154 farmers in Abda. The results show a high degree of efficiency of the two types of producers studied. This work was followed by research on cereals and chickpea (Azzam *et al*. 1993, Azzam *et al*., 1994). The same analytical approach was undertaken by Fadlaoui (1995) to analyze the allocative (technical and economic) efficiency of corn in Saïs region. Boughlala (1998) undertook an analysis of the techno-economic efficiency of farmers for systems based on crop-livestock integration. The system approach adopted makes it possible to measure the evaluation of the efficiency indices for the system in order to assess its performance. However, the approach does not allow targeting a product or speculation alone, which limits the scope of interventions to improve efficiency. Also, as part of the BENCHMARK research, two studies of technical and economic efficiency of water users in Tadla (Elkired Youcef 2012, Najah Kamilia, 2013) were conducted in the perspective to improve water allocation and use. The particularity of his research is to try to analyze water losses for the main crops such as wheat, sugar beet and alfalfa. The estimated technical and economic efficiencies have shown that the shortfall is relatively high and small farmers are technically more efficient than large. Both studies have shown that there is considerable variation in the efficiency among farmers. On average, each producer can realize productivity gains of 46% and 35.4% of the production potential for bread wheat and sugar beet, respectively. In average, the efficiency indices for breadwheat are respectively 0.55, 1.86 and 1.03 for the technical, allocative, and economic efficiency, as regards the beet; it has an efficiency score of 0.53, 3.30 and

2.20 for technical, allocative, and economic efficiency. The decomposition by cultivation revealed slight superiorities, in terms of averages, of the producers of bread wheat relative to those of the beet. All these results suggest that considerable gains in production are possible through the rational use of available technological resources and knowledge.

Efficiency indices were regressed on the socio-economic variables, i.e. levels of experience and education, age, area exploited, family size, geographical location, quantity of water used for irrigation, and commercialization of crops. These variables explained 35% and 60.2% respectively for bread wheat and 33% and 96.4% for beet of the variation in technical and economic efficiency. Farms that use a minimal amount of water are more technically efficient. Farmer education improves the level of technical efficiency. Increased commercialization of crops translates into a positive impact on technical and economic efficiency. All these studies have shown that small farms are as technically efficient as large farms.

There is no doubt that this strand has provided important guidance, not only for development but also for research priorities.

V. RISK

Agricultural production is inherently risky due to the biological nature of typical agricultural products. The rising levels of fixed assets and increased financial leverage in many agricultural firms have further exacerbated the total risk facing any particular firm. Therefore, the need for accurate decision models that incorporate risk remains a concern for decision analysts. The first models used for analyzing farmer's behavior were deterministic. The hypothesis behind this approach is that farmers are operating in non-risky environment. These models were criticized because they ignore market production and input price variability and supply risk. Production risk, such as the inter- and intra-year variability of rainfall, can affect the profitability and hence the acceptance of a technology by farmers. Empirical analysis of production risk is often difficult because of data, information, and methodological deficiencies. Market forces represent another major source of risk. Sensitivity analysis which varies the prices and costs over the relevant range can be utilized to respond to this problem. Some innovations may be sensitive to small changes in prices or costs which may alter their relative profitability ranking. This justifies the need for risk analysis in relation to the transformation of agricultural technology. Farmers' perceptions of riskiness comprised a major factor in the success or failure of technology transfer.

The portfolio approach used in the Dryland Agricultural Research Program has the advantage of incorporating the effects of diversification. Additionally, many farm decisions can be modeled by the portfolio concept because of the consideration of several production alternatives and the interaction of an alternative with existing non-production activities or non-agricultural investments (Bernard Tew *et al*., 1988). It is assumed that the objective of the rational producer is to maximize utility derived from present and future consumption. The conventional method of empirical analysis in an expected utility framework is to consider the tradeoff between expected value and variance of income (net return), commonly identified as E-V analysis. The expected value and variance of income was used in studying the adoption of wheat improved varieties (Tew *et al*., 1988; 1990; Driuochi, 1990; Laamari, 1991; 2015; Bendaoud, 2004).

Farm practices and production technologies used by farmers are region and climate specific. These practices have been shaped to ensure a less risky income. The level of income depends also on the producers' objectives, production constraints, knowledge, available information and expected income given the random variables that can affect the decision-making process. Farmer's decisions are interrelated (Moussaoui, 1989, Driouchi, 1989). They concern daily practices that are seasonal or annual decisions. Most of the decisions are related to climatic and market conditions. In the case of arid and semi-arid zones, the situation is much more complicated because decisions are subject to high climatic variability. Agricultural decisions in these regions consist of predicting events that can affect their well-being on the basis of daily and monthly expectations. Given such behavior and technology specificities, agricultural research must target risk-efficient technologies in concordance of farmer behavior. In the policy side, government must develop widely adapted policy instruments.

Fadlaoui have safety first model to estimate Pratt coefficient for two samples in Chaouia. Tree types of farmers were identified within the interval of Pratt coefficient [-4.00, 0.6]. More than 77.3% of farmers are risk averse in Chaouia. According to these results specific technologies can be identified and target technology transfer program can be implemented. Also, it's important to notice that technologies can be classified according to their risk efficiency behavior.

In addressing farmer risk behavior and the interaction between anticipated technology adoption and risk attitudes, interesting conclusion can be drawn. Assessing risk behavior in arid and semi-arid regions indicated a large proportion of farmers being risk taking (37.5%). This result runs counter to the conventional wisdom of assuming that most farmers and small farmers in particular, are risk averse. It also points out the damaging effects from using average farmers instead of individual data in assessing risk behavior. Also, it's important to notice that in a highly risky environment, farmers are unlikely to display fixed strategies in decision making. Using stochastic approach as an alternative tool to evaluate income distribution among wheat producers (deficit irrigation) was possible and can be based on the outputs of farmer risk behavior interval (Moussaoui, 1994).

VI. TRENDS IN TECHNOLOGY TRANSFER APPROACHES

Since the establishment of the arid and semi-arid research center, technology transfer was one of the priorities in it research programs. Researchers have continually tried to use methods for data collection and planning which incorporated local farmer's perspectives, skills, and priorities. In early 1990s the concept of "system" was adopted, and farming operations have been examined as systemic wholes involving farm households' members allocating their resources to three interdependent processes (crops, livestock, and off-farm activities) to attain their culturally and materially defined goals. Scientists were convinced that a better understanding of the links between different components of the farming system would lead to the development and transfer of technologies appropriate to arid and semi-arid regions of Morocco. During this same period the concept of "on-farm research" or "on-farm trials" was born. The first step was to understand farmers' conditions using for the first time, participatory approaches such as SONDEO and transects.

Participatory diagnosis was used to help identify major factors that limited farm productivity. The information from the diagnosis was used in planning and experimental research program that includes experiments in farmers' fields. Economic evaluations of on farm tested technologies were also introduced. This helped to determine the cost-effectiveness and feasibility (acceptability) of an agronomic treatment from the producer's point of view. The identification of the best economic treatment contributes to the formulation of recommendations that a producer can adopt.

During the second phase of Mashreq& Maghreb Project, (1998-2002) new participatory methods were adopted, especially in data collecting. Probably the most powerful one was rapid rural appraisal (RRA). It is a field technique where the informant is guided by the researcher in session interview by means of a key, predetermined set of questions. Through an interview schedule, the construction of key questions must be prepared with care. A variant of this semi structured interview method is focused group discussions (FGDs). This same project introduced also the "community approach" that fostered different researchers from different disciplines to work together and build models for evaluating the extent to which, selected technical, institutional, and policy options, may affect on communities and groups. Stakeholder's analysis methods such as Venn diagrams was used to show the relationships between different groups and organizations within a community. Particularly useful in identifying potential conflicts between interest groups, Venn diagrams also clarify roles of individuals and institutions. Moreover, the assessment of privatization policies and their impacts on the ability of farmers to improve their production systems and livelihood strategies constitute an important contribution to helping policy makers target institutional reforms that would enhance the decision-making environment under which farmers in the dry areas operate. Furthermore, the development of a methodology for identifying the factors that contributed to women involvement in the off-farm labor market (gender approach) will help target further policies seeking to support the development of women and the improvement of rural livelihood strategies. Community approach helped to develop appropriate technical, policy and institutional options for studied communities.

In 2012, CANA project introduced the concept of "innovation platform" (IP). IP are seen as a significant improvement over the linear, less inclusive, and less interactive traditional agricultural research and extension approach. IP is also defined as a forum in which multiple actors/stakeholders with meaningful interests in a common issue collaborate in identification of problems, share, and develop new technologies.

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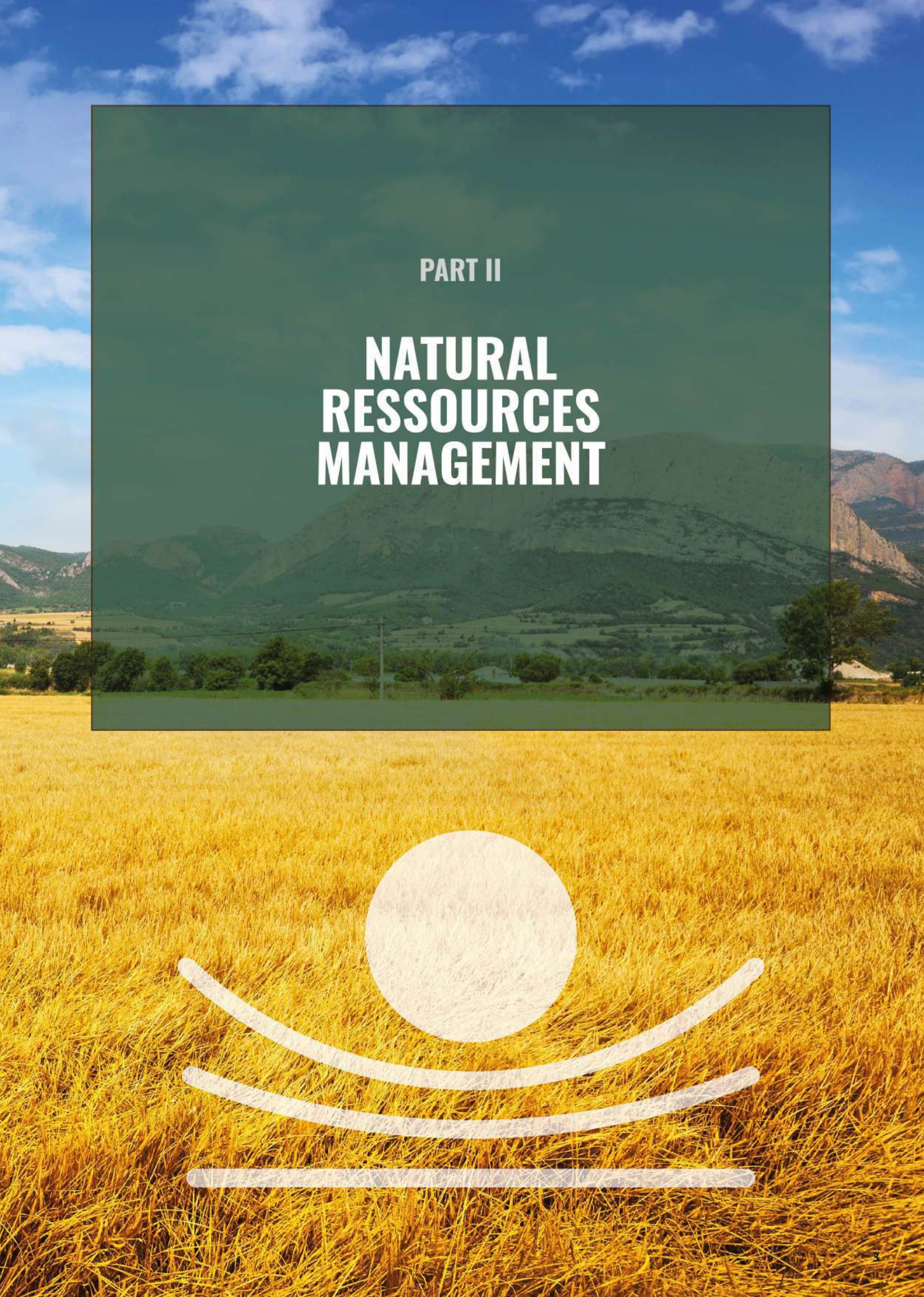

PART II

NATURAL RESSOURCES MANAGEMENT

CONSERVATION AGRICULTURE AND NO-TILL SYSTEM RESEARCH IN MOROCCO

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SYNOPSIS

Morocco has been actively promoting farm mechanization and tractors use. Tillage with tractors and harvesting with combines reduced labor constraints, thereby allowing an expansion on rangeland and yield improvement of wheat and barley. Other important crops such as beans, chickpeas, lentils, and oil crops have not received the same importance and some of them faded away. This intensification caused structural damage to the farming system, mainly in the fragile soils of the arid regions.

Research on Conservation Agriculture (CA) and No Tillage (NT) specifically started in Morocco early eighties. Results reported in this paper, from a group of scientists, shows all the achievements and the great improvements on water use efficiency, grain and biomass productions, soil physical and chemical qualities. Despite, all the advantages that NT offers and all the advances that research has achieved the adoption of CA is still very slow. Farmers and mechanization service providers state that unavailability of NT seed drills and the high prices of imported NT seeders are the main reason of the slow adoption. However, it is also clear that research on its own cannot achieve much even with the high-quality work. Therefore, the involvement of all stakeholders is the key to the success.

I. INTRODUCTION

Morocco's rainfed agriculture, production systems rely on crop-livestock integration. Water is the most limiting factor and is the primary driver no matter what crops or livestock are produced. In fact, this integration becomes more dependent on livestock as we move to low rainfall environments (less than 250 mm) where barley is used to be the main and key crop in the farming system.

The first promotion of tractors' mechanization was launched just after independence in 1957/58 cropping season. It was called "opération labour" and aimed to generalize tractor power in all farms that used to be animal traction mechanized. The traditional wooden plow used to have a metallic ploughshare and disturbs only the top soil (5 to 10 cm) in order to cover hand broadcasted seeds and eliminates the germinating weeds. This simple implement was used also for inter-row weeding of food legumes and spring crops. During the protectoral period, the French protectoral government introduced metallic animal traction plows to replace the traditional wooden plows.

These tolls had a moldboard, a heel and a point and used to work at 7 to 12 cm depth depending on the power of the animals and the soil type. However, from all the research conducted over the last decades, the majority of beneficial tillage effects are short-term then soils and land degradations become exacerbated.

During the late seventies, bread wheat was intensively introduced over all Morocco and has been promoted through subsidies and guaranteed market even in agro- climatic areas with less than 200 mm annual rainfall. In these harsh environments, the production and cropping systems were dislocated and complementarity is not any more insured. Indeed, with the pressure on land, livestock today relies more on feed coming from outside the farm productions. In 1980-81, the government launched a fertilizer program "opération engrais". The objective was to promote the use of fertilizers in order to enhance crop production that was declining and improve water use efficiency because of soils and land degradation.

Efficient storage of precipitations and efficient plant use of water becomes the key for sustainability of the dryland production systems and then main research topics. The problem continues to amplify with Climatic Change (CC) effects and the growing and more demanding populations. Peterson and Westfall (1994) stated that the success of dryland agriculture hinges on efficient management of its water and soil resources. They also acknowledged that we must change from thinking about managing an individual crop to thinking about the entire farming system management.

Traditionally in Morocco, the cropping system was much diversified. Even if cereals (barley and durum wheat) were predominant and considered as the basis in the cropping systems, the weedy fallow that is grazed by herds and food legumes used to be very important. Many other secondary crops, as coriander, flax, fenugreek, cumin, etc., were practiced for soil health as well as for weed and diseases management. In general, the traditional fallow used to be a fourteen-month break between successive cereal crops and was very nourishing, diversified and considered as a free forage source.

After the generalization of tractors use, the promoted cropping system was basically one-year cereal, one-year tilled fallow rotation in low rainfall environments (less than 300 mm) or two years' cereals and a third-year fallow in less stressed environments. Food legumes became less cultivated mainly because agronomic practices have not been improved; they are hand-labor demanding for their management in general and especially weeding operations (2 to 3 times during the crop growth). There is as well, the market price that is not guaranteed and when the productions are good, the prices are down, and the crops are not any more profitable. Today, the tilled fallow is as well almost abandoned due to the climate risk and cost. Subsequently, the shift in the cropping systems is due to population urbanization that leads to agricultural labor shortage and policies that neglected the value chains of food legumes and the other rotation crops (from seed multiplication to marketing). The new cropping system is largely cereals based (continuous wheat, wheat/wheat/barley, or wheat/barley/weedy fallow) intensively using new technologies (mechanization, varieties, fertilizer and pesticides). According to Laâmari (1992), the level of adoption of the technological package is correlated to the farm size and farmers' income.

II. CONSERVATION AGRICULTURE AND NO-TILL

FAO (2007) defined Conservation Agriculture (CA) as an approach to managing agro- ecosystems for improved and sustained productivity, increased profits and food security, while preserving and enhancing the resource base and the environment. CA is characterized by three linked principles (Figure 16), namely: (i) continuous minimum mechanical soil disturbance; (ii) permanent organic soil cover; and (iii) diversification of crop species grown in sequences and/or associations. The academics and promoters of CA stick to the definition pillars and restrict the entrance to less than 20% soil disturbance, at least 30% ground cover around the season and at least three different crops in the rotation. According to Loss *et al.* (2015), this rigid view of CA is not helpful for widespread adoption, even if it is agronomically justified.

The authors said that they are not arguing that farmers in dryland Mediterranean climate (Middle East) may not benefit from diversifying their rotations and in some cases retaining crop residues to improve their soil structure and fertility. The three pillars remain important in maximizing the benefits and producing a stable cropping and farming systems. But in practice the decision to adopt

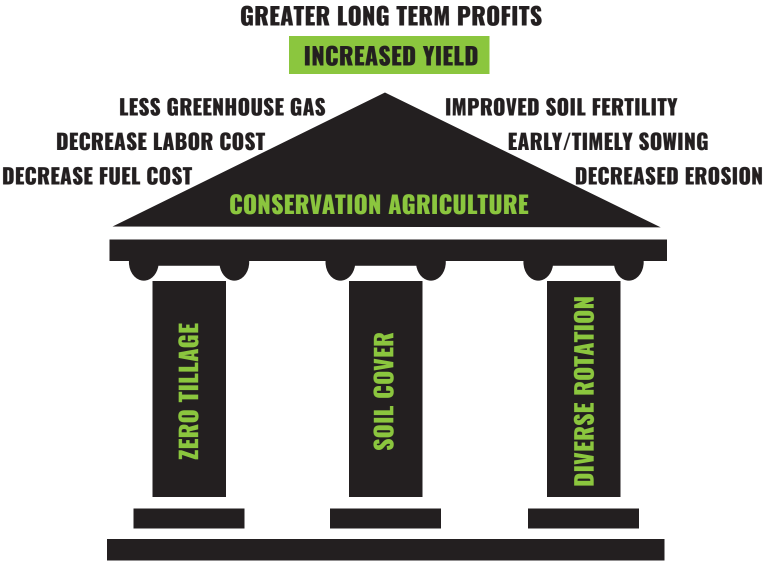

Figure 16. A mainstream model of CA with the three key principles acting as equal 'pillars' which produce a range of benefits, leading to greater long-term profits. (Adapted from Loss *et al.*, 2015)

different crops or retain crop residues is not straightforward as a change to Zero Tillage, because new crops and residue retention may reduce farm incomes at least in the short term.

In the middle East experience, where the agro-climatic and socio-economic conditions are similar to Morocco, Loss *et al.* (2015) reported that farmers who adopt Zero Tillage and early sowing usually saw immediate benefits after two or three years and many started to become more interested in the other principles of CA (Figure 17). The successful adoption of CA is a gradual process and innovative farmers around the world are constantly modifying their cropping practices to make their farms more sustainable and productive. This gradual approach is a key risk management strategy which delivers lasting adoption.

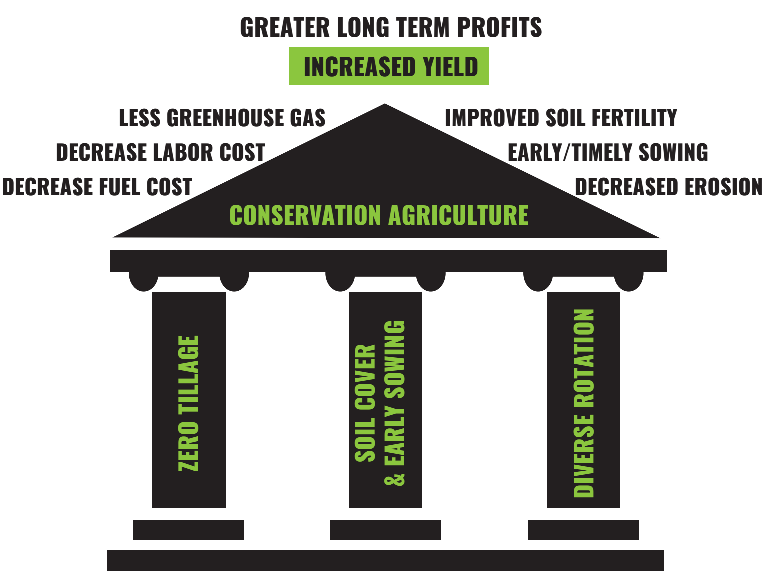

Figure 17. A middle Eastern model of CA with Zero-Tillage and early sowing forming the main central 'pillar' which is capable of producing many benefits, even without soil cover and rotation. *The three pillars remain important in maximizing the benefits and producing a stable cropping system* (Adapted from Loss *et al.*, 2015)

Since early eighties, No-tillage or conservation tillage research was conducted in Morocco at the Dryland Center in Settat with the National Institute of Agricultural Research (INRA). The fundamentals of this research were reported in the doctoral theses of soil scientists; Bouzza (1990), Kacemi (1992), and Mrabet (1997), and then reported in various proceedings and journal articles. The work grew out of need to improve the efficiency of rainwater in Morocco, especially in the 200-400 mm agro- ecological zones. Theoretically, residual moisture from the fallow year should increase the available moisture and therefore crop yields in the subsequent cropped year. However, in practice at farmers' fields, fallows are kept "weedy" and grazed over the cropping season. Farmers are considering the weedy fallow as a free forage resource as well as a break in the cropping system. At the end of the fallow season, there is little stored moisture, and the soil is bare and prone to erosion because the weeds that are not palatable green are hayed, and the soil is tilled. Therefore, with increasing mechanization and cultivations, any perceived advantage of fallow is eliminated, and land degradation is accelerated.

The main drivers of NT adoption in Morocco are: (i) Eliminating all tillage operations during the cropping season and prior to sowing and then related fuel and labor consumptions, machinery wear and maintenance and finally reduced evaporation since soils are not returned upside down; (ii) Conserving soil moisture if any rains occur before sowing time by eliminating soil disturbance; and (iii) Allowing early sowing since untilled soils are accessible earlier than tilled ones after rain events.

Due to the lack of imported direct drill machinery, adapted to local conditions (cost and effectiveness), a program to develop new NT seed drill prototypes was launched by INRA Morocco in 1989. The research program started by the comparison of commercial soil engaging components, single disc, double discs, and hoe (furrow) openers (Bahri, 1992). Information was collected on the soil-seed environment characterized by soil disturbance, bulk density, soil moisture, seeding depth and plant stand. The hoe opener outperformed the other openers for all parameters except uniformity of sowing depth. Plant emergence, being the best parameter from farmers' point of view, was statistically greater for the hoe than for the two-disc openers. Bahri's study demonstrated mainly that hoe openers are more suitable for hard and dry soil conditions at sowing time because of their better penetration.

The furrow opener also created the greatest amount of soil disturbance compared to other types of openers. This may also be an advantage for creating a better soil-seed contact and allowing water harvesting in the seeds zone. Moreover, the furrow opener performs better on stony fields compared to disc openers that roll over the stones and leave seeds on the top soil. Finally, the furrow openers do not generate any compaction at top soil and is capable of breaking all the compaction effects from animal trampling. Based on these findings, a program to design and develop an affordable and/or low-cost direct seeding drill was launched in 1995. The main drivers for this project are that on the international market, the size of seed drills (6 meters and more) and the technologies does not fit the Moroccan farmer's needs. The requirements of INRA soil- scientists for the drill were: (i) A machine capable of being operated by a 60 to 65 PTO HP tractor that are the mostly used by farmers; (ii) A seed drill able to operate in dry as well as humid soil conditions at seeding time; (iii) An opener capable to ensure minimum soil disturbance in order to minimize soil moisture losses; and (iv) A machine able to leave most of the residues on soil surface to cope with runoff and erosion and to conserve soil moisture.

At the beginning, the research, at the Agricultural Engineering laboratory of INRA Settat, started by development of a soil engaging elements (hoe opener) that will satisfy the above requirements (Bahri, 1996/97). The seed drill was able to deposit fertilizer and seeds at an adjustable depth and allow individual rows to follow the soil surface contour. The design came up to a soil engaging components that are composed of: (i) The coulter (notched disc) that cut the residues and open the first slash to the opener; (ii) The opener with an interchangeable point that opens the row and deposit the fertilizer and seeds at distinct depth placement; (iii) The press wheel that adjusts the depth of seed placement and improve soil-seeds contact.

The first industrial prototypes were developed in collaboration with a private manufacturer and tested with farmers (El Gharras and Idrissi, 2006). The agronomic performance was reasonable, but the industrial technological quality was just bearable. From farmers' point of view, even if the quality of the seed drill was much improved over the four generations, the product was not really up to their expectations mainly because this machine requires lot of maintenance during the work to keep the performance at the top level and the maintenance requirements during use of the machine (greasing of rolling parts). Up to today, about 50 seed drills of this design was sold and used for CA promotion and development.

Following a roundtable discussion with experimented NT farmers and mechanization service providers, INRA agricultural engineering laboratory decided to develop a new low-cost seed drill design. The product is a tine basic chisel that was developed as a seed drill for fertilizer and seeds placement in the soil with adjustable depth control on the frame. This seed drill is 2 to 3.5 m working width, for tractors from 55 to 120 HP, and a spring harrow behind the tines to improve seed covering or press wheels that are optional (ICARDA. 2015).

In 2008, Kuhn dealer in Morocco imported the first NT seed drill that was sold in the market. It is a double disc opener with press wheels that allow depth adjustment, and the price was above 50 000 $US. The seed drill of 3 m width requires at least a tractor of 110 HP. A small number of large farms were really able to buy this product that requires qualified labor for use and maintenance.

In 2014, Gil seed drills dealer introduced NT tine seed drills for the PICC-PMV project in Chaouia platform. Today, Gil retailer is still the only importer of NT seed drills that are available on demand in the Moroccan market. About 15 seed drills were sold and are used by farmers and/or mechanization service providers in different regions of Morocco.

IV. NO-TILLAGE IMPACT ON WATER AND CROPS PRODUCTION

The work of Bouzza (1990) and Kacemi (1992) assessed various cultivation implements under different fallow and rotation systems. Ten years of Bouzza results (Table 2) highlighted the potential of no-tillage to conserve moisture.

Table 2. Storage efficiency and amount of stored water for different types of fallow in semi-arid Morocco (Bouzza, 1990)

Type of fallow	Fallow storage efficiency [a] (%)	Amount of stored water [b] (mm)
Clean chemical	28	84
Clean tilled	18	54
Stubble mulch	21	63
Weedy	10	30

a Calculated as the ratio of stored water and the annual received rainfall during the fallow period.

b Amount of water stored in the 1.2 m profile.

Bouzza's work showed that where weeds were controlled exclusively by chemicals with evaporation being negligible in the absence of soil disturbance by tillage, the no-till system increased stored soil water by 54 mm and promoted increased wheat yields (Table 3) and consequently better water-use efficiency. However, it is regrettable to mislay 72% of rain water without producing any crop and spraying chemicals to control weeds for an entire cropping season.

Table 3. Wheat grain yield (t/ha) as affected by tillage (Bouzza, 1990)

	Sidi El Aidi (350 mm)		Jemaa Shaim (270 mm)	
Tillage system	Continuous Wheat	Wheat/ Fallow	Continuous Wheat	Wheat/ Fallow
No-Tillage	1.9	3.7	1.6	3.1
Reduced tllage (sweep)	1.6	3.7	1.6	3.1
Conventional tillage	1.4	2.6	1.4	2.4

on farm trials conducted in central Morocco, Settat region, (Figure 18) showed that bread wheat production under No-Till outperformed the conventional practices since the first year and every year, no matter what the rainfall amount and distribution were over the cropping seasons (El Brahli *et al.*, 2009 and El Gharras *et al*., 2009, 2017). This is mainly due to good agronomic management of the crop (seeding time and rate, fertilization, weed and diseases control). The NT and conventional plots were side by side and all the treatments over the growing season were adapted to better fit the crops needs in order to achieve the potential yield levels for both NT as well as the conventional. The soil on the farm experimental plot is a shallow (between 30 and 50 cm) and Calcimagnesic, stony (~ 15% soils cover) and on a sloping land (~3%) that is vulnerable to erosion.

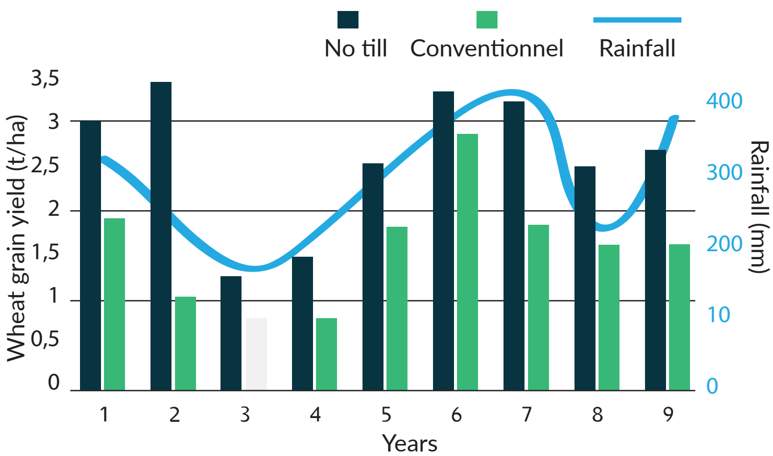

Figure 18. Wheat grain yield at farmer's field under conventional and no-tillage. (El Gharras *et al*., 2009)

During the cropping season 1999-2000, the total annual rainfall over the experimental site was about 200 mm (Figure 18). All crops failed and the region was considered a stricken area by drought. The only harvested field was the 4 ha of NT wheat sown on a chemical fallow that yielded more than 1 t ha^{-1} of grains and about 50 bales/ha with 14 kg of straw per bale. In 2003-04, the total amount of rain was more than 400 mm, but the CT wheat plot was significantly affected by 50 days of drought combined with day time high temperatures (over 20°C during the day) during the period of January and February. No-Tillage affects water and nutrients status within the soil and offers opportunities to improve WUE.

According to Mrabet (2000), WUE ranged from as low as 2.5 kg/ha/mm in offset disking during the cropping season 1998-99 to 10.7 kg/ha/mm for chisel plowing during 1995-96. He stated that reduced evaporation in the No-Till is reflected in WUE.

Kacemi (1992) reported that corn, lentil, chickpea and faba bean responded favorably to NT system with residues retention. El Brahli *et al.* (1997) and Aboudrare *et al.* (2006) stated that vetch-oat mixture and sunflower respectively yielded as conventional tillage or better from the first years. In arid rainfed areas, crops that yielded under NT less than conventional or minimum tillage systems (using sweep) have been related to several factors of crops management such as delayed crop establishment and development, increased difficulties with pest control and water shortage in late development stages for spring crops (as chickpea and corn) (Kacemi, 1995 and Mrabet, 1997).

V. WEED MANAGEMENT UNDER NO-TILL

In the crop-livestock integrated production systems, weeds are an important challenge since they are considered as free forage for livestock and the weedy fallow is widely practiced El Brahli and Mrabet, (2000). Abandoning the plow induces a qualitative and quantitative change in the flora which is why NT crop production relies on herbicides and particularly glyphosate, for weed management Aibar (2006); Blackshaw *et al*., (2015) and Loss *et al*., (2015).

Weed seed bank abundance and composition can be used as indicators of the success or failure of cropping systems and management practices (Buhler *et al*., 2001; Cardina *et al*., 2002; Rahali *et al*., 2010 and Kleemann *et al*., 2016). Integrated weed management systems have the potential to provide long-term management of weeds (Blackshaw *et al*., 2005; Holm *et al*., 2006; Harker and O'Donovan 2013 and Blackshaw *et al*., 2015).

According to Tanji *et al*., 2017, in a three years on-farm experimentation, integrated weed management combining glyphosate before NT planting, post-emergence herbicide use in wheat and haying mixture forage in a two years crop rotation reduced the weed seed bank by up to 35%, species richness by up to 47% and weed density prior to harvest by up to 83%. The authors stated that, in order to achieve good weed management as well as crop-livestock production system, grazed weedy fallows should be replaced by forage crops for hay. It is concluded that weed seed banks and weed densities can be managed effectively when a multi-year weed management program is implemented into NT system.

VI. DISEASES MANAGEMENT UNDER NO-TILL

Intensive exploitation of soil, especially under arid and semi-arid conditions directly affects soil composition and its structure (Mrabet *et al*., 2004a; Govaerts *et al*., 2008; Ziervogel *et al*., 2008; Mrabet *et al*., 2012). A consequence of the combined effect of these factors has been a drastic reduction in soil fertility, organic matter and in soil biological diversity (Reeves 1997; Dalal and Chan 2001; Garcia-Orenes *et al*., 2010 and Lal 2011), which in turn hampers soil health development (Doran 2002 and Kibblewhite *et al*., 2008).

From research conducted in thirty-three farm soils, that had adopted conservation agriculture for a period of 3 to 9 years, results show that food legumes and canola increased biological soil health in less than two consecutive crop rotations; and canola rotations would be the best in the long run (El Yousfi *et al.*, 2017). Canola rotations left soils with much more diverse bacteria species, higher dry biomass, and higher percent germination of seeds, while cereal rotations reduced the diversity of soils in terms of bacterial species and raised the level of fungal species especially those that are pathogenic to cereals such as *Fusarium culmorum* and *Bipolaris sorokiniana*. These findings are striking even within the no-till system. Microbial biomass in no-till soils was found to contain more nutrients than microbial biomass in conventional tillage systems (Balota *et al.*, 2003). Root rot diseases can be used as bioindicators of soil health (Hornby and Bateman, 1997), and the presence of pathogens such as *Fusarium culmorum* and *Bipolaris sorokiniana* will increase root rot disease severity index, when not properly managed.

VII. NO-TILLAGE IMPACT ON SOIL QUALITY

The concept of soil quality is relatively new and came to discussion in the nineties. Soil quality can be defined as the fitness of a specific kind of soil, to function within its capacity and within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen *et al.*, 1997; Arshad and Martin 2002). Soil physical and chemical parameters are the only parameters that are still used to evaluate the quality in Morocco, but soil biology is of interest and not yet taken into consideration.

VII.1. SOIL PHYSICAL QUALITY

Wet soil aggregation index, in semi-arid Morocco, increased under NT system with residues retention mainly at the soil surface (Lahlou, 1999; Mrabet 2002; Mrabet and Beqqali, 2005). Furthermore, Mrabet *et al.*, (2004); found that even without residues the untilled plots had higher levels of aggregation than tilled plots near the soil surface. Kacemi *et al.* (1994) reported that mean aggregate weight diameter measured for 0- 10 and 10-20 cm showed that NT systems has a more developed aggregation than the minimum tillage with a V Blade Sweep. However, after 4 years, Lahlou, (1999) reported a mechanical compaction under NT. On another side, after 6 years, Ait Cherki (2000) did not find any significant increase in dry bulk density under NT systems compared to conventional tillage in his experiments.

On the other hand, Dimanche and Hoogmoed, (2002) compared two soil tillage systems; off-set disking and reduced tillage with spring cultivator under simulated rainfall on a Chromic Calcixert soil of the semi-arid region of Meknes and concluded that disc harrow caused excessive pulverization and sub soil compaction that limited and hindered water infiltration. Kacemi, (1994) found that residue cover in continuous wheat had a tremendous effect on infiltration processes and he reported that it is then obvious to say that the soil structure is favoring better hydrodynamic properties of the NT plots. However, he concluded that the stability of the system soil-plant was not yet reached and more relevant comparisons should be pursued after few more years.

VII.2. SOIL CHEMICAL QUALITY

Intensification, of wheat and tillage using soils inversion implements like discs and moldboards plows, has led to considerable soil degradation in arid and semi-arid regions of Morocco. Investigation of NT benefits on soil chemical properties was initiated in the late 1990s (Bessam *et al*., 2001 and Mrabet *et al*., 2001). NT accumulates residues and improves the level of organic matter, even without any specific threshold of residues retention, as stated above (Mrabet *et al.* 2004). Bessam and Mrabet, (2003) reported that the quality of organic matter is improved by increasing the level of the active fraction that consists primarily of living plant roots, rapidly decomposing material and micro- and macro-organisms of soils (Table 4).

Table 4. Carbon content in particulate organic matter (t/ha) as affected by contrasting tillage histories in semi-arid Morocco (Bessam and Mrabet, 2003).

Time In Years	Horizon 0-50		Horizon 50-100		Horizon 100-200	
	NT	CT	NT	CT	NT	CT
5	10.62 A	9.75 B	9.45 A	9.32 A	17.23 A	16.81 A
13	11.88 A	8.94 B	8.53 A	9.07 A	14.80 B	16.28 A

NT: No Tillage and CT: Conventional Tillage using disc harrows.

Horizon in mm

Values followed by the same letter are not significantly different at p=0.05 using LSD test.

Disparities in accumulations of organic matter mean changes in concentration and distribution of nitrogen. Mrabet *et al.* (2001) reported that nitrogen content of the intermediate soil depth (2.5 to 7 cm) was higher in NT than CT for three rotations (Continuous Wheat, Wheat-fallow and fallow-wheat-barley) (Table 5). Tab, (2003) reported that after 7 years of NT under the continuous wheat rotation N sequestration was the highest. Bessam and Mrabet, (2001 and 2003) reported that particulate nitrogen (Npom) was higher under NT than conventional tillage in the seed zone of the experimentation from 4 to 13 years.

Table 5. Total nitrogen (g/kg) in the calcareous soil after 11 years of NT and conventional tillage systems (Mrabet *et al.*, 2001).

Depths (cm)	No-Tillage	Conventional Tillage
0 - 2.5	1.84 A	1.33 B
2.5 – 7	1.49 A	1.34 B
7 - 20	1.20 A	1.20 A

In the same line, values followed by the same letter are not significantly different at 5% LSD test.

However, Rice and Smith, (1984) reported that the effect of reduced tillage with residue retention on N mineralization is lower than conventional tillage. Zero tillage is generally associated with lower N availability because the residues on the top soil mobilize N for their decomposition. This is also the case on the on-farm trials conducted in Morocco whenever residues are abundant during the three to four first years of NT where we have to use 20 to 30% more nitrogen to compensate compared to conventional tillage plots.

According to Mrabet *et al*. (2001a) available P and K contents near the top soil were higher on NT than tilled soil, whereas in deeper layers the reverse has been observed. They stated that P and K were probably higher in the surface of NT soil due to higher soil organic carbon and to the fact that these systems, maintained surface-applied P. They concluded that NT systems affect the vertical distribution of plant nutrients within the topsoil. The authors found as well that NT permitted a surface slight acidification of surface horizon, mainly due to organic matter accumulation in the depth of 0 to 2.5 cm. This decrease in pH by 0.2 units may be important for nutrient release for use by wheat or other crops in Morocco's Calcareous soils.

VIII. ADOPTION

Little work has been conducted in North Africa in general and Morocco as part of that region about CA and/or NT adoption. The first and lonely experience was within the Australian Center for International Agricultural Research (ACIAR) funded project with ICARDA and INRA from 2012 to 2015. Unfortunately, the CA for North Africa (CANA) project was interrupted in the second year and the preliminary results showed that there is a big potential. The suitability study conducted within the CANA project shows that more than 4.5 million hectares in Morocco are highly suitable for NT. Similar study was conducted by Moussadek *et al*. (2015) for central Morocco within Integrated Natural Resources Management (INRM) project and reported that more than 2.8 million hectares within central Morocco is highly suitable for NT.

The area under NT is increasing and the number of seed drills imported and/or manufactured sold on the Moroccan market is increasing at a snail's pace and not to most of stakeholders' expectations. The small farmers (more than 80%) say that the prices of NT drills are very expensive, and they cannot afford buying. The manufacturer says that he is waiting for orders to lunch serial manufacturing and marketing. The agricultural department is waiting for a CA strategy to be developed and all training programs are still teaching and promoting tillage practices. The private sector (tractors and farm equipment importers, pesticides retailers and mechanization service providers) is concerned by the reduction of their business opportunities if CA is practiced at large scale. The research institutions cannot develop CA nor NT technologies within research programs and projects. The objectives are contrasted and cannot be implemented at farmers' level even if the research is conducted on the farm.

Adoption of CA should be gradually undertaken within Innovation platforms that consider farmers and farm production as the heart of the system. Then the impacts will include more knowledge and capability amongst stakeholders, especially in the areas of agronomy (crop managements, rotations, and sequencing), crop-livestock integration, machinery development and socio-economic and policy. This work should develop a base for collective knowledge improvements in productivity and sustainability, and importantly the potential for CA to be adopted by farmers over a wide range of scales and environments.

IV. CONCLUSIONS AND RECOMMENDATIONS

Conservation Agriculture is all about natural resources preservation and must improve farm productions. The challenge is to guarantee the economic viability and the environmental stability within the risk of climate uncertainty in dryland agriculture. ZT and/or NT is the first step into CA if it is adopted as a system integrating minimum soil disturbance (no soil tillage operation just a seeder for crop establishment), early sowing, crop diversification and rotations. Then NT technologies should be introduced at farms with and by farmers (or farmers' organizations). They should concentrate on the components of CA to improve their production systems with the support of research, development, extension, and private sector businesses.

Farming systems in North Africa were developed based on crop-livestock integration. The history proved that autochthon practices (the wooden plow, crop diversification, weedy fallow, etc.) and knowledge developed allowed the survival of the societies over historical drought that crossed the region. The introduced post-colonial tillage practices have led to land and natural resources degradation and exposed the population to vulnerability.

All the research work focused on water conservation and water use efficiency, soil fertility and/or quality improvement, and lately weeds and disease management under NT. These findings are valuable if they are implemented within the production systems. The next step is to undertake an integrated CA research on the crop-livestock productions and introduce animal production as a full component of the farming system. Improving crops management and narrowing crops' yield gap by itself will not solve farmers' problems in North Africa.

Zero-Tillage or No-Tillage is the key to a CA system that need to be developed for farmers in Morocco. Farmers and farmers' organizations, mechanization services providers and input suppliers can start from this simple technology and manage to control their weed and disease problems in order to improve water use and water scarcity. Crop rotations are part of this solution since the introduction of forage mixtures, hayed crops to replace the weedy fallow, are part of the weed and disease management. The residues and summer grazing of stubble should not be compulsory from the beginning to implement the CA principles. Tine seeders can solve all compaction problems and contribute to soil rehabilitation.

X. RESEARCH PROSPECTS

A research program specific to WANA region should be undertaken. Many of the findings that are reported rely on science developed under conventional tillage like soil calibration for fertilization, seeding rates, dates of sowing, seeders technologies, etc. Therefore, a team of researchers should undertake these basic experiments within a transect from dry to wet regions and readjust the recommendations for CA promotion.

More deep fundamental research should target: (i) Biological soil indicators related to crop rotations and crop sequencing; (ii) Animal grazing impact evaluation on the farm and farming system and its impact on soil physical and chemical properties; (iii) Adoption constrains identification and measures to overcome the obstacles.

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SUPPLEMENTAL IRRIGATION AND WATER HARVESTING

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SYNOPSIS

The precipitation in Morocco is in general an erratic and extremely discontinuous phenomenon and it is mostly less than the normal. Though water deficit can occur at any time during the growing season of crops, but two periods of drought are likely to occur in Morocco; the early drought that occurs usually in November and December and affects stand establishment of Fall grown crops and late drought during Spring and early Summer that is more frequent and have negative effects on grain set and development of annual crops.

Water resources and climatic constraints management is a permanent challenge in Morocco. On one hand, the country has increased its agricultural production, while the water resource is becoming limited, and hence satisfy the rapidly growing and diversified food demand; and on the other hand, it has to save water for domestic and industrial uses that have become important. Consequently, the sustainability of production systems is found to be conditioned by the efficient use of this scare resource and the optimization of production.

Supplemental irrigation is an efficient mean to overcome or at least to reduce the effect of water stress on crop production.

In Morocco, both indigenous water-harvesting techniques and small irrigation systems are still used in many regions. Among the well-known water-harvesting systems in use in Morocco's arid and semi-arid areas are the matfia (cistern), which was introduced into the country by the Portuguese in the 16th century, when they colonized cities on the coast of the Atlantic Ocean, and the rhettara (qanat), an underground water- harvesting system developed during the period of the Almohad.

I. SUPPLEMENTAL IRRIGATION

Supplemental irrigation is an efficient mean to overcome, or at least to reduce, the effect of water stress on crop production, and to increase and stabilize yields. In Morocco, supplemental irrigation studies have been conducted mostly in large agricultural perimeters mainly Chaouia, Abda, Doukkala, Saiss, Gharb and Tadla (Belbsir, 1990; Bazza and Laaroussi, 1992; Boutfirass, 1990, 1997; Boutfirass *et al*., 1992, 1994; Chaouch, 1990; El Mourid *et al*., 1992; Handoufe *et al*., 1987; Ouattar *et al*., 1992). These works have been undertaken on cereals and more particularly on wheat. Other researchers have tried to apply this technique on other crops such as sunflower (El Asri, 1990), sugar beet (Chati, 1996) and winter chickpea (Boutfirass, 1997).

In cereals, the beneficial effect of supplemental irrigation on production and water use efficiency is significant. In most of studies mentioned above, supplemental irrigation was applied at critical development stages of wheat. These are tillering, booting and grain filling stages. Crop watering has been targeted to one or the other of these stages, but the effect in terms of yield increase varies considerably. In the case of a single irrigation, water supply at the pre-anthesis stage increased the yield more than when it is at post-anthesis. This difference in yield increase is explained both by the production of a minimum biomass threshold at the anthesis, that is needed for grain production and estimated at 6000 kg/ha (El Mourid, 1988) and by the fact that the two most important grain yield components (number of spikes and number of grains) are elaborated early in the cycle of wheat development and benefit from the early irrigation. Post-anthesis irrigation can help only in the increase of kernel weight.

If we consider the pre-anthesis phase with its two stages of tillering and booting, differences in response to supplemental irrigation can be explained by: (i) differences in soil water storage capacity of different soil types; (ii) differences in soil profile recharge that can vary with crop life cycle positioning as compared to the rain fed season (seeding date, thermal amplitude and evaporative demand during the vegetative phase), and rainfall intensity and number of rainy days during the vegetative phase; (iii) differences in the soil water depletion rate, depending on the use of different cultural practices (seeding rate, planting depth, seed bed preparation), weather conditions (evaporative demand), crop type and varieties used, and plant cover early in the season.

For a better integration of most of these variables, a simulation of the effect of supplemental irrigation for different growth stages has been carried out using a wheat growth model SIMTAG (El Mourid *et al*., 1992). In this simulation, the authors used a climatic data series of more than 20 years in two contrasted regions. For each region, the simulation has been made for two soil types (deep and shallow soils) and three bread wheat varieties (early, semi-early and late maturing cultivars). Results showed that the effect of supplemental irrigation varies with the soil and variety. On a deep soil, supplemental irrigation at tillering stage gave the best yield increase, whereas in a shallow soil, irrigation at booting stage did better. The same results were also obtained in terms of probabilities. Early and semi-early maturing varieties are the best-adapted varieties for the simulated conditions of arid and semi-arid zones. However, late maturing varieties should be avoided under similar conditions. Yield variability over years is greater for shallow soils with low water storage capacity. The best yield stability has been obtained for deep soils irrigated at tillering stage. In terms of water use efficiency, the same trends as for grain yield are obtained. These results confirmed those found by Boutfirass (1997) in a field experiment conducted during two contrasted years (342 mm v.s 247 mm) in a deep soil. The latter author concluded that in semi-arid regions where the soil is deep, it is better to apply supplemental irrigation early in the growth season.

In the case of the other crops, preliminary results showed the importance of supplemental irrigation in yield improvement and stabilization. Yield increases obtained for some crops and irrigation water saving brought for others show that this technique is promising. Indeed, in the case of sugar beet, Chati (1996) concluded that as long as this crop is well watered at seedling stage, the crop would be suitable to supplemental irrigation. He found that the number of irrigations is not as important as the period of irrigation.

On winter chickpea, a single irrigation of 60 mm water at pod elaboration stage helped the crop to maintain green area duration for more than 45 days as compared to the rain fed plot (Boutfirass, 1997). This green area duration contributed to an important increase in grain yield.

For sunflower, irrigation applied at the most sensitive stages of the crop (floral bud, flowering) increased considerably yield (El Asri, 1990). The highest grain yield is obtained with one irrigation at floral bud stage. Nevertheless, oil content of the grain can be negatively affected due to the fact that the total oil production remains similar for different grain yields.

In summary, supplemental irrigation is an efficient mean to improve and stabilize yield of cereals. In the case of one irrigation only, it would be more efficient to apply it early in the crop life cycle (at tillering stage) more particularly when the soil presents a large water storage capacity. In the case of more than one irrigation, it is necessary to target the three most sensitive stages of the crop to water stress. These stages are respectively tillering, booting and grain filling, in the case of wheat.

Most of the mentioned studies were conducted with cultural techniques that are normally recommended for rain fed agriculture. This supposes that possibilities of improving yields under supplemental irrigation remain to be exploited while adopting cultural practices adapted to irrigated agriculture (such as seeding date and rate, seed bed preparation, fertilization, pest control, etc.). Attempts have been made

(Handoufe *et al*., 1992; Bahaja, 1994), but remain insufficient to draw at this stage some practical recommendations.

As long as supplemental irrigation requires an investment for the equipment, the economical profitability should be considered. Therefore, relative profitability studies using supplemental irrigation in different conditions and with different irrigation systems were undertaken. Different approaches were used in these studies, but in all studies, the bank is 14 to 15%.

Ouattar *et al.* (1992) presented a case study using the mobile ramp irrigation system. In their calculations the authors considered the pre-anthesis supplemental irrigation outputs and found that this technique is economically justified from a minimum area of 10 ha. Moreover, when they increase the bank interest from 14 to 28% the technique starts only to be profitable at 13 ha of equipped and irrigated area.

Lamrani *et al*. (1992) tempted to evaluate the financial profitability of supplemental irrigation through the analysis of "farm models" where they considered three typical farms of an area of 5, 30 and 50 ha. The first farm is equipped by the classic sprinkler system, the second is equipped with self-propelled ramp and the third is equipped with center pivot system. Simulation of output gains was run for over 30 years. Results showed that in order to make the technique profitable, the upper limit of investment is 2250 USD/ha for an output of 6000 kg/ha, and 1740 USD/ha for an output of 5000 kg/ha and 1230 USD/ha for an output of 4000 kg/ha. This latest alternative was therefore possible only with self-propelled ramp. Nevertheless, it would be necessary to notice that subsidies granted by the government in this area were deduced from these investments.

Wheat production in the rainfed areas of North Africa is constrained by drought and heat stress, especially when anthesis and grain filling periods are delayed due to late planting. For optimization of yield, an early sowing and/or application of supplemental irrigation (SI) are critical to ensure a good kernel set and grain filling. Recently, a case study was conducted to develop potential options that improve the adaptation of wheat to high temperature and drought through better management and use of green and blue water resources (Karrou *et al*. 2016). To expose the crop to different soil moisture and temperature conditions, four bread wheat genotypes were sown at two planting dates - December 12 and January 30 in year 2012-2013 and November 19 and December 23 in 2013-2014 under two water regimes, Rainfed and Supplemental irrigation. Data shows that late planting, under rainfed conditions, decreased 1000- seed weight from 38.7 to 32.3 g in 2012-2013 and from 45.6 to 26.8 g in 2013-2014. This corresponds to reductions of yields from 2.5 to 1.2 t/ha and from 2.8 to 0.3 t/ha, for years 1 and 2, respectively. However, under supplemental irrigation regime, yields from early and late plantings were similar in both years.

The yield increase, during 2012-13 growing season due to supplemental irrigation, was from 2.5 to 4.3 t/ha under early planting and from 1.2 to 4.4 t/ha under late planting. The application of irrigation water increased productivity from 2.8 to 5.4 t/ha in early planting and from 0.3 to 5.3 t/ha in late planting in 2013-14. Under rainfed conditions, actual evapotranspiration varied from 236 mm to 330 mm under early planting and from 181 mm to 232 mm under late planting. Under SI, it varied, in general from 396 mm to 593 mm. Data shows also that, early planting increased significantly water productivity (WP) under rainfed conditions. However, the effect of planting date on this parameter under supplemental irrigation was observed only during year 2. On average, WP was respectively, for early and late planting, 9.2 and 7.8 kg ha^{-1} mm^{-1} in year 1 and 10.5 and 5.1 kg ha^{-1} mm^{-1} in year 2. The effect of SI on WP was not consistent. It was positive only in year 1 under both early and late planting dates. The increase, in year 1 varied from 144% for early planting to 218% for late planting. From this study, we can conclude that early planting and supplemental irrigation in late planting are key options to mitigate the effects of drought and heat stress which are getting exacerbated by the effects of climate change in the dry areas in North Africa.

II. DEFICIT IRRIGATION AT LARGE SCALE

Results of on farm demonstrations dealing with deficit irrigation (DI) management confirmed the advantage of this technique. Table 6 shows that, when used with an improved technical package, DI can be efficient and successful in saving one third of irrigation water with little or no impact on wheat yield.

Table 6. Effect of full supplemental irrigation and deficit irrigation on grain yield of wheat in Tadla site. (Adapted from Boutfirass 2014).

Irrigation management	Grain yield (ton/ha)	Water productivity (Kg/m^3)
Full supplemental irrigation	7.1	1.3
Deficit Irrigation (30% less water)	7.0	1.6

Irrigation systems, alternative to conventional basin one, were tested thoroughly on experimental stations. The tested systems included drip irrigation and raised bed-based system. The results showed that the tested systems are globally more productive than the basin system with respect to biological and grain yields. The water use efficiency (WUE) was also better with drip irrigation than with the other two systems (Table 7). Moreover, the control of irrigation either in water distribution over the plot or in the applied amount of water was easier and more efficient under drip irrigation and raised bed.

Moreover, with respect to the land used, and if the area of the furrows reserved for the flow of irrigation water in the case of basin irrigation and raised bed is deducted, the total production is higher under drip irrigation. In fact, the portion area used by the furrows (thus not planted) is 10% under basin irrigation with basins 10 x 10 m^2, and 20% under raised bed when the width of the bed is 1 meter, and the length is 40 meters.

Table 7. Effect of different irrigation systems on WUE (Kg/m^3) in wheat production in Tadla site. (Adapted from Boutfirass 2014).

Irrigation system	2010/11	2011/12	2012/13	2013/14	Mean	Change over basin
Drip Irrigation	1.2	1.5	1.4	1.15	1.31	42%
Raised Bed	1	1.2	1.1	0.91	1.05	13%
Basin	0.9	1.1	0.9	0.81	0.93	

III. RAINWATER HARVESTING

Water has always been an important component of societal development. Many of the powerful and sustainable civilizations of the past developed in areas where just enough water was available. These civilizations developed irrigation schemes and hence agricultural production, which was the main source of income. In dry areas, where water was scarce and where drought was more likely, people developed techniques for collecting and storing rainwater for domestic uses, the watering of livestock, and the irrigation of crops. Such water harvesting not only helped people survive drought, it also insured their well-being.

The main reasons for the development of water-harvesting techniques were that alternative sources of water for drinking and irrigation were not available, and the expertise needed to pump groundwater did not yet exist. Following the technological developments of the 19th century, however, small irrigation schemes and water-harvesting techniques received little attention. Large irrigation schemes were encouraged instead. But, because of population growth during the 20th century and the appearance of new water uses (which have increased competition for the limited amounts of water available) more interest is now being shown in Water-harvesting techniques, though mainly in arid and semi-arid areas.

In Morocco, both indigenous water-harvesting techniques and small irrigation systems are still used in many regions. Among the well-known water-harvesting systems in use in Morocco's arid and semi-arid areas are the matfia (cistern), which was introduced into the country by the Portuguese in the 16th century, when they colonized cities on the coast of the Atlantic Ocean, and the rhettara (qanat), an underground water- harvesting system developed during the period of the Almohad (AD 1147-1269).

Since the 1960s, the government of Morocco has encouraged large-scale irrigation. Although a major effort has been made in terms of the construction of dams, water resources are becoming more and more scarcer. In addition to the problem of water scarcity, only 1.6 million ha of Morocco's 9.2 million ha of arable land show the potential for irrigation (1.3 million show potential for perennial irrigation and 0.3 million show potential for seasonal irrigation). Around 67% of the country's (7.6 million ha) of rainfed cropland is located in arid and semi-arid zones, where the risk of crop failure, water losses through runoff and evaporation, soil erosion, and desertification are very high.

To ensure agricultural production and sustainability in the arid and semi-arid areas of Morocco, and to reduce the migration of rural people to the cities, new sources of water need to be found and sound techniques for water management need to be developed, in order to meet the demands of humans, animals, and plants. Rainwater is one of the possibilities, under-developed, water resources in such areas. One strategy for improving the efficiency with which rainwater is used is the development of adapted techniques for the collection and storage of runoff water. However, in order to adapt such technologies, it is important to first describe and evaluate the existing techniques. This will allow us to improve them and to propose other, more efficient, alternatives.

The rainy season in Morocco occurs, in general, from November through April. Approximately 80% of the precipitation delivered returns to the atmosphere through evapotranspiration: only 30 billion m^3 (comprising infiltration and runoff water) is considered to be potentially “useful” rainfall. This potentially useful water consists of 22.5 billion m^3 surface water and 7.5 billion m^3 groundwater (Benazzou, 1994). The management of this resource and of the associated hydraulic infrastructure (i.e., dams and reservoirs), currently allows only 10.9 billion m^3 of water to be used effectively (7.3 billion m^3 surface water and 3.6 billion m^3 of groundwater). In 1990, most of the water effectively used (92%) was used in agriculture, but more competition is expected from other sectors (domestic and industrial) in the future. Prediction studies indicate that by the year 2020 only 81% of this water will be used by agriculture (AGR 1995). More than that, water requirements will, by this time, be greater than the available water resources.

Various water-harvesting systems are found in Morocco. The different techniques are discussed: Indigenous water harvesting techniques in Morocco. Indidenious Water-Harvesting Systems in West Asia and North Africa (Karrou and Boutfirass, 2004).

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RESEARCH ACHIEVEMENTS ON FORAGE CROPS AND RANGELANDS IN MOROCCO

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SYNOPSIS

Sheep based farming systems in arid and semi-arid areas of Morocco are facing tremendous challenges affecting their sustainability. Among these challenges we cite climate irregularities, with frequent severe droughts, in addition to irrational farming practices (mechanization, rangeland ploughing, herbicide use, wheat crop displacement in the arid land, etc.) and farm size reduction and partitioning. Since the early 1980's, the National Institute of Agricultural Research (INRA) has set an ambitious research program to improve fodder and agro-pastoral resources in these farming systems located in different agro-ecological zones of Morocco. In this work, we present a synthesis of major achievements on forage crops and rangelands/pastures improvement research obtained by INRA researchers and particularly those in the dryland research center of INRA Settat. Concerning "Forage crop species selection and breeding" many barley, oats and triticale varieties and ecotypes were obtained. Similarly, legume forage crops were identified and released such as common vetch (Vicia sativa L.), hairy vetch (Vicia villosa L.), Narbonne vetch (Vicia narbonnesis L.), Fodder pea (Pisum sativum L.) in addition to local and introduced ecotype of annual medics and clovers. Also new adapted fodder-crops based cropping systems were developed such as the Ley farming, cereals/fodder legumes mixtures, grazed weedy fallow improvement, pastoral shrub and cactus. Mono-cropping and alley cropping based systems were developed. Some achievements on adoption and impact of conservation agriculture in marginal areas: case of agro-forestry system with alley cropping are showed in this chapter.

I. INTRODUCTION

Climate irregularities accented trends and socio-economic changes in semi-arid and arid areas, where sheep farming based production systems dominate, have aggravated the environmental vulnerability, and weakened the sustainability. Also, farms size reduction, farming land heritage-split and fragmentation, mechanized farming of rangeland and pastures and the change in attitudes of the agro-pastoral population led to an imbalance of the integration "cropping systems and animal systems" and that feed resources have become scarce and insufficient to meet livestock needs. This has led to an increased dependence on the market for feed purchase, pasture degradation, an acceleration of rural exodus and vulnerability of local production and natural resources (soil, rain water and biodiversity).

Faced with this situation, the needs of sheep growers become urgent for the identification of fodder and pastoral alternatives/options to mitigate the drought effects, to rehabilitate plant cover, to improve fodder production and quality, and to reduce the dependence on the market for feed supply.

The technology package that could meet all of these needs must have the following characteristics: (i) Improves fodder and agro-pastoral resources availability on the farm that is productive and of good quality; (ii) Extends the use of farmland for a longer period of the year than it is now; (iii) Increases the use efficiency and natural resources conservation; (iv) Respects current agricultural practices of local production systems in order to not cause imbalances and affect their sustainability; (v) Be available and can be extended locally; (vi) Be simple, easy to practice with the minimum risk of adoption; (vii) Allows the integration of scientific, technical, institutional, organizational, and political findings during the late phases of adoption.

In the following sections we will list the inventory of the major achievements on forage crops and rangeland/pasture improvement research that were obtained by the dryland research center of INRA Settat according to the following axis: (i) Forage crop species selection and breeding; (ii) Newly developed fodder-crops based cropping systems; (iii) Adoption and impact of conservation agriculture in marginal areas: case of the agro-forestry system with "alley cropping".

II. FORAGE CROP SPECIES CHOICE AND VARIETY CREATION

Forages have always been a priority within the national research system since the protectorate. Indeed, since the creation of the National Institute of Agronomic Research (INRA), the research and development of different fodder and pastoral alternatives had taken a special scope to support various strategic plans approved by the Ministry of Agriculture such as the dairy plan, red meat plan, etc. Research programs have reached very important and diversified achievements (INRA, 1997) within different agro-ecological areas and different farming systems.

II.1. FODDER CEREAL CROPS

II.1.1. BARLEY

Barley is the most adopted crop in arid and semi-arid regions due to its adaptation to the bio-physical environments and its multipurpose uses (human food and animal feed). Depending on the use purpose, there are three types of barley: (i) Biomass barley used as pasture near by the house on well organically fertilized land (grazed-biomass called locally “Glass”); (ii) Grain barley used for grain production on suitable land, and (iii) Dual purpose barley (pasture and grain) suited for grazing under favorable rain conditions and let for grain production.

INRA have been developing different varieties according to the three types, since 1982 (Table 8).

Studies of the behavior of different barley varieties for the dual purpose (pasture and grain production) under the conditions of grazing by sheep in real environments (El Mzouri, 1994, 1994, 1995 and 1996(a)(b)) showed the suitability of ACSAD 176, Annoceur, ACSAD 60 and Tamallalt varieties for this practice under semi-arid conditions of Chaouia, Ouardigha and Zaer regions.

Barley varieties suited and appreciated by farmers for their grain production and quality are those of six rows such as: Annoceur, ACSAD 176, Oussama, Amira, Taffa and Arig 8 (Amri *et al*., 1993, El Mzouri, 1994). The assessment criteria were their levels of grain production (1.3 to 3.6 t/ha), straw production (1.8 to 4.0 t/ha), and their grain quality linked to their digestibility by sheep. As for two-row varieties, they were less appreciated for their low straw production and grain hardness and low digestibility by ruminants, despite their excellent levels of grain production and their adaptations to harsh environments. Best two-row varieties under semi-arid conditions were ACSAD 60 (1.5 to 3.8 t/ha), Aglou (1.2 to 3.2 t/ha) and Azilal (1.2 to 3.3 t/ha) (Amri and El Mzouri, 1997).

II.1.2. TRITICALE

A number of varieties have been selected and registered by INRA since 1988 (table 9). Triticale is very suited for the difficult water stress conditions and acid sandy soils. Used in fodder mixtures, it showed a broad adaptation for coastal areas, interior plains of Zaer, Chaouia, Rhamna, Tadla and Hmar, the plateaus of phosphate (Ouardigha and Béni Meskine) and central plateau (Mergoum, 1988, MARA-CAE, 1989, Mergoum *et al*., 1992, Mergoum and Kallida, 1997, El Mzouri, 1994; 1995; 1996 a and b; El Mzouri and Aouragh, 1997, El Mzouri, 1997a and b; El Mzouri *et al*., 1997; El Mzouri *et al*., 2009). Its production of dry matter exceeds other grain feed under the conditions of acid soils, sandy and schistose soils and in the case of biotic (diseases) and abiotic (water and heat) stresses. Obtained biomass yields varied between 2.87 and 4.45 t DM/ha. Yields and the quality of the grain of newly created varieties are better.

Table 8. Main traits of INRA barley varieties

Variety	Adaptation area	Main features	Registration year
Barlis	Favorable and semi- arid areas	6 rows, fodder, long straw, susceptible to diseases	1982
Merzaga	Favorable, semi-arid and arid areas	6 rows, fodder, long straw, susceptible to diseases	1982
Rabat	Favorable, semi-arid and arid areas	6 rows, fodder, long straw, susceptible to diseases	1982
Brasserie Maroc	Favorable and semi- arid areas	2 rows, early, medium straw and susceptible to diseases	1982
Arig 8	Favorable and semi- arid areas	6 rows, early, medium straw and susceptible to diseases	1982
ACSAD 60	Arid and semi-arid areas	2 rows, early and resistant to net blotch	1984
ACSAD 176	Semi-arid areas	6 rows, early and resistant to net blotch	1984
ASNI	Semi-arid mountain and irrigated	2 rows, 128 days, resistant to powdery mildew	1984
TAMELLAT	Semi-arid	2 rows, 118 days, resistant to rust and powdery mildew	1984
TISSA	Favorable areas and irrigated	2 rows, 142 days, resistant to brown rust and powdery mildew	1984
ACSAD 68	Favorable, semi-arid and arid areas	6 rows, moderately late	1985
AGLOU	Favorable, semi-arid and arid areas	2 rows, 127 days, resistant to net blotch	1988
TIDDAS	Irrigated	6 rows, 125 days, resistant to rust and powdery mildew	1988
AZILAL	Semi-arid and arid areas	2 rows, 118 days, resistant to rust and powdery mildew	1989
LAANOCEUR	Favorable and semi- arid areas	6 rows, 135 days	1991
TAFFA	Favorable and semi- arid areas	6 rows, 115 days, resistant to brown rust and powdery mildew	1994
MASSINE	Favorable and semi- arid areas	6 rows, moderately early	1994
OUSSAMA	Favorable and semi- arid areas	6 rows, moderately early	1995
AMIRA	Favorable and semi- arid areas	6 rows, medium early, resistant to brown rust and powdery mildew	1997
IGRANE	Favorable, semi-arid and arid areas	2 rows, medium early, resistant to brown rust and powdery mildew	1996
AMALOU	Semi-arid and arid areas	6 rows, Early, resistant to brown rust and powdery mildew	1997
ADRAR	North West and mountains	2 rows, medium late, resistant to brown rust and powdery mildew	1998
FIRDAWS	Favorable, semi-arid and arid areas	6 rows, medium early, powdery mildew resistant	1998

However, grain yields have fluctuated between 1.23 and 3.62 t/ha according to the site, the variety and the climatic conditions (El Mzouri, 1993; 1994; 1995; 1996; El Mzouri *et al.*, 2003; El Mzouri *et al.*, 1997; El Mzouri *et al.*, 2009). Forage quality is intermediate between those of wheat and rye. Indeed, its crude proteins content is 12.2% compared to 13.2 and 10.0% for wheat and rye, respectively (Jaritz, 1997).

Table 9. Main features of INRA triticale varieties

Variety	Adaptation area	Main features	Registration year
Beagle	coastal, sandy soil and unfavorable areas	Resistant to diseases and insects, Tolerate water stress, dark grain	1988
Juanillio	coastal, sandy soil and unfavorable areas	Resistant to diseases and insects, Tolerate water stress, dark grain	1988
Borhan	coastal, sandy soil and unfavorable areas	Resistant to diseases and insects, Tolerates water stress, large grain	1993
Moumtaz	coastal, sandy soil and unfavorable areas	Resistant to diseases and insects, Tolerate water stress, dark grain	1993
Drira	coastal, sandy soil and unfavorable areas	Resistant to diseases and insects, Tolerate water stress, dark grain	1988
Maroua	coastal, sandy soil, semi-arid and arid areas	Resistant to diseases and insects, Tolerates water stress, white grain	2007
Ain N'Zagh			2011

II.1.3. OAT

Oat is mainly grown as fodder crop in Morocco. Its farming is limited to restricted geographical areas of the country even though its cultivation area is increased lately on the behalf of oat/vetch fodder mixture particularly in Khemisset, Tangiers and Meknes areas (El Mzouri *et al*., 1996a and b, El Mzouri, 1994, EL Mzouri, 2004). The on-farm introductions of oat varieties have been appreciated by most dairy and sheep farmers. The results obtained by most investigators at the farm level were very encouraging (El Mzouri, 1994, 1995 and 1996 and b; 1997a and b; El Mzouri and Chriyaa 2009; Jartiz, 1994; MAMVA, 1994-1995; Al Faiz *et al*., 1994; Al Faiz, 1990). However, the lack of seeds at the local level is still a barrier in front of the adoption of this species.

Among the varieties which have given the best average biomass yields with more than 4.5 t DM/ha quoted Ghali, Tissir, Zahri, Faras, Soualem and Tislit (Table 10). Varieties: Tislit, Tissir, Zahri have produced the highest average grain yields ranging from 2.7 to 3.3 t/ha. Despite drought conditions that prevailed during the testing period, these different varieties constituted a good forage alternative that tolerates middle-growth- cycle drought and gave a good performance for the double use (pasture and grain) under relatively deep soil (El Mzouri, 1994, 1995 and 1996 and b; 1997a and b; El Mzouri and Chriyaa 2009).

Table 10. Main features of INRA oat varieties

Variety	Cycle	Dry matter yield (t/ha)	Grain yield (t/ha)	WTS (g)
Amlal	Semi-early	5.4	1.7	32
Nasr	Semi-early	5.8	1.6	32
Rahma	Semi-early	4.5	2.3	29
Soualem	Semi-early	4.3	2.4	29
Tislit	Semi-early	6.3	3.3	34
Tissir	Semi-early	5.9	2.7	28
Zahri	Semi-early	5.3	3.1	29
Rommani	Early	4.5	1.6	32
Farass	Semi-late	6.4	2.1	27
Ghali	Late	6.7	2.8	30

WTS: Weight of Thousand Seeds

II.2. FORAGE LEGUMES

The legume crops play an important role in livestock feeding and in the improvement of cropping systems, that's why other legumes have been introduced and evaluated under agro-climatic conditions in western Morocco. Among the species studied and improved by INRA in these zones we cite those recorded in the official catalog (INRA, 1997) (Table 11).

Table 11. Main features of INRA some forage legumes varieties

Variety	Number of days Lifting-flowering	Yield (t/ha)	
		DM	Grain
Vicia sativa Nawal	127	3.53	1.12
Vicia sativa Guich I	147	4.99	0.94
Vicia sativa Nora	110	4.57	0.84
Vicia sativa Hallaba	97	3.24	1.14
Vicia sativa Yamama	107	4.12	1.34
Vicia sativa Ghazza	155	4.86	0.64
Vicia sativa Salhouma	115	3.98	1.08
Vicia narbonensis Khasba	95	3.56	3.35
Vicia narbonensis Marhaba	95	3.61	2.89
Vicia ervilia commun	87	2.65	1.68
Lathyrus ochrus commun	95	2.56	1.12
Lathyrus cicera	105	2.34	1.34
Medicago sp	88	4.53	0.45

DM: Dry Matter

The number of forage legumes in the Moroccan semi-arid regions is still very limited. In fact, we mostly encounter only fodder pea and vetches that are usually grown in a mixture with small grain cereals (barley or oat). Given the importance of legume species for livestock feeding and also for improving the cropping systems performance, other legumes were introduced and evaluated as well, under the dryland Moroccan climatic. Among the species studied and improved by INRA in these areas we cite (INRA, 1997): (i) Common vetch (*Vicia sativa* L.): 5 varieties; (ii) Hairy vetch (*Vicia villosa* L.): 2 varieties; (iii) Narbonne vetch de (*Vicia narbonnesis* L.): 2 varieties; (iv) Fodder pea (Pisum sativum L.): 4 varieties.

Besides these forage legumes, other grazed-forage pastoral legumes were introduced and evaluated in different areas of dryland farming of Morocco. Among these plants we cite in the first place the medic specie: *Medicago Polymorpha* (Serena, Santiago and Cyrcle valley), *M. littoralis* (Harbinger), *M. truncatula* (Cyprus, Jemalong, Parabinga, Praggio et Sephi), *M. scutellata* (Sava et Robinson), *M. rugosa* (Praponto), *M. Tornata* (Tornafield), et *M. murex* (Zodiac). With the exception of *M. murex*, which is well adapted to acidic soils, all the others are well adapted and cultivated on alkaline soils of the semi-arid areas of Western Morocco and gave a biomass yields that varied between 1.2 to 4.8 T DM/ha.

Secondly, and especially on the acidic soils of Had Laghoualem, Oulmès and Tangier, subclover species were studied and cultivated such as *Trifolium subterraneum* l. (Nungarin, Dalkeith, Seaton Park, Junee, Woogenellup and Karridale), *T. brachycalycinum* l. (Clare and Rosedale) and *T. yanninicum* (Trikala). Best annual successful prairies were obtained on acidic soils by varietal blends of Nungarin, Dalkeith, Seaton Park, Clare and Trikala (Jartiz, 1994b; Jartiz and Mr. amine, 1993; Bounejmate, 1984; Bounejmate, 1992; Jaber, 1994; Jaritz, 1993; Jaritz, 1996).

Other forage legumes, on which research has been initiated but never completed, we quote the *Lathyrus* species (*L. ochrus*, *L. cicera*, and *L. sativus*), orobe (*Vicia ervilia*) and Sulla (*H. comosum* and *H. coronarium*). These species showed a significant capacity of adaptation and production under the soil and climatic conditions of the Chaouia, Ouardigha, Zaer and Abda without any registered varieties (El Mzouri and Bounejmate, 1996, El Mzouri *et al.*, 1997).

II.3. LEGUME/SMALL GRAIN CEREAL MIXTURES

Knowing that feed deficit is very acute during periods of late summer and autumn, the use of hay or silage is a suitable solution to solve this deficit (Ouknider and Jaquard, 1986). The best suited forage crops for rain fed areas are mixtures of small grains cereals with forage legumes (Table 12). The practice of these mixtures in Morocco is mostly limited to the dairy farms of dryland areas of Meknes, Casablanca, Berrechid, Benslimane, Khemisset and Rabat.

The introduction of these fodder mixtures in other regions of Chaouia-Ouardigha and Doukkala-Abda were well appreciated by farmers for their forage quality and productivity in addition to their adaptation to the rotation systems of semi-arid and arid regions. During dry seasons, these mixtures were of excellent quality for sheep pasture (El Mzouri, 1994, 1995 and 1996 and b; 1997a and b; El Mzouri and Chriyaa 2009).

II.4. WEEDY FALLOW PASTURE IMPROVEMENT

Weedy fallow constitutes a source of feed as seasonal pasture for livestock particularly sheep. It is taken an important part of cropped land in rotations with barley or wheat in many cropping systems of the arid dryland areas. Its contribution becomes less and less important in the feeding calendar of small holding farms as result of land size reduction, the deterioration of weed productivity and quality (El Mzouri 2004b). Two ways are possible for the improvement of the weedy fallow: (i) sowing adapted species that are productive and of high-quality feed; (ii) the application of fertilizers where seed stock of desired species is at a satisfactory level.

Prospection Studies conducted on weedy fallow composition in sheep growing areas of Western Morocco (Tadla, Ouardigha, Beni Meskine, Rhamna and Ahmar) showed the biodiversity and richness of these fallows in annual pastoral legumes, mainly Medics. Seed storage of these desired pastoral legumes is still at satisfactory levels despite overgrazing, succession of droughts, and weeding. The main pastoral legumes identified in these pastures and weedy fallows we quote: medics, vetches, clover, and scorpirius. Medic's species were present everywhere in the arid and semi-arid lands that were covered by the studies. The most dominant species were *Medicago polymorpha*, *M. truncatula* Gaertn, *M. aculeata Willd*, *M. laciniata* Miller, *M. littoralis* Rhode, *M. minima* Bart, *M. orbicularis* Bart *and M. Tornata* Miller. The application of phosphate fertilizers such as TSP 45% or DAP 18-46 on these legume-rich sites has improved dry matter production and pods yields by 30 to 180% and 80 to 280%, respectively, on the average (El Mzouri *et al*., 1998; El Mzouri and Thami Alami, 2000; El Mzouri, 2014; 2016) (Table 13).

Table 12. Types of forage legumes & small grain cereals introduced in the farming systems of semi-arid & arid areas

Mixing type	Target Areas	Productions (t DM/ha)	Recommended Usage Type
Vesce/Oats	Favorable, semi-arid areas for wheat systems	3.41 - 5.57	–Hay-Grazed
Vesce/Barley	Semi-arid intermediate: Wheat - barley systems	2.89 - 6.82	Hay-Grazed
Vesce/Triticale	Semi-arid intermediate: Wheat - barley systems	2.34 - 4.53	Hay-Grazed
Peas/Barley	Unfavorable Semi-Arid: System barley	1.63 - 3.45	Hay-Grazed
Peas/Triticale	Unfavorable Semi-Arid: System barley	2.54 - 3.74	Hay-Grazed
Medics/Barley	Semi-arid barley system	2.31- 4.56	Grazed
Medics/Pastoral grasses	Semi-arid favorable / irrigated	3.87 – 6.85	Grazed

DM: Dry Matter

Table 13. Management type and dry matter (DM) production of grazed weedy fallow/annual pastures of western Morocco.

Management type	Conditions of application	DM productions (t DM/ha)	Recommended use
Sowing of annual legumes	Seed storage of pastures are low particularly in wheat and Barley based systems	3.56-5.89	Hay-grazing
Sowing of annual pastoral mixtures of legumes and grasses	Medium Seed storage of desired pastures in favorable wheat-based systems	4.23-7.73	Hay-grazing
Phosphate based Fertilizers (TSP 45%, DAP 38-46) Nitrogen fertilizers	High seed storage of desired legumes (medics/clover) species in favorable wheat and Barley based systems	2.74-6.35	Hay-grazing
(Ammonium sulfate: 21%, Ammonium nitrate 33% or urea46%)	High seed storage of desired grass (Lolium sp, Dactylis) sp species in favorable wheat and Barley based systems.	3.26-6.85	Hay-silage-grazing

II.5. PASTORAL GRASSES

Research conducted on grasses in semi-arid and arid areas are very limited. Few perennial grasses species were studied alone or in mixture under the dryland areas (INRA, 1997; Arif, 1990; Jartiz, 1992). These species concerned *Festuca arundinacea* Schreb, *Dactylis glomerata* L., *Phalaris tuberosa* L., *Ehrharta calycina*. SM, *Agropyrum elongatum* L. The preliminary results were encouraging in research stations, but once introduced on farmers' field they were not adopted because they were not adapted to dominant cropping systems (biannual and tri-annual wheat rotations) in addition to the non-availability of seeds in the local markets.

II.6. CACTUS PEAR

Cactus pear is well adapted to the most hostile conditions and produces a significant biomass in a very efficient way. It was adopted by humans for various purposes such as: (i) consumed fresh or dry preserved; (ii) feed (fresh cladodes or fruit silage); (iii) vegetable ("Nopalitos"), (iv) pharmaceutical plant (flowers, cladodes); (v) agro-industrial crop (jams, juices, natural colorants, liquor, cosmetics, etc.); (vi) honey production/beekeeping plant; (vii) erosion control tool in agroforestry and improved pastoral areas; and (viii) plant protection (closing/hedge). As a forage crop, cactus pear manages to produce between 12 to 16 T GM/ha, with a productivity of 1.37 kg DM/m²/year compared to that of other species under the same conditions which do not exceed 0.71 kg DM/m²/year. While the Opuntia species are low in protein (only 4-9%) their production in digestible energy per unit of water consumed is high which makes the growth of these plants requires less nitrogen by absorbed water amount.

The research program on this crop is recent at INRA, it was started in early 2000's and getting the interest of many scientists as the planted areas are increased recently in arid land of Morocco. Aspects of research currently covered are: characterization and behavior of national collected plant material, plant selection and genetic improvement, food and feed quality, ways of human and animal valorization, technological transformation, commercialization and local knowledge studies (EL Mzouri and Chriyaa, 1998; Mazhar *et al*., 2000; El Mzouri *et al*., 2007; Hillai *et al*., 2007; El Mzouri *et al*., 2007, El Mzouri, 2008; Chriyaa *et al*., 2007; El Mzouri *et al*., 2009, El Mzouri *et al*., 2012; 2013; 2015; El Kharrassi *et al*., 2013; 2014; 2015, El Mzouri, 2016; 2017).

II.7. TREES AND FODDER SHRUBS

Shrubs known for their abilities of resistance to the harsh dryland conditions, makes them a suitable plant material for the enrichment of local flora and fauna that promotes microclimate conducive and reduced erosion. Agronomic research conducted on fodder shrubs in Morocco remains below potential needs given the diversity and the vastness of pastoral and forest-pastoral areas of the country and their level of degradation.

Less than 100,000 hectares have been planted in fodder shrubs, mainly *Atriplex nummularia* in addition to a few thousands of hectares in cactus in the anti-Atlas Mountains and Rhamna plateau. Some work on behavior and adaptation on the following fodder shrubs have been conducted in the arid dryland but with very little impacts on improving rangeland at the national level (Arif *et al*., 1994; Arif and Chriyaa. 1995; Boulanour *et al*., 1996; Chriyaa and El Mzouri. 1999; Chriyaa *et al*. 1999; Hall *et al*., 1994): *Atriplex nummularia*, *A. canescens*, *A. halimus*, *A. visicaria*, *Acacia cyanophylla*, *A. salicina*, *Celtis australis*, *Ceratonia siliqua*, *Medicago arborea*, *Morus alba*, *Artimisia herba-alba*, *Maireanab revifolia*, Morus alba, *Opuntia ficus indica*, *Prosopis juliflora*, *Argana spinosa* etc. The work of domestication of native species such as *Cytisus mollis*, and *Chamaecytisus profilerus* is not started yet.

The shrubby species, which has been largely studied for its agronomic and nutritional quality traits, is the *Atriplex nummularia*. Indeed, research conducted in arid regions like Rhamna and beni meskine (less than 300 mm of annual rainfall) showed that the optimal density, which ensures adequate production of shrub biomass without affecting the plant vigor of the shrub, is about 1000 plant/ha. Shrub cover productivity varies with the species, the plant age, the management mode (frequency, intensity of defoliation), and climatic conditions of the year. The first use of young stand can take place from the age of 18 months. Different studies have reported that productivity of edible biomass varies from 0.5 to 3 kg of dry matter (DM) per plant of *Atriplex nummularia* when planted at 1000 plants/ha in semi-arid dryland environment. These studies have made it clear that a cutting height to 60 cm from the floor improves fodder productivity and quality, and extends the shrubs life (Arif *et al*., 1994).

III. FODDER CROP BASED INTERCROPPING SYSTEMS

The most studied marginal cropping system in the semi-arid and arid areas of Morocco is the "alley cropping" system that combines woody forage (shrubs) with annual herbaceous forage (El Mzouri, 1995; El Mzouri and Chriyaa, 1996; 1999; Chriyaa and El Mzouri, 1999; El Mzouri, 2004; 2000; 2007) (Table 14). This system was introduced by El Mzouri through a "Research-Participatory-Action-" in 1995. It is suitable for privately owned/managed marginal land. The choice of species to grow in association depends on soil, climatic, social conditions, and the goal of production. This system has several advantages among which we cite: (i) Efficient conservation and use of natural resources: rainfall, soil, and plant biodiversity; (ii) Improved biomass production and quality that managed to relief the neighboring collective rangeland; (iii) On farm improved feeding calendar: biomass production is spread over a longer period for 9 to 12 months instead of 3 months in addition to the reduction of feeding costs and help farmers during harsh periods; (iv) Increases land use efficiency particularly for small holding farms: LER: varied from 1.3 to 1.9; (v) Enhanced transfer of research results and achievements: several new technologies developed and intended for marginal areas, arid and semi- arid can be transferred in one package at the same time under this system.

III.1. FARMING SYSTEMS TARGETED BY THE "ALLEY CROPPING" SYSTEM

Agro-ecological and socio-economic characterization studies showed that generally the integration of juxtaposed systems, that are the agro-pastoral systems based on barley and pastoral systems (annuals or steppe), in the arid and semi-arid have known certain imbalance in the last four decades. Sheep herders from rangeland come frequently from nearby areas where land is cultivated with cereals (barley) and increases animal stocking rate on the collective rangeland, especially during the early stages of juvenile pastoral species and lead to early overgrazing and consequently an accelerated deterioration of the collective rangeland. The "alley cropping" system target, therefore in the first place, the barley-based farming systems nearby these over-used rangelands to reduce their carrying capacity and reinforce the integration of cropping systems with the animal production system that have been coexisting for many years.

This participatory approach will help educate farmers on the interest of having fodder shrubs in order to better manage and preserve them once on their private lands or introduced in the collective rangeland. So, by this way we will manage, on the one hand, to create belts of agro-forestry systems around the neighboring rangeland, and in the hand to involve farmers to better preserve their common rangeland once improved.

Experience in the different areas where this system has been introduced (North East of Morocco, Ouardigha, Beni Meskine and Rhamna), has shown that this system has succeeded. Among the reasons for this success, we quote: (i) The adoption of the agroforestry system by the extension services (CCA and CT) and their conviction of its feasibility; (ii) Priori adoption by farmers' ranchers who visited the pilot sites of Settat and Doukkala and who insisted that this type of technology should be introduced in their farms; (iii) The availability of funding projects (IFAD PRDT, WB-DRIMVB, FDR-Beni Meskine, IDRC-Rhamna, etc…) consistent with a pragmatic view on the approaches to follow, and the interest and awareness of these partners about the role that could be played by INRA especially regarding human development and technical monitoring of activities with local communities; (iv) The implementation of encouraging policies within these projects for the adoption of INRA achievements in forage-rangeland research in general, and those on the "alley cropping" system in particular; (v) The availability of local communities to better organize themselves in association and

Table 14. Example of research findings on the agro-forestry system "alley cropping" in marginal semi-arid and arid areas (El Mzouri and Chriyaa, 2004)

	Total biomass		Equivalent energy		Equivalent crude proteins	
Cropping system	yield (kg DM/ha)	Gain (%)	Forage unit (UF/h a)	Gain (%)	CP (kg/ha)	Gain (%)
Barley Mono-cropping system	3015	-	1803	-	180	-
Weedy fallow practice	2505	-17	1132	-37	200	+11
Alley cropping: Barley + shrubs	4433	+47	2531	+40	395	+134
Alley cropping: Weedy fallow + shrubs f	3417	+13	1602	-11	376	+109

cooperatives around the newly introduced agro-forestry based system; (vi) The presence of a land status and agrarian structures in favor of the introduction of the fodder shrubs (the neighbors respect each other in terms of decision-making, and implement protection measures of shrub plantations). In several sites where the collective status dominates, particularly where stubble grazing is collective, this system was not successful (case of Beni Chris in the Tadla, Beni Meskine, etc.); and (vii) The presence of active, motivated extension services and well-trained personnel.

III.2. PRODUCTIVITY, QUALITY AND NATURAL RESOURCES USE EFFICIENCY

III.2.1. BARLEY/FALLOW ALLEY CROPPING BASED SYSTEM

This long-term experimentation was conducted on four hectares fenced at INRA-Ain Nzagh station from which 2 hectares were planted in fodder shrubs. One hectare was sown with barley between the lines of shrubs for grain and straw production and the other one was left as grazed weedy fallow. The other two hectares without shrubs (control) have been cultivated with mono-cropping barley (1 ha) and grazed weedy fallow (1 ha). Applied packages are those recommended by INRA for semi-arid and arid areas. This experiment was initiated in 1993-94, but the observations began only after the age of exploitation of shrubs.

a.Annual production of total biomass and grains:

During the fourteen years of experimentation, the average total biomass production and grain yields of barley were higher under the alley cropping system (Table 15). The fertilized weedy fallow under the alley cropping system produced more herbage than the one without shrubs. The shrubs biomass production per hectare was higher under monoculture this comes down to the fact that the planting density exceeds that in the alley cropping by 600 to 700 plants/ha (1200 plants/ha on average for the first against 500 seedlings/ha on average for the second). However, individual plant production increased more in the alley cropping with the age of the plantation and cutting frequencies which increased the plant vigor as well as the diameter of the shrubs (El Mzouri and Chriyaa 2001; Chriyaa and El Mzouri 1997).

Table 15. Different yields of barley, fallow and *Atriplex nummularia* under monocropping and alley cropping systems (El Mzouri, 2009)

Treatments	Barley crop			Fallow (Kg DM/ha)	Atriplex (Kg DM/ha)
	Straw yield (Kg DM/ha)	Grain yield (Kg/ha)	Total biomass (Kg DM/ha)		
Mono-cropping	2912	1357	4269	1905	1951
Alley cropping	3146	1656	4802	2739	902

b. Relation between total biomass and annual rainfall:

During the period of this long-term experiment different types of water regimes were experienced by the studied treatments. Some years were dry with less than 200 mm/year and others very favorable which exceed the 450 mm/year (Figure 20). We found that, with the exception of the improved weedy fallow under the alley cropping which has still a continuous increase, all the other alternatives whether it in mono- cropping or in association with shrubs, had a response with polynomial trend under the semi-arid conditions of the Western Central Morocco. Indeed, dry matter production is low in dry years as result of water stress, but in favorable years more than 450 mm, this production becomes limited by excess moisture than favor biotic stresses. This is especially true for barley which still suffers from diseases (rusts especially) in rainy years since their early juvenile stages of growth (El Mzouri, 2009).

As for the comparison of the different treatments-responses, we notice that crop production (grains, straw, or total herbage biomass) in the alleys was higher for both barley and the weedy fallow (Figure 19). These results show that the agro-forestry system (alley cropping) improves total biomass of barley and pastoral productivities in marginal areas while stabilizing them during dry years. In fact, in favorable years we can earn more than local practices but in a dry year the presence of shrubs, which are tolerant to drought, are able to produce a minimum for the local livestock.

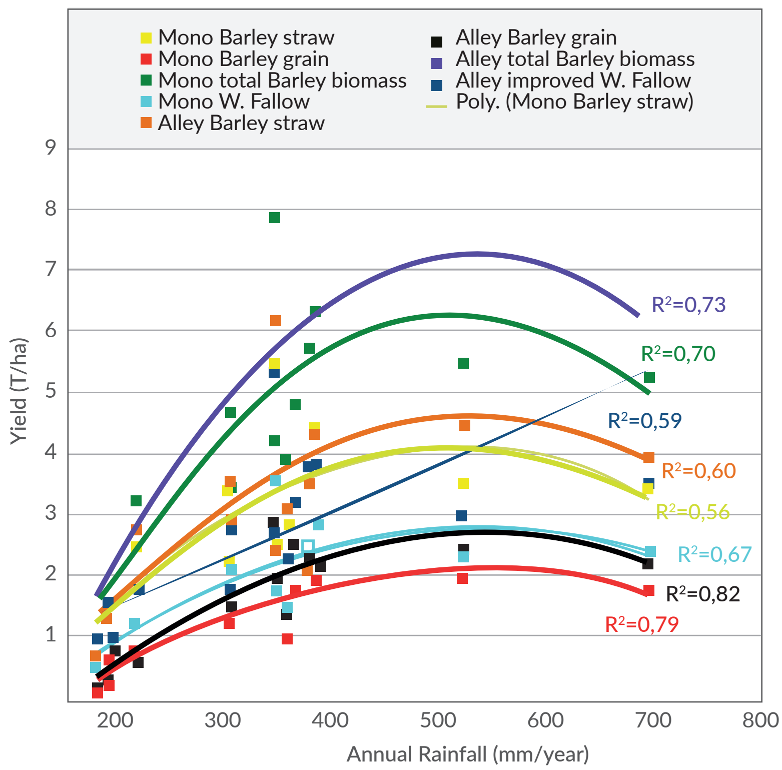

Figure 19. Response of the biomass production and grain yields of barley crops and fallow grown under mono-cropping and in association with fodder shrubs under different rainfall conditions (El Mzouri, 2009).

c. Grain and straw yields and relative gains:

Barley grain yield increased by 22.1% and that of straw has been increased 8% on average under the alley cropping system compared with barley mono-cropping (Table 15). The weedy fallow produced less biomass than the control- barley either under mono-cropping or in alley cropping with -55.4 and - 35.8% of DM, respectively. The presence of shrubs with fertilization reduced the deficit of weedy fallow but without producing as much as the control (barley mono-cropping). This last result explains largely why farmers tend to cultivate rangeland or reserve less of their land for weedy fallow this just to improve productivity (El Mzouri, 2009).

d. Energy and crude proteins yield:

The combination of barley cultivation with fodder shrub significantly improved energy and digestible nitrogen (CP) yields per hectare by 22.4% and 32.8%, respectively. Regarding the level of production in energy (FU) and crude proteins (CP) per hectare of weedy fallow, it remains below that of barley, and the association of this fallow with shrubs only reduces the deficit by 19% and 14% for both cases, respectively. It should also be noted that these fodder shrub resources are available during a critical phase of the needs of sheep, namely, late gestation phases, lambing and lactation (Table 16).

e. Land use efficiency (LER):

Barley/fallow alley cropping system case:

The Agricultural Land Equivalence Ratio (ERR) was improved for both barley (straw, grains and total biomass) and the weedy fallow when practiced in intercropping with Atriplex as fodder shrub. Indeed, it varied on average between 1.54 and 1.68 for barley crop and reached an average of 1.90 for the weedy fallow (Table 17). The best intensifications were obtained for barley grain + fodder shrubs (LER = 1.68) and improved fallow + fodder shrubs (LER = 1.90). These results confirm those found in the southern marginal land of Doukkala (El Mzouri, 1997a and b), demonstrating therefore the possibility of improving current levels of production and improving the quality, productivity, and land use efficiency particularly for small holding farms.

Relation between LER and annual rainfall :

Regarding the LER vs annual rainfall relationship, the results in Figure 20 clearly show that under dry conditions this ratio is improved for the weedy fallow. The marginal lands use efficiency of fallow under stressful conditions can be doubled when this fallow is associated with the *Atriplex nummularia*. Regarding the evolution of the LER ratio under the different climatic conditions, it is relatively stable around 1.5 with a slight downward trend (not significant) under favorable rainfall conditions.

Table 16. Yields of barley, weedy fallow and *Atriplex nummularia* under two cropping systems: Barley mono-cropping and alley cropping (El Mzouri, 2009).

Cropping system	Grain		Straw		Total biomass	
	(Kg/ha)	Relative gain (%)	(Kg DM/ha)	Relative gain (%)	(Kg DM/ha)	Relative gain (%)
Barley mono-cropping	1357	0	2912		4269	
Barley + Atriplex	1656	22.1	3146	8.0	4802	12.5
Weedy fallow	-	-	-	-	1905	-55.4
Improved fallow + Atriplex	-	-	-	-	2739	-35.8

The relative gains of barley and straw are calculated in relation to monoculture without considering the biomass of the shrubs.

Table 16. Energy and protein yield of barley and weedy fallow under mono-cropping and alley cropping systems with *Atriplex nummularia* (El Mzouri and Chriyaa, 2009).

Cropping system	Grain		Straw	
	FU (Kg/ha)	Relative gain (%)	CP (Kg/ha)	Relative gain (%)
Barley mono-cropping	3020	-	470	-
Barley + Atriplex	572	-81.1	191	-59.4
Weedy fallow	3698	22.4	624	32.8
Improved fallow + Atriplex	1150	-61.9	265	-43.7

Table 17. The Agricultural Land Equivalence Ratio under the alley cropping system: Case of the association *A. nummularia* / barley or *A. nummularia* / improved fallow (El Mzouri, 2009).

Component of the alley cropping system	LER
Barley grain +fodder shrub	1.68
Barley straw + fodder shrub	1.54
Total biomass + fodder shrub	1.59
Improved fallow + fodder shrub	1.90

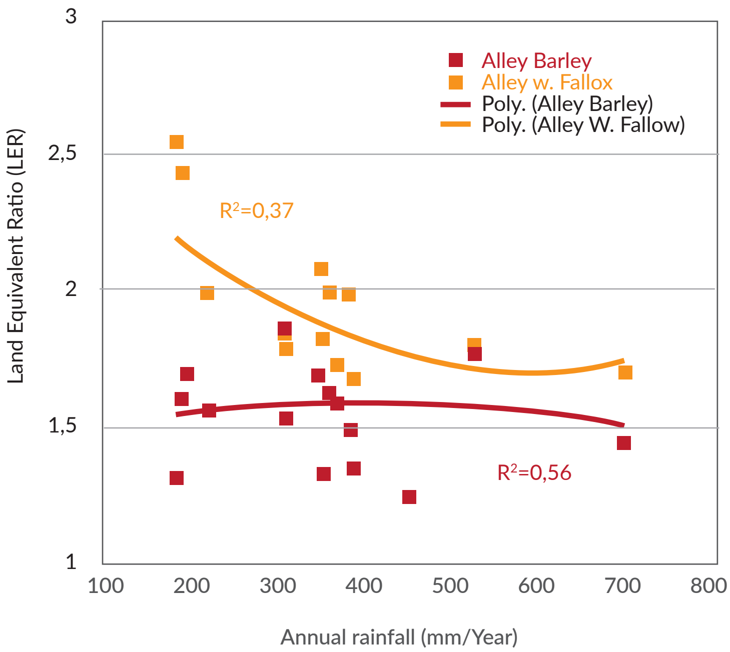

Figure 20. Response of agricultural equivalence ratio (LER) to the annual rainfall of Barley and weedy fallow under Alley Cropping (El Mzouri, 2009).

III.2.2. STRIP ALLEY CROPPING OF DIFFERENT FORAGE CROPS

Forage crops: barley, oats, vetch/oats mixture, pea/barley mixture, medics in addition to the fertilized weedy fallow were installed in strips in association with *Atriplex nummularia*. The varieties used in the different bands are those registered and recommended by INRA. The main results on biomass and grain yields of the various treatments (strips) are summarized in Table 18.

Table 18. Yields (Kg DM/ha) of different forage alternatives cultivated in strips under two cropping systems: monoculture and alley cropping Average of 25 years (1995-2016)

Yields of the different treatments (Kg DM/ha)

Type of association	Barley	Oat	Pea/ barley	Vetch/ oat	Fallow	Medics	Atriplex
Mono-cropping	3217	3258	2598	3019	1843	2304	1866
Alley cropping	3533	3507	2790	3169	2277	2635	924

a. Annual biomass production

The biomass yields obtained during the trial period show the consistency of the production advantage of the Strip-alley cropping system compared to the mono-cropping systems of all different forages resources (Table 12). In fact, when the alleys are well oriented against the prevailing winds, they help the annual forage crops to better take advantage of available resources like CO_2, water and light while reducing the effect of wind. In addition, the rotations recommended in the Atriplex corridors helped to improve the productivity and the richness of the soil in organic matter (of the order of 70 to 120% depending on the plots).

b. Relation between total biomass and annual rainfall

Barley or fodder peas/barley mixture gave the best yields when intercropped with Atriplex constitute in dry years (Figure 21). The more favorable the rainfall conditions become, the more alternatives such as oats and vetch/oats mixture produce more. However, when the growing season is exceptionally favorable, barley-based associations (Atriplex + barley or Peas/barley + Atriplex) have production limits and perform less than those that combine oats. Figure 3 clearly shows that in the most favorable cropping season of the last fourteen years oats has not yet reached its production potential and continues to increase almost linearly.

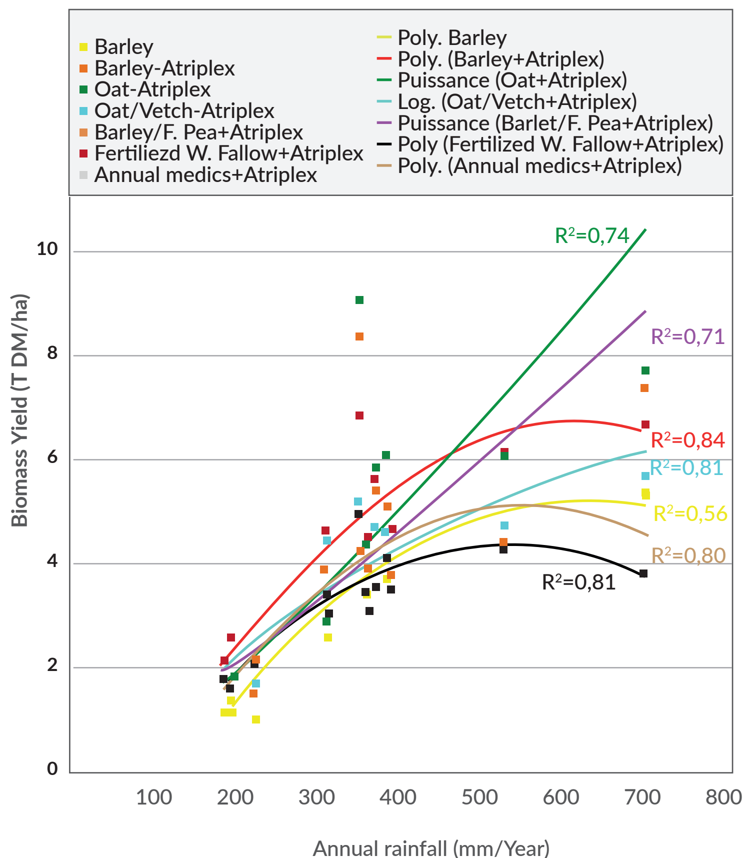

Figure 21. Response of the biomass production of different forage crops strips grown in association with fodder shrubs under different rainfall conditions (El Mzouri, 2009).

c. Relative yields and gains in straw and grain

The average biomass production of forages in mono-cropping is lower if not similar to that of mono-cropping barley. However, when intercropped with fodder shrubs, these alternatives increased their yields with rates ranging from 10 to 38.5%. Fertilized weedy fallow in alley cropping produced as well as mono-cropping barley (Table 19). Also, we note that this obtained production gain is not only available on the farm but is stored as good quality hay from the annual forages in addition to the fresh biomass of the fodder shrubs that is available for a longer period of the year (10 to 12 months). It is therefore possible to extend the period of use of the plots from 3-6 months to more than 10 months by significantly intensifying herbage production on the same plot (two biomass production: annual herbaceous in spring and woody in autumn and winter).

Table 19. Comparison of biomass yields of different forage alternatives grown in bands under two cropping systems: monoculture and alley cropping (El Mzouri, 2016).

Type of association	Treatments	Biomass yield (Kg DM/ha)	Relative gain (%)
Mono-cropping	Barley	3217	-
	Fallow unimproved	1843	-42,7
	Oats	3258	1,3
	Fodder peas/ barley	2598	-19,3
	Vetch /Oats	3019	-6,2
	Medics	2304	-28,4
Alley cropping	Barley + Shrubs	4457	38,5
	Fertilized fallow + shrubs	3201	-0,5
	Oats+Shrubs	4431	37,7
	Peas/ barley+shrubs	3714	15,5
	Vetch/ Oats+shrubs	4093	27,2
	Medics+shrubs	3559	10,6

d. Energy and protein relative yields and gains

The intercropping of different forage crops in alternate strips to fodder shrubs significantly improves the energy and digestible crude proteins yields per hectare with gains ranging between 10 to 40% and 65 to 123.9%, respectively. For energy yields, the biggest gains are made by oats and vetch/oat. For the crude proteins, the best gains per hectare are made under the associations: Vetch/oats+shrubs and Medics+shrubs. Once these types of forage resources are available on the farm, not only the physiological needs of the sheep are secured during the late gestation phases, lambing and lactation, but also the weight gains of the young lambs will be achieved (Table 20).

Tableau 20. Energy and protein yields of different forage alternatives cultivated in a band under two cropping systems: mono-cropping and alley cropping (El Mzouri, 2016).

Type of association	Treatment	Energy yields (UF/ha)	Relative gain (%)	Protein yield (KgCP/ha)	Relative gain (%)
Mono-cropping	Barley	1995	-	322	-
	Fallow unimproved	147	-92.8	147	-55.2
	Oats	2281	11.9	358	8.9
	Peas/barley	1948	-4.4	390	18.4
	Vetch/oats	2354	15.5	483	46.8
Alley cropping	Medics	1290	-36.7	346	5.0
	Barley+shrubs	2719	33.4	624	89.7
	Fallow fertilized + shrubs	2017	-1.1	544	65.4
	Oats + Shrubs	2747	34.8	620	88.5
	Peas/ barley+shrubs	2823	38.5	669	103.2
	Vetch/ oats+shrubs	2865	40.6	737	123.9
	Medics+shrubs	2242	10.0	712	116.3

e. Land-use efficiency (LUE):

LER of the different bands of the Strip alley cropping System:

The agricultural land equivalence ratio was significantly improved under the association of forage crops in alley cropping (Table 21). Indeed, it varied, on average, between 1.92 and 2.11, confirming therefore the possibility to intensify fodder production by 100% in cases where the technological packages of the Strip-alley cropping system are well applied in semi-arid marginal areas.

Relation between LER and Annual Rainfall

The agricultural land equivalent ratio of the Strip-alley cropping system remains fairly high (greater than 1.70) despite its regression under favorable rainfall conditions (Figure 22). However, under dry season conditions, this ratio tends to improve especially in the fallow+Atriplex, Medics+Atriplex, and vetch/oat associations. In drought conditions, the marginal land use efficiency of these associations can be doubled.

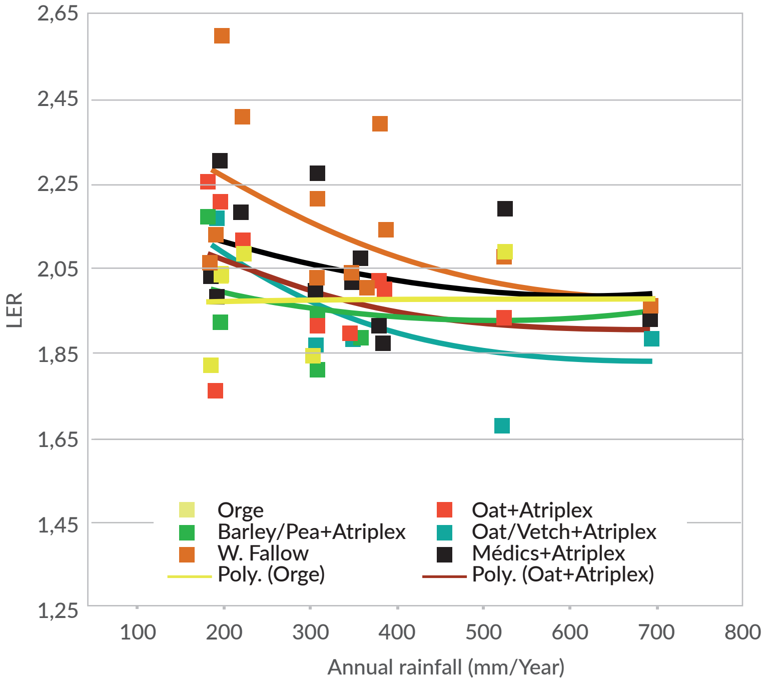

Figure 22. Response agricultural land equivalence ratio (LER) to the annual rainfall pattern of various forage crops associations in Strip-alley cropping with *Atriplex nummularia* (2009).

III.3. FODDER CROPS IN CULTURAL ROTATIONS

Studies on fodder crops effects and it place within rotation of rainfed cropping systems were covered in different dryland areas of Morocco. Indeed, these two aspects were studied since the mid 80's on two research stations, Sidi El Aydi and Jemâa Shaïm, in the mid favorable and less favorable dryland areas, respectively. The main aspects studied on station concerned, forage type (annual legumes-based ley farming, fodder oat/vetch mixture, weedy fallow) either under conventional farming (Mazhar, 1988) or notill farming (El Kacemi, 1992; El Brahli, 1995 and El Mjahed, 1998). Other research experiments were carried out on farms' large plots in Chaouia and Beni Meskine (El Mzouri, 1997; El Mzouri & Chriyaa, 1999; Bahri *et al.*, 1997) in Abda-Ahmar (El El Mzouri, 1998; El Mzouri and Okbi, 2016; El Mzouri and Al Ahiane, 2016). The most covered aspects of these research concerned: effects of fodder crops on the subsequent cereal grains yields, soil nitrogen content, soil water balance, phosphorus application on annual medics- based pastures, and economic assessment).

The main results could be summarized as follow: (i) The annual medics pasture, even though they have a positive effect on N-soil supply, they result in a negative water balance for the following wheat crop which reduces its grain and straw yields, particularly in dry years. Therefore, it is recommended to apply this rotation with barley either in wheat or in barley-based systems; (ii) Oat based mixtures or monocrops are not recommended for shallow rainfed soils because of their negative water balance for the subsequent wheat crop. Also, the presence of oat crop in rotation with durum wheat could increase root rot diseases incidence of this crop; (iii) The practice of weedy fallow in the wheat-based system have a negative effect on water and nutrient balances, soil structure (soil compaction), and weed management, particularly under no till system; (iv) Phosphorus application on annual forage legumes (medics in ley farming, vetches, Lathyrus, and peas) increases: early growth, biomass and grains yields, soil nitrogen and organic matter contents, but reduces water balance particularly in dry seasons; (v) The most recommended rotations in wheat-based systems are Oat/vetch, Barley/vetch Triticale/vetch mixtures in addition to vetch, fodder pea, narbon vetch, Lathyrus, and Lupins monocrops (vi) The most recommended rotations in barley-based systems are Oat/vetch, Barley/vetch Triticale/vetch, Barley/peas, and triticale/peas mixtures in addition to fodder pea, fertilized annual legumes and Lupins monocrops; (vii) Phosphorus application during the annual forage legumes cropping season increases winter growth and vigor, total biological and grain yields of the subsequent cereal crops (wheat, barley or oat) under favorable rainfall cropping seasons; and (viii) Fodder crops-based rotations generated the lowest production cost, the highest economic benefits, and the lowest risk under rain fed agriculture.

IV. INTERESTS AND IMPACTS OF THE AGRO-FORESTRY SYSTEM: CASE OF THE COMMUNITY OF IRZAYENE IN NORTH EASTERN MOROCCO

The agro-forestry intercropping system-based fodder, "alley cropping" in our case, is considered in this work as an example of integrated and innovative research approach, with new tools and quality of a “Participatory action-research” that has multiple interests. It can be summarized as a holistic systemic approach that has agronomic, economic, food, social, and environmental impacts. In the following sections we will present briefly some monitoring and evaluation results that was carried out by multidisciplinary teams at the community level of Irzayenne CR Tincherfi, Circle of El Laayoune in the Eastern Morocco (Laamari *et al.*, 2001. El Mzouri *et al.*, 2001. El Mzouri, 2004. El Mzouri *et al.*, 2009).

IV.1 AGRONOMIC IMPACTS

Among the main advantages and impacts achieved from an agronomic point of view we quote: (i) Improved biological productivity per unit area (30-65%) and per unit of consumed water (14-37%); (ii) Yield improvement and stabilization in difficult periods coupled with significant gain in a favorable year; (iii) Extension of the farmland use period under marginal soil conditions from less than 3.5 months to over 11 months per cropping season; (iv) Increased choices of adapted forage alternatives in addition to the diversification of the species used in the same system (minimum 2 and a maximum of 6 not including the grazed weedy fallow); (v) Technology packages are simple, adapted, and easy to multiply; and (vi) The flexibility of cultivation practices: farmers can cultivate forage crops, grain crops (barley and oats), or other plants with special economic interests such as aromatic and medicinal plants, muscari, etc.

IV.2. ANIMAL HUSBANDRY IMPACTS

The benefits and impacts of animal husbandry of local communities were: (i) Diversification of livestock feed resources while improving the quality of locally produced feeds; (ii) Higher energy and protein yields produced locally (10-80% increase), with an added value to locally available food resources such as straw and grain barley; (iii) On-site feed availability for sheep-lamb farms in particular throughout the agricultural year, which has reduced the movement of livestock to neighboring forests and to other territories and regions in the event of drought; (iv) Increased animal carrying capacity with better performance of sheep-lamb herds (the load increased from less than 0.5 head /ha/year to more than 3 head /ha/year), (v) Fodder and feeding calendar based on the foliage of *Atriplex nummularia*, straw, molasses (sugar beet or cactus fruit) and grain barley, sufficient for good animal performance (gain of lamb weight at birth, milk production of sheep, Weight of females and lambs during the lean period, etc.); and (vi) The products of breeding farms better valued by local fattening based on locally produced hays of good quality.

IV.3. ENVIRONMENTAL IMPACTS

Following the introduction of the alley cropping system by agricultural development services in Eastern Morocco, different research teams (INRA Settat and Oujda), ICARDA, CIRAD, ILRI, and certain European universities in France, Holland, etc. carried out several studies on the environmental impacts of this system and reported the following impacts (Figures 23, 24 and 25): (i) Soils that were bare and subject to erosion became covered and the applied cultural and management practices helped to diversify the vegetation cover in space and time: the presence of shrubs in rows and seasonal protection have contributed to the return of certain annual and perennial species (Medics, Salsola, alfa, etc.); (ii) Panoramic improvement of pastoral areas; (iii) Conservation, sustainability, and efficient use of natural resources (water, soil and plant genetic resources) were achieved through rainwater-harvesting techniques, biological hedges (Atriplex lines), fallow seeding, minimum tillage and the use of high-performing species and varieties, etc.; (iv) The marginal agricultural land rehabilitation and its sustainable use and rational exploitation allowed the recovery of soil organic matter and the reconstitution of the soil structure; (v) Reducing soil losses through water and wind erosion and combating desertification in rehabilitated sites through conservative storm water harvesting techniques and semi-permanent cover;

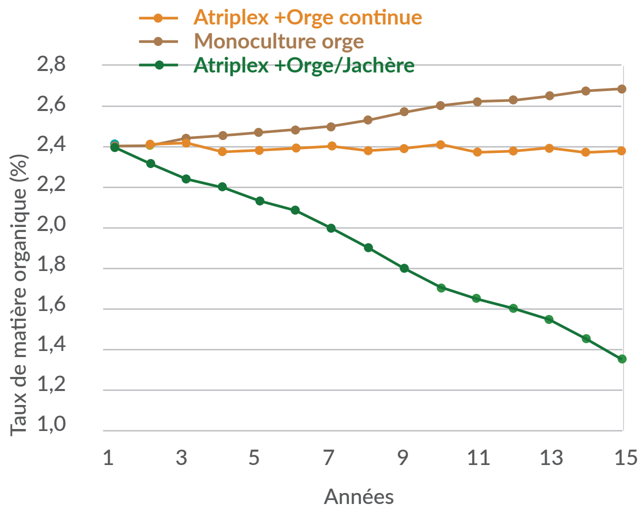

Figure 23. Evolution of soil organic matter under three types of cropping systems introduced in the commune of Tincherfi, Eastern Morocco (Benaouda *et al*., 2004)

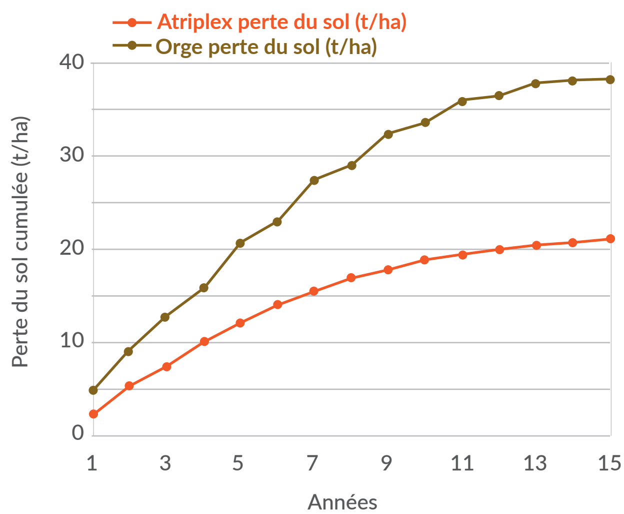

Figure 24. Significant reduction of soil losses under the alley cropping system (Benaouda *et al*., 2004)

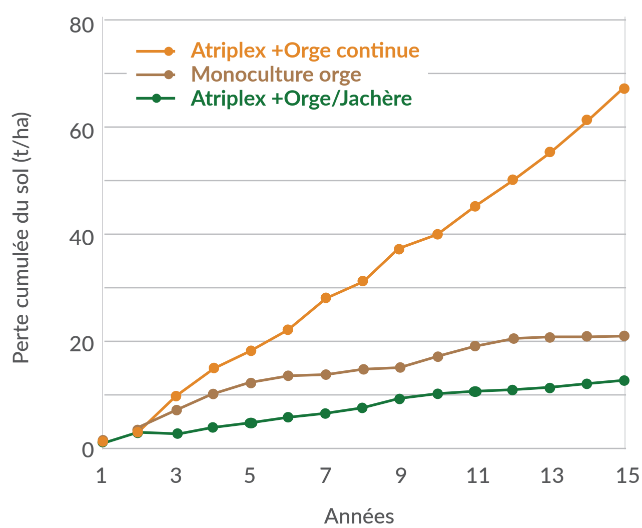

Figure 25. Evolution of soil losses under three types of cropping systems introduced in the commune of Tincherfi, Eastern Morocco (Benaouda *et al*., 2004)

(vi) The almost permanent pasture on the sites planted with shrubs allowed seasonal wildlife rehabilitation and native flora at the nearby forests following the downturns of population movements between the plain and the mountain, which reduced grazing pressure, and hunting; and (vii) The availability of fuel wood as a byproduct of the alley cropping has reduced the collection pressure of wood on neighboring forests.

IV.4. ECONOMIC IMPACTS

The economic evaluation of the alley cropping system has demonstrated its high profitability, which will encourage farmers/herders and the public sector to invest in high-risk areas such as marginal areas to secure their livestock with on-site production of a low-cost biomass that is diversified and adapted to harsh climatic conditions (Table 22 and Figures 26,27, 28).

The annual profit over the average period of 20 years varied from 2555 to 4122 Dh/ha depending on the type of rotation recommended.

The cost/benefit ratio varied between 3.67 and 5.08. This means that the investment in the alley cropping system on a period of 20 years is highly profitable.

As for the internal rate of return over the life of the alley cropping system, which is estimated at 20 years, it is clear that it is very profitable to invest on all the rotations of the system and that its value varies between 17.6 And 33.8% depending on the type of rotation within the strip alley cropping system.

The annual financial and animal feed costs are reduced mainly in dry years, and the economic efficiency of the marginal agricultural land available is highly improved.

Farmers/herders all communities confirmed that this intensive agroforestry forage-based cropping system is the alternative to be adopted to: (i) Reduce the risks of food availability; (ii) Save the livestock; (iii) Increase rural employment opportunities; (iv) Ensure the rational use and conservation of natural resources; (v) Ensure the sustainability of agricultural activities in marginal areas; and (vi) Reduce pressure on collective rangeland, stabilize the rural population, and mitigate the drought effects.

Table 22. Long-term earnings per hectare, cost-benefit ratio and internal rate of return for three types of rotations of the alley cropping system (Laamari *et al.*, 2004).

	Net Annual Income (Dh/ha)	Cost/ Benefit Ratio (%)	TRI Ratio (Dh/Dh)
Barley+Atriplex --Fallow+Atriplex	2555	3.67	4.44
Barley+Atriplex --Medics+Atriplex	4058	18.5	19.7
Barley+Atriplex -- Vetch/Oats+Atriplex	3505	4.76	5.08
Oats+Atriplex -- Peas/Barley+Atriplex	4122	17.6	33.8

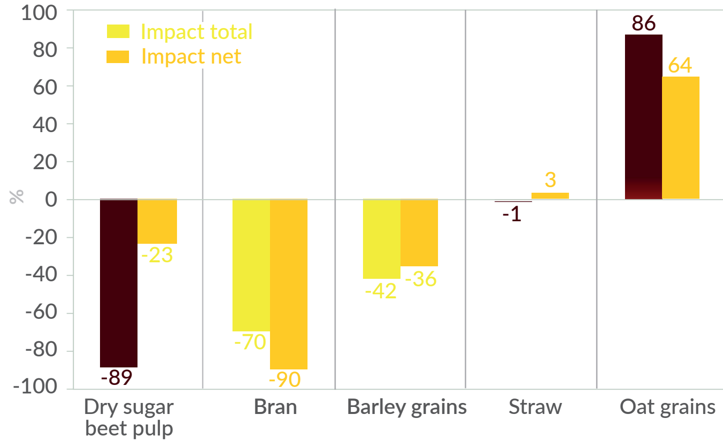

Figure 26. Impact of the Atriplex plantation on the consumption of other purchased alternative feed resources (Laamari *et al.*, 2004)

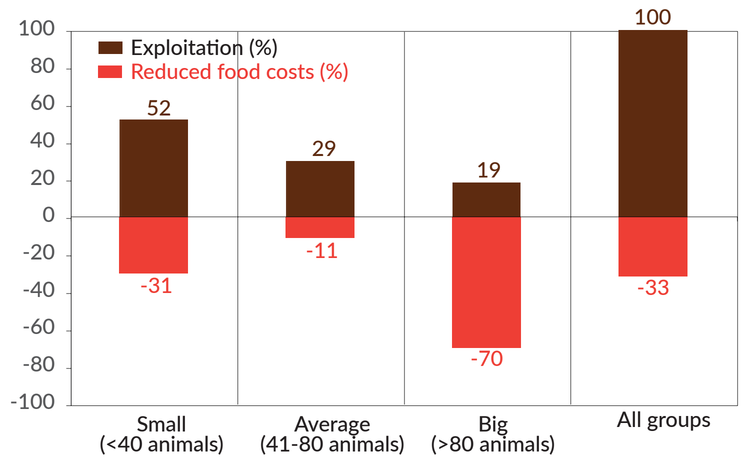

Figure 27. Impact of alley cropping on reducing food costs (Laamari *et al.*, 2004)

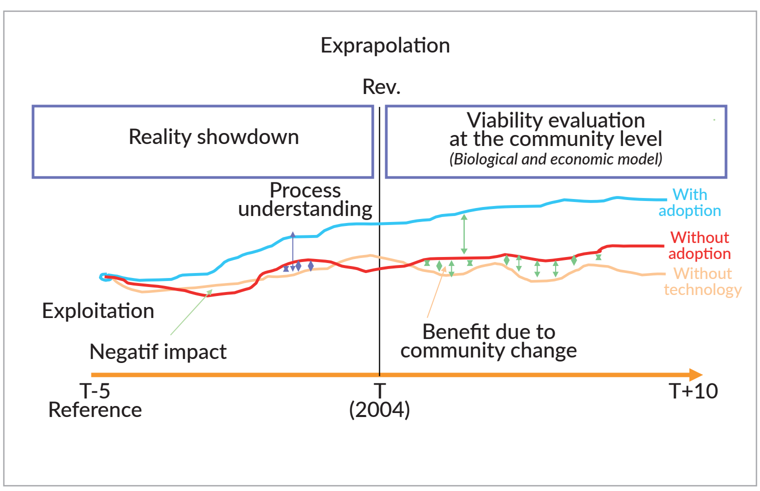

Figure 28. Evolution of change with and without alley cropping in the commune of Tincherfi in Eastern Morocco (Laamari *et al.*, 2004)

IV.5. SOCIO-INSTITUTIONAL IMPACTS

The social impacts observed are listed as follows: (i) Rural employment opportunities have been created during shrub planting periods, slash & feed season, and reasonable occupancy of family labor during management phases; (ii) A significant reduction in human suffering as a result of the production of on farm quality biomass and fuel wood, which has also made it possible to make rational use of the available family labor and the production of additional added value that will contribute in improving family incomes of farmers; (iii) High land use efficiency (LER>1.5 on average) encouraged small and medium-sized farms to adopt the alley cropping system; (iv) The movement of livestock and pastoral families in search of pastures has been reduced; (v) The shepherd's profession is beginning to take its place in the newly introduced production systems of marginal areas, especially in large and medium-sized farms; (vi) The stability of pastoral families and the sustainability of production systems were felt; (vii) Creation of local associations for human development, livestock sustainability and conservation of natural resources around the alley cropping system; and (viii) Return of social investment of emigrants and public authorities in the area.

IV.6. IMPACTS TO MITIGATE CLIMATE CHANGE AND THE DROUGHT EFFECTS

(i) Presence of a biomass on feet that tolerates drought; (ii) Stabilization of production and sustainability of production systems during difficult periods of drought; (iii) Maintain and stabilize living capital in difficult years, and (iv) Increased resilience for the poor farmers and sheepherders in marginal dry areas.

IV.7. AGRICULTURAL POLICY IMPACTS

(i) A pilot agricultural policy experiment to meditate for the rehabilitation of marginal lands that have been almost subtracted from agricultural production; (ii) An increase of 79% in the area covered by alley cropping through subsidies; (iii) This public-state investment has helped to improve the adoption rate of forage varieties and technological packages for dryland agriculture, poverty alleviation, stabilization of rural populations and re-exploitation and conservation of available natural resources.

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PART III

WATER USE AND WATER USE EFFICIENCY

OPTIMIZING SOIL WATER USE RESEARCH IN WATER DEFICIENT ENVIRONMENTS OF MOROCCO

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SYNOPSIS

Arid and semi-arid regions of Morocco face severe water deficits. Average annual rainfall is limited and highly erratic in amount as well as in distribution. The traditional dry farming techniques used are not well adapted. They usually cause waste of scare soil water and make crop production risky in these regions. Research has been conducted to address production constraints and improve production and soil water use. Different sources of information were used to assess research findings regarding the optimization of soil water use in dryland agriculture. Technologies that have been developed are related to crop, soil and nutrient management, and the supplemental irrigation. These technologies showed the potential of improving soil water use under deficient conditions of Morocco, but some issues are still to be investigated. This paper, in fact, discusses past and current research and illustrates some of the prospects and future research.

I. INTRODUCTION

Moroccan arid and semi-arid regions are of Mediterranean type with winter rainfall and mild temperatures and a long period (5 to 6 months) of dry hot summer (Ionesco, 1965). These regions lie in the northeast (high plateau and Moulouya valley) the central-west (Casablanca-Beni Mellal-Marrakech-Essaouira) and in the southwest in the souss region. They cover 27 of the whole country and 80% of the arable land. They comprise 60% of cereals acreage and produce 55% of cereal production. In addition, livestock is very important, with 56, 45 and 51% of sheep, cattle, and goats, respectively (El Mourid and Sefrioui, 1991).

II. BIOPHYSICAL CHALLENGES

The arid and semi-arid regions of Morocco face severe water deficits. Average annual rainfall is limited and highly erratic in amount (200-450 mm) as well as in distribution within the year, and from region to region (El Mourid and Watts, 1993). These regions are characterized by a high risk of drought occurrence over years. In the last 50 years, Morocco has experienced four cycles or 11 years of drought (Lahlou, 1986), and the most drastic drought ever faced was from 1980 to 1985. During these five years of drought, average rainfall deficits or departure from average rainfall varied from 20 to 51% depending on the years and regions, with extremes of 85% in 1982-83 and 1983-84 cropping seasons (Belkheir *et al*., 1987). Morocco experienced another two-year drought (1991/92, 1992/93) where the lack of rainfall lasted 120 days, which was never seen in the country. This latter drought has been well-documented (Derkaoui *et al*., 1992; Benaouda, 1993; Bendaoud, 1993; Herzenni, 1992). Nicholson and Wigley (1984) showed that when droughts occur in Morocco, (i) they tend to affect quite wide areas; (ii) there is a long period of drought during summer with no rain from the end of May to October; (iii) it is during the last part of the growing season (March-April), and erratically at the beginning of the cropping season (November to January), that short term seasonal lack of moisture is common (El Mourid and Watts, 1993). The temperature regime with high temperatures during cereal grain filling (Mekni and El Mourid, 1991), high evaporative demand and shallow and eroded calcareous soils (more than 80%) aggravate the lack of soil moisture (Eloumrid, 1994).

Foliar diseases (rusts, septoria...) and insects (hessian fly, green bug, sowfly...) are wide spread and affect crop yields. With all these environmental characteristics, the crop and livestock productions are very low and highly irregular, and years of marginal crop production are quite common. In fact, in 1994-1995 season (harsh conditions) the total production of cereals was as low as 1.7 million tones. Whereas in 1995-1996 season (favorable conditions) this production was as high as 9.7 million tones.

III. AGRO-ECOLOGICAL CHARACTERIZATION

In the semi-arid environments of Morocco, erratic rainfall sequences within and between years and unpredictable occurrences of extreme temperature led to great uncertainty in rain fed crop production for individual farmers as well as at the national level. Furthermore, there is a large spatial variability in climatic conditions, soils, and other land resources. This biophysical variability is associated with contrasts in land use, agronomic practices and economic potential, often over short distances.

This uncertainty complicates the planning, conduct and interpretation of agricultural research results, the transfer of innovations, and the formulation of effective agricultural policies that optimize allocation of scarce resources. It means that new technologies must be tested in a range of environmental conditions, over many years and locations, to ensure that the adaptations are appropriate. Thus, agricultural research in these regions is time consuming and costly.

To alleviate these problems scientists at the Aridoculture Center used simulation methods which make it possible to quantify and model climatic variability over time and space and its effects on crop growth and production (Lamine *et al*., 1993; Balaghi et El Mourid, 1994; Elouali *et al*., 1994).

Moreover, results of experiments can be supplemented with simulated data predicting performances over large number of years and sites. Use of simulation methods facilitates the determination of zones of similar physical potential and constraints for dryland crop production. They also allow the rapid identification of target areas for the transfer of existing or new technologies. They, furthermore, facilitate the definition of research priorities through identification of the spatial extent and frequency in time and the severity of environmental constraints to crop production.

VI. SOIL MANAGEMENT

Soils of the semi-arid regions are characterized, in most cases by a good status of calcium and magnesium. They are in general well provided by potassium, often have high content of unweathered reserves of mineral nutrients and high pH. On the other hand, they have a low content of humus and in most cases, they are deficient in nitrogen and occasionally in iron and zinc due to fixation. A common characteristic of these soils is the low content of nitrogen and in some cases of phosphorus. It must, however, be stated that under these conditions the high calcium content and the correspondingly slightly alkaline reaction may impair the availability of iron and manganese while molybdenum availability is improved (Ryan *et al.* 1990).

Several soil water conservation practices, cropping systems management and weed control techniques have been investigated over many years (Kacemi *et al*., 1994; El Mejahed, 1994). They involved different fallow types and tillage systems at different periods in biennial rotation of fallow/wheat, continuous wheat, wheat/maize, wheat/food legumes, wheat/forages, as well as weed management.

Conservation tillage techniques (no-till, minimum till, chemical fallow) and weed control generated higher wheat grain yields owing to more water storage and water use efficiency. It was also found that clean fallow-wheat rotation was best in conserving water (80-100 mm) and stabilizing crop yields. Finally, improved cropping systems management such as seeding date, seeding rate, and adapted genotypes, could result in even sharper differences among conservation tillage systems for conserving soil and water, and increasing and stabilizing crop yields.

V. SEEDING RATE AND DATE

Studies on the effect of date of seeding showed that under Hessian fly and weed free conditions the optimum time for seeding wheat for maximum yield was early November. Grain and straw yield, spike number, kernels weight and plant height were reduced and maturity was delayed when wheat was seeded after the optimum time. Soil water with-drawal by wheat was confined to the upper 100 cm soil depth and water use was consistently greatest for earlier plantings which improved water use efficiency (Table 23).

Table 23. Water use efficiency (WUE, in kg mm^{-1}) as affected by seeding date (Bouchoutrouch 1994).

	1984/85	1985/86	1986/87
Seeding dates	11.1	12.6	14.8
Early	7.6	10.9	14.0
Intermediate Late	6.4	9.2	6.5

Studies on water use by weeds (Tanji, 1994; Tanji and Karrou, 1992) showed that competition for water between wheat and weeds is high from stem elongation to maturity of wheat. Weeding in that period can save up to 50 mm of soil water and increase yield by 35%.

Under dryland conditions, increasing vegetative cover early in the growing season by changing row spacing in wheat crops appears attractive as a strategy. The idea is to reduce evaporation rate and save water for later stages when water deficit and high temperature are experienced, and thus increase grain.

Grain yield, biomass and WUE for grain are shown in Table 24 for the experiment station, and Table 25 for the farmer's trial. The average yield is satisfactory for the region. There were significant differences in grain, biomass and WUE which are related to planting pattern and weed control.

Table 24. Grain yield and biomass (kg/ha), and RWUE (kg/mm) at experiment station (2000-2001) (Boutfirass *et al.* 2001)

	WF	W	WF	W	WF	W
P1R1	1508	1135	4320	3947	6.7	5.3
P1R2	1778	1402	4977	4827	8.0	6.3
P2R1	1487	1123	4487	3873	6.7	5.3
P2R2	1422	1050	4730	4037	6.3	4.7
P3R1	1558	1030	4270	3523	7.3	4.7
P3R2	1663	1400	4970	4533	7.7	6.3
Mean	1569	1190	4626	4123	7.1	5.4

SignifiancePR (*) W (*) PR (n.s) W (*) PR (*) W (*)

(*) Factors studied are seeding methods (broadcast and row spacing with 12 cm and 24 cm) and seeding rate (200 and 400 kernels/m²). Different levels of the two factors were combined in six treatments: P1R1(12 cm+200 kernels/m²), P1R2 (12 cm+400 kernels/m²), P2R1 (24 cm+200 kernels/m²), P2R2 (24 cm+400 kernels/m²), P3R1 (broadcast+200 kernels/m²), P3R2 (broadcast+400 kernels/m²).

Table 25. Grain yield and biomass (kg/ha) at Farm level (2000-2001) (Boutfirass *et al.* 2001)

Planting pattern	Grain yield	Biomass
P1R1	1655 ^{ab}	4331 ^{ab}
P1R2	1749 ^{a}	5470 ^{a}
P2R1	1175 ^{c}	3942 ^{b}
P2R2	1374 ^{bc}	4377 ^{ab}
P3R1	1186 ^{bc}	3942 ^{ab}
P3R2	1300 ^{c}	4377 ^{b}
Mean	1406	4407

NB: W: Weedy; WF: Weed free; P: Planting pattern; R: Seeding rate

Chemical weed control increased yield by 23% at the station and 54% at the farm site. The difference between the two sites is essentially due to a higher infestation rate at the farm, and higher average yield at the experiment station. On the other hand, with the weedy treatment at both sites, the best yield was obtained with the closer planting pattern (narrow spacing and high seeding rate, P1R2). Planting pattern affected grain yield, biomass and WUE in both experiments. On the station, where seedbed preparation and sowing conditions were optimal, and weed competition was low, with favorable weather conditions, yield increased mainly as a result of planting rate. On the farm, planting space had more effect, and the best planting pattern was 12 cm row spacing and 400 kernels/m$^{2.}$

V. SPECIES AND VARIETIES

One way of increasing soil water use efficiency in rain fed agriculture of Morocco is the selection of adapted species and varieties. In fact, many varieties used by farmers are not well adapted to dryland conditions. Although they produce a lot of dry matter and hence are well appreciated because of their high straw yield, they have the disadvantage of depleting the soil moisture early in the season and have their grain yields usually affected. Moreover, being late they are always exposed to late drought and high temperatures. To provide better material to farmers, scientists have been developing improved varieties and testing species and alternative crops under different soil moisture conditions. Mechanisms involved in drought resistance and WUE have been studied. In most experiments the line source system of irrigation was used to create different soil moisture regimes.

The parameters measured are those related to growth and development of plants such as dry matter accumulation and partitioning, leaf area index and duration, root growth, grain filling rate and duration. Water use, water use efficiency, plant water relations, leaf gas exchange, nitrogen use efficiency and (Malonylamino) cyclopropane-1-Carboxylic Acid (MACC) accumulation were also investigated. In this paper, only results on soil water use, water use efficiency and some important physiological criteria will be presented.

V.1 COMPARISON OF SPECIES

The main species studied are bread and durum wheat, barley, triticale, corn, and chickpea. To compare the performances of these crops under wet (400-450 mm of rain and irrigation water) and dry conditions (less than 300 mm of rain water), results from different experiments have been summarized (Table 26). Data presented are averages of varieties that belong to the same type of earliness. This table shows that under both soil moisture regimes bread and durum wheat used similar amounts of water and that their grain yields and water use efficiency indices were equivalent. Moreover, they were more efficient under wet conditions. Barley had similar trend except under more favorable conditions where it had higher grain yield and water use efficiency than durum and bread wheat. Triticale turned out to be the most adapted crop to different soil moisture conditions since it used water more efficiently than wheat and barley under wet and dry regimes. Although, its actual evapotranspiration values were not that different than those of the other cereals, its grain yields were significantly higher. For the spring crops, corn yielded better and used water more efficiently than chickpea.

Experiments were also conducted with alternative crops, such as sorghum, which was thought to be more adapted because of its tolerance to drought. Unfortunately, results (Karrou, 1986) showed that this crop does not fit the conditions of this environment. If planted early like corn (first week of February) it suffers cold stress; consequently, germination and vigor of the seedlings and hence grain yield is negatively affected. However, if sorghum is planted later (March or April) stand establishment is frequently very low because of soil moisture deficit.

V.2. COMPARISON OF VARIETIES

Table 26 shows also the variety earliness effect. In general, although the total amounts of water used were not significantly different from one type of earliness to the other, early cultivars yielded better and used water more efficiently. In fact, late and old durum (Kyperounda) and bread (florelle) wheat and barley (Arig 8) did not perform like the earlier cultivars Cocorit, Potam and Acsad 60, respectively. Moreover, Samir (1993) confirmed this result when she compared relatively early durum wheat (Marzak) with the relatively later cultivars Karim and Oum Rabia.

For corn (Table 27), early hybrids (Pioneer 3969 and Pioneer 3994) and medium (Funks 4065) in maturity produced more grains and used water better than late varieties (DRA 400, TX 21 and HT 308) under dry conditions. However, if both grains and total dry matter (feed) are targeted, it is better to use medium varieties. Under wet conditions, this table shows that there was no tendency of a maturity class to have higher yields or better WUE. In the case of chickpeas, cultivar differences were also shown (Dahan, 1993). Flip 84-182C exhibited significantly higher seed WUE than Flip 84-92C, Flip 83- 48C and PC-46. As it was mentioned for corn, WUE of chickpea was more related to grain yield than to the amount of water used.

Different strategies are used by varieties to tolerate drought. Earliness, as mentioned before, is one of the criteria used by some cultivars. Early varieties have the advantage of escaping terminal drought and maintain longer their leaf water potential high and hence their stomata open (Karrou and El Mourid, 1993). Consequently, photosynthesis and most of the components of yield are less affected by late drought. The early vigor of Merchouch 8 and its high CO_2 assimilation efficiency and CO_2 exchange rate (Karrou and Maranville, 1993b) offer the possibility of an early root growth and development and hence a better use of water during the wet season. The early seedling establishment characteristic gives this cultivar more time for seed set and more seeds per spike are formed (Karrou and El Mourid, 1993).

Another variety characteristic that can help reduce evaporation, save soil water for later growth stages, and increase transpiration is the early soil shading. To verify the advantage of early soil cover as a good criterion, experiments were conducted on row spacing to create different soil shading conditions. Results (Karrou, 1997) showed that reducing row spacing in wheat from 25 cm to 12 cm increased significantly grain yields without affecting significantly the amount of water evapotranspired. Consequently, soil water was used more efficiently. However, more research on varieties is still needed to identify varieties that have the capacity of shading the soil early in the season.

Table 26. Water use efficiency (WUE, in kg mm^{-1}), Water use (WU, in mm) and grain yield in kg ha^{-1} of different species under wet and dry conditions.

Species	WUE	WU	Wet Yield	WUE	WU	Dry Yield
Durum wheat						
Coccorit (Early)	10.3	382	3938	5.8	244	1416
Keyperounda (Late)	6.6	375	2473	2.5	237	592
Mean	8.5	379	3206	4.2	241	1004
Bread wheat						
Potam (Early)	10.5	363	3807	6.5	248	1614
Florelle (Late)	6.5	394	2558	2.2	242	533
Mean	8.5	378	3183	4.4	245	1074
Barley						
ACSAD 60 (Early)	10.6	379	4013	6.1	242	1177
Arig 8 (Late)	11.8	375	4424	2.9	249	808
Mean	11.2	377	4219	4.5	245	993
Triticale						
Juanillo	14.1	390	5500	11.6	232	2750
Corn						
Pioneer 3969 (Early)	17.6	150	2650	5.1	126	643
TX 21 (Late)	14.5	172	2250	1.5	144	216
Mean	16.1	161	2450	3.3	135	430
Chickpea	3.2	188	602	1.2	97	116

Table 27. Water use efficiency (WUE, in kg mm^{-1}), water use (WU, in mm) and grain yield in kg ha^{-1} of different hybrids of corn in Sidi El Aidi (SED) and Jamaa Shaim (JS) Experiment Stations (Karrou *et al.*, 1992)

	SEA - 1985			SEA - 1986			JS - 1986		
	WUE	WU	Yield	WUE	WU	Yield	WUE	WU	Yield
DRA 400 (L)	16.1	156	2520	2.02	143	290	-	-	430
Tx 21 (L)	14.5	172	2250	1.50	144	220	5.46	175	950
HT 308 (L)	16.5	164	2690	2.44	133	330	3.22	172	580
Funks 4065 (I)	16.0	149	2340	4.06	154	640	5.91	182	1070
Pioneer 3969 (E)	17.6	150	2650	5.13	126	650	6.31	172	1090
Pioneer 3994 (E)	15.8	153	2420	4.37	143	630	7.52	171	1230

L: Late; I: Intermediate; E: Early

In addition to the earliness and soil shading, some of the varieties mentioned above and others tolerate also drought. Durum wheat Marzak and Oum Rabia (Samir, 1993) and chickpea PC-46 (Dahan, 1993) have osmotic adjustment capacity, low stomatal sensitivity, and turgor maintenance characteristics under water deficit conditions. Consequently, drought escape and tolerance help plants maintain leaf transpiration under dry conditions and hence low leaf and canopy temperature.

In fact, the difference between the canopy and air temperatures was found to be very well correlated to yield in the dryland areas (El Mourid, 1988; Karrou *et al.*, 1992; Samir, 1993). Karrou and El Mourid (1993) reported that early senescence of parts of leaves and tillers (case of bread wheat Nesma) and grain filling rate increase and seed size maintenance (case of barley Acsad 60) under drought are other strategies used by cereal genotypes to tolerate late water and heat stresses. Benichou *et al*. (1993) found that solutes (MACC) accumulation under drought might play an important role in genotype adaptation to drought and in the improvement of water use and water use efficiency.

VI. WATER AND NITROGEN USE EFFICIENCY

The possibility of fertilizer use in dryland agriculture is limited by nature. The efficiency of fertilizer application depends to a large extent on the distribution and amount of rainfall. Since rainfall is unpredictable, fertilizer applications under such climatic conditions are much more a matter of a good luck. With deficit rainfall the effect of fertilizer might be zero or even detrimental if growth during the early stage has been promoted by fertilizer and later on no reserve of soil moisture are left to the plant for grain formation. On the other hand, omission of fertilizer application might impair vegetative growth to such an extent that even the small amount of available soil moisture will not be utilized efficiently by the plant. Many experiments in arid and semi-arid regions have shown that adequate fertilizer supply increases yield and improve water use efficiency.

Nitrogen use efficiency in rain fed agriculture is not explicitly described and has been shown to vary from year to year and from one field to another. The factors that mostly affect the crop N use efficiency are, in general, those related to climatic conditions, soil chemical and physical characteristics, plant characteristics and/or to cropping systems.

It is generally accepted that N use efficiency by crops in wet years is higher than in dry years. Soil characteristics such as depth, N mineralization potential and initial mineral N content also affect the efficiency of N use by plants. Crops are less efficient in term of N use at high levels of N application (Karrou and Maranville, 1993 b). Varieties with high yielding capacity use N more efficiently than those with low yield potential.

Results on fertilizer N use efficiency (kg yield/kg applied N show a large variability, i.e. from 25 to 50% in rain fed agriculture, and from 40 to 75% in irrigated areas. Soltanpour *et al.*, (1989) reported values of apparent fertilizer N recovery of 50% in wet year and 34% in drier one. However, Abdel Momen *et al.*, (1990) in a study on dryland wheat response to N and P reported values of 28% and lower depending on soil type and previous crop. Nitrogen use efficiency for barley and triticale was found to fallow the same trend, low in dry years and high in wetter ones (Ryan *et al.*, 1991a). El Mejahed (1993), using isotopic methods (15N) found that real N recovery values for wheat ranged from 25 and 35% depending on climatic conditions and cropping systems. Karrou and Maranville (1994, 1995) have reported that the effect of N on N- content of the above ground parts of the plant was masked by severe water stress and that of under ground parts was not affected. In fact, the N content of the under-ground parts was increased with N applications. However, these results were not the same for all cereal varieties studied.

On the other hand, Agbani and Badraoui (1994) have studied the effect of water stress on corn roots capacity to absorb nitrogen and potassium and found a close relationship between soil water availability and N and K uptake. They also reported that corn absorption capacity for N and K could satisfy the plant needs for these nutrients even under high soil water osmotic pressure (-1 Mpa).

Research on water and nitrogen use efficiency per se is not well studied in Morocco with the exception of few studies conducted mainly in green houses by INRA (Karrou, 1994, 1995) and IAV Hassan II (Agbani and Badraoui 1994). Relationship between water and N use efficiency is still not well developed and require more attention and should be considered in making fertilizer recommendation. Methods of fertilizer N recommendations used nowadays take into consideration mainly the yield goal, N available in soil before planting, soil type and previous crop. It is suggested though to study the possibility to consider water availability in the soil and determine the relationship between this parameter, fertilizer application and yield.

VII. CONCLUSION

Rainfed agriculture in arid and semi-arid regions is prone to different challenges. In spite of these challenges, crop production has continued for many centuries. In dryland areas of Morocco, crop yields have increased substantially for the last twenty years, and this is mainly due to the development and adoption of new technologies.

Production potential of these areas is not reached yet. Hence, it has been shown that crop yield in arid regions could be increased by more than 60% only by adopting the available new technologies developed at the Aridoculture Center. However, efforts still have to be deployed especially in terms of soil water use optimization in order to achieve higher yields and ensure agricultural sustainability in these areas that represent 80% of the total arable land in the country.

VIII. PROSPECTS AND FUTURE AREAS OF RESEARCH

The concentration of rainfall in the cooler half of the year, during winter, when evaporative demand is low offers advantages for improving water use efficiency and increasing biomass. Moreover, deep soils (vertisoils) can store water that can be used later in the season.

In Morocco strategies for agriculture production in arid and semi-arid regions should be founded on the mix productivity, stability, and sustainability. The challenge is to have a balance between all three qualities. Productivity is usually expressed per unit of area, per person, per unit of energy input or per unit of capital investment. Stability is the reliability or consistency of farm production. Sustainability is defined as the ability of an agroecosystem to maintain productivity when subject to a major disturbing force (salinity, erosion, declining market...). It concerns whether a given level of productivity is maintained over time.

Crop production objectives in these drought-prone regions are to improve, stabilize and sustain yields through selection of species, and cultivars and cultural practices that will reduce yield fluctuations and permit stable production. The emphasis should be placed on the interrelationships of environment and soil and crop management factors on crop productivity, which are limited not only by low and uncertain rainfall, but also by extreme temperatures and shallow soils.

Privileged means of reducing these stresses are the application of sound agronomic practices as well as selection of cultivars. These means involve mainly i) evaluation of genotypes-environment interactions, ii) soil and water conservation through appropriate soil and crop management systems; iii) water use and water use efficiency; iv) nitrogen use efficiency through modeling N fertilizer recommendations based on nitrogen spatial variability and N, crop, soil and climate interactions and their impact on the environment quality; v) better understanding of yield processes and determination in relation to phenological stages, agronomic practices, and environment.

Hence, one can infer that all breeding programs and improved agronomic practices should claim the efficient use of the limiting resource, water, by avoiding its waste, by improving the capacity of soil water storage and the choice of crops which are best adapted to these conditions, as well as the agrotechnical practices that lead toward increased soil moisture availability for. In other words, the task is to devise very efficient water-use cultural practices and highly efficient crops and cultivars. Using the water more efficiently may mean fewer crop failures and thereby stabilize yields.

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STRESS PHYSIOLOGY RESEARCH IN ARID AND SEMI-ARID ZONES OF MOROCCO

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SYNOPSIS

Developing crops that are more tolerant to water deficits and other abiotic stresses, while maintaining productivity, will become a critical requirement for stabilizing yield, under stress-prone areas in the future. Understanding how plant tolerates water loss is a vital prerequisite for developing strategies that can impact agricultural and crop productivity under these conditions of decreasing water availability and increasing temperature. Significant work has been accomplished in this area. This review examines morphological, physiological, and biochemical attributes of adaptation and tolerance of cereals and food legumes to abiotic stresses in arid and semi- arid zones of Morocco, compares strategies for water economy and provides some insight to the aspects of adaptation to water-limiting, and heat stress environments, which may lead to improved crop performance in stressful environments.

I. INTRODUCTION

Plant species grown across climatic regions that are prone to extreme dry conditions suggests that, in nature, plants have evolved to endure drought and heat stresses with an array of morphological, physiological, and biochemical adaptations. Drought tolerance is a wider term applied to plant species with adaptive features that enable them to escape, avoid, or tolerate abiotic stresses in general, and drought stress in particular. Drought escape is the ability of a plant species to complete its life cycle before the commencement of drought. Thereby, plants do not experience drought stress, as they are able to modify their vegetative and reproductive growth according to water availability, basically through two different mechanisms: rapid phenological development and developmental plasticity. Rapid phenological development involves rapid plant growth, producing a minimal number of seeds before the soil water depletes, and these plants are considered not to have any special morphological, physiological, or biochemical adaptations. Plants with mechanisms of developmental plasticity show slow growth during the dry season, but in wet seasons they grow normally. Drought avoidance is the ability of plants to maintain, relatively, higher tissue water content regardless of reduced water content in the soil. This is achieved through a variety of adaptive traits involving the minimization of water loss (water savers) and optimization of water uptake (water spenders). Water spenders achieve higher tissue water status by maintaining the water uptake through increased rooting and other mechanisms. Under drought stress. In contrast, water savers use water effectively through reduced loss of water by reducing transpiration, leaf area, radiation absorption, under drought stress. Drought tolerance is the ability of plants to sustain low tissue water content through adaptive traits. These adaptive traits involve maintenance of cell turgor through osmotic adjustment. It is very hard to resolve the role of different mechanisms of drought tolerance in the stability of the crop yield as the major objective. However, there exist an array of different mechanisms for drought escape, avoidance, or tolerance in natural germplasm that can improve drought and heat stress tolerance and stabilize grain yield in crop plants.

II. RESPONSE OF CEREALS TO DROUGHT STRESS

The arid and semi-arid regions of Morocco face severe water deficits. Average annual rainfall is limited and highly erratic in amount (200 - 400 mm) as well as in distribution within the year and from region to region (El Mourid 1988). These regions are characterized by (i) a high risk of drought occurrence over years; (ii) a long period of drought during summer with no rain from the end of May to October; and (iii) an occurrence of drought during the last part of the growing season (March-April), and an erratic drought at the beginning of the cropping season (November-January), where short term seasonal lack of moisture is common (El Mourid, 1988). The temperature regime with high temperatures during cereal grain-filling (Mekni and El Mourid, 1987), high evaporative demand and shallow calcareous soils (more than 80%) aggravate the lack of soil moisture. Each growth stage can face a more or less severe water stress. With all these environmental characteristics, the cereal yields are very low and highly irregular.

II.1 PHENOLOGICAL ATTRIBUTES OF AVOIDANCE

The way to improve grain yield stabilization in semi-arid zones of Morocco is the use of early cultivars (Drought escape). Genotypes with the capacity to complete their growth cycle earlier will sustain the wet season of the year, escaping the dry period of the cycle and producing grain even in the year when winter rains are insufficient. Earliness is one of the criteria used by some cultivars to escape drought. Because of their earliness, bread wheat Potam and Merchouch 8, durum wheat Cocorit and Marzak, escape drought and maintain longer their leaf water potential high and hence their stomata open (Karrou et El Mourid 1994). Consequently, photosynthesis and most of the components of yield are less affected by terminal drought. The early vigour of Merchouch 8 and its high CO_2 assimilation efficiency and CO_2 exchange rate (Karrou and Maranville 1994b) offer the possibility of an early root growth and development and hence a better use of water during the wet season. The early seedling establishment characteristic gives this cultivar more time for seed set and more seeds per spike are formed (Karrou and El Mourid 1994).

2.2 WATER USE AND WATER USE EFFICIENCY

Higher water use efficiency (WUE) is usually achieved through high crop growth rate (CGR) and early vigour, and optimal flowering date. Actually, the drought-resistant cultivars, compared with the susceptible ones, were characterized by a higher CGR and dry matter accumulation during the early vegetative growth period under stress (El Mourid, 1988). High yields under early-season drought can rise from different combinations of traits. High relative growth rate (CGR) and early vigour were identified as potential traits associated with improved resistance to early-season drought.

El Mourid (1989) studied the performances of selected wheat and barley cultivars widely used by Moroccan farmers. Their performance is evaluated in terms of water use (ET), transpiration efficiency (TE), solar radiation conversion (Ec), and growth efficiency (Eg), as well as physiological responses under different moisture regimes. The grain water use efficiency (WUEg) results indicate different responses of cultivars to available water. The levels of WUEg reached are in the range reported for wheat in a semi-arid region by Bouchoutrouch (1986); (2.8 - 13.0 kg ha^{-1} mm^{-1}), and Mazhar (1987); (3.7 - 14.0 kg ha^{-1} mm^{-1}). The maximum average WUEg was reached by ACSAD 60, with 19 kg ha^{-1} mm^{-1}.

Considering the above ground dry matter water use efficiency (WUEt), for all cultivars, WUEt improved with water availability; maximums of 42-45 kg ha^{-1} mm^{-1} were reached under more favorable environments. In the case of durum wheat, there was a decrease in WUE for grain or biomass production, which exceeded 30% between early November planting and late planting in January (Bouchoutrouch, 1986).

Under high ET, the cultivars studied were not able to produce more grain. Moreover, the late maturing cultivars have higher ET but lower grain potential. The difference between genotypes increased if one considered transpiration efficiency (TE) instead of WUE (El Mourid, 1988). Under dryland conditions TEg ranged from 9.7 to 12.0 kg ha^{-1} mm^{-1} for early cultivars and from 3.6 to 4.6 kg ha^{-1} mm^{-1} for late maturing cultivars.

El Mourid (1988) suggested the importance of considering ET (water use) in terms of its two components, i.e., soil evaporation (Esc) and crop transpiration (T). However, Esc was higher under dryland than under wet regime. This soil evaporation constitutes 37 to 47% of total ET under dryland and 20 to 30% under wet regime. A large part of soil evaporation occurred early in the season (in the first 60 days when LAI were very low; 0.5 to 0.6).

A higher percentage of the ET left for grain filling was observed with cultivars reaching anthesis earlier. These cultivars had 45 to 64 mm for grain filling under dryland regime, representing 20 to 26% of whole season ET. The levels of ET observed were similar to the results of Bouchoutrouch (1986) and Mazhar (1987).

Crops under semi-arid conditions of Morocco do not extract all plant available water from the soil (PAW) throughout the growing season. 85 mm of PAW remains in the soil under dryland conditions of Morocco. This PAW was in the deep horizons (80 to 120 cm). To improve grain yield and dry matter production in the semi-arid environments, El Mourid (1988) suggested that water use (ET) has to be increased through increasing water extraction from deep horizons. A maximum proportion of this ET should be oriented to crop transpiration by minimizing soil water evaporation, especially early in the season by obtaining early rapid growth and ground cover.

Optimum time to anthesis has to be determined. Indeed, cultivars reaching anthesis no later than the first week of March would perform very well. These cultivars should have maximum green area index of not more than 5. The amount of dry matter at anthesis should match water availability, and 4000 to 6000 kg ha^{-1} should be enough to efficient water use in the semi-arid environment.

Research indicated that bread and durum wheat used similar amounts of water, and their grain yield and water-use efficiency indices were equivalent. Barley showed a similar trend, and under the more favorable conditions it had higher grain yield and water-use efficiency than durum wheat and bread wheat. Triticale turned out to be the best adapted crop to different soil moisture conditions since it used water more efficiently than wheat and barley under both regimes. Although, triticale's actual evapotranspiration values were not very different than those of the other cereals.

In general, although the total amounts of water used were not significantly different between early and late cultivars, early cultivars yielded better and used water more efficiently. Samir (1993) confirmed this result in durum wheat.

II.3 PRE-ANTHESIS PHASE AND YIELD DETERMINATION UNDER DROUGHT STRESS

Water deficit significantly reduces WUE for total biomass and grain, whether for bread wheat (Boutfirass, 1990; Lamine, 1991; Hamadi, 1992) or durum wheat (Bouchoutrouch, 1986). El Mourid (1988) reported that green area index (GAI) is reduced drastically under dryland conditions. The same reductions were observed for dry matter at anthesis which was highly decreased under dryland regime. At the same time low crop growth rates (CGR) were observed under dryland conditions with large differences among genotypes.

Higher growh efficiencies, which is defined as the product of solar radiation to dry matter efficiency are associated with high yields. The amount of light intercepted by a crop is a major determinant of production as El Mourid (1988) pointed out. Indeed, the occurrence of green and healthy leaf and stem area over a large part of the growing season, especially early in the season is very important. The phenology data pinpointed the importance of anthesis date in a semi-arid environment. Cultivars with early anthesis dates performed better than old, late-maturing cultivars. Results indicated that to improve crop production in a semi-arid region where crops are water-limited, it is important to have a balance in dry matter production between the two periods in which the yield processes occur, namely, pre-anthesis and post-anthesis phases. El Mourid *et al*., (1988) have shown the importance of the pre-anthesis phase for yield determination. Indeed, maximum GAI, dry matter at anthesis, number of grains per gram dry matter at anthesis, water use efficiency at anthesis and sum of growing degree at anthesis are all traits established during the pre-anthesis period and played a major role in yield variation. Dry matter at anthesis was highly correlated to grain yield and, depending on cultivar, explained from 61% to 93% of yield variation, whereas GAI alone explained 49% to 92% and when they were used together, they explained 64 to 95% of yield variation. The number of grains per gram dry matter at anthesis explained 67% of grain m^{-2} variation, and when used together with water use efficiency at anthesis it explained 90%. Growing degree days (GDD) at anthesis had significant negative effects on grain yield even though the relationship was low (R^2 = 0.31). However, GDD explained 58% of grain water use efficiency variation.

Furthermore, GAI explained a large part of variation in dry matter at anthesis (52 to 69%) depending on the cultivar. Water use at anthesis had also a positive effect on grains but a negative effect on HI. These results illustrate the importance of solar radiation interception and conversion.

II.4 POST-ANTHESIS PHASE AND YIELD DETERMINATION UNDER DROUGHT STRESS

The post-anthesis phase role in yield determination is also imperative. This phase usually occurs under stressful conditions (lack of water, increase in temperature, high solar radiation and high evaporative demand) (Mekni and El Mourid, 1987). Indeed, results of this study showed that only 1 to 26% of water use under dryland and 5 to 30% under irrigated regimes are left for grain filling. Results had showed a high positive correlation between HI and water use post-anthesis (ETp). Furthermore, and depending on the water regime, ETp explained 74% under dryland, 85% under intermediate, and 81% under wet regime of yield variation.

Results reported by Karrou (2003) showed that grain yield of barley cultivars was more correlated to grain filling rate and kernel number than to one thousand seed weight. Kernel weight was positively linked to kernel growth rate. Negative relations between kernel numbers and kernel filling rates were demonstrated. In terms of grain yield, the variety "Aglou" seems to be more stable under different environments. The old genotypes tend to have the highest grain growth rates but low to medium kernel numbers. Varieties "Annoceur and Amalou" had the lowest rates and relatively high kernel numbers. "Azilal" had the highest rates and kernel numbers. Results revealed a significant genotypic variation for the different parameters measured. Among the genetic materials tested, there were genotypes that had heigh grain filling rates and kernel numbers that can be used in crossing to generate varieties that are adapted to the conditions of rainfed agriculture of Morocco.

II.5 PHYSIOLOGICAL CHANGES UNDER DROUGHT STRESS

In response to water deficit, the osmotic potential of some wheat varieties known to be suitable for semi-arid zone adaptation is reduced (Samir *et al*., 1996). Strong positive correlations were recorded between the osmotic potential and the relative water content (RWC) in the case of durum wheat. This relationship assumes the ability of plants to lower their osmotic potential as soon as cell turgor begins to be affected (Samir *et al*., 1996). The study of the behaviour of certain varieties of durum wheat in the presence of water deficit has shown that the most resistant varieties are those with the highest water potentials (El Hafid, 1996). Under these conditions, resistant varieties maintain a higher RWC compared to susceptible varieties (El Hafid, 1996). For example, for severe water stress, the relative water content varies from 47 to 67%, respectively, for LA V18 (sensitive variety) and Marzak (resistant variety) varieties.

Indeed, drought-resistant species delay the rapid decline of their relative water content compared to sensitive species. In durum wheat, under water deficit conditions, there is a positive correlation between osmotic adjustment and grain yield (El Hafid, 1996). This correlation becomes increasingly close to the rise in water deficit in the soil. However, osmotic adjustment has no effect on WUE. The latter is negatively related to stomatal resistance, whether in water deficit or irrigated (El Hafid, 1996).

Another mechanism to tolerate drought is the combination of osmotic adjustment capacity, low stomatal sensitivity, and turgor maintenance characteristics under water deficit conditions as observed in durum wheat Marzak and Oum Rabia (Samir 1993). This mechanism helps plants maintain leaf transpiration under dry conditions and hence a low leaf canopy temperature. Certainly, Marzak and Oum Rabia were characterized by low stomatal sensitivity under conditions of water stress, and therefore by a continuous supply of carbon compounds. The latter two varieties therefore appear to be more tolerant to drought. They would have a wider adaptation. Moreover, the existence of such genetic variability makes it possible to use these physiological parameters as selection criteria to distinguish between varieties as to their tolerance to drought.

Saidate (1988) reported that it is not advantageous to have a long grain filling period because, even if the water is available, the high temperatures limit its use and increase the losse of dry matter by transpiration. The combination of rapid growth at the beginning and high number of grains by spike, which is the case of the variety "Merchouch 8", may lead to the conception of more efficient genetic material for semi-arid zones.

Independently of the mechanisms used by the plants to resist water shortage of the end of the growing season, it is important to look for genotypes with the ability to keep their stomata relatively open during grain filling to allow flowering and filling of the grain to take place under favorable photosynthesis conditions (Saidate, 1988).

El Mourid (1988) suggested for the semi-arid zones of Morocco a total dry matter levels at flowering of 5 to 6 tons/ha, a leaf area index of 3 to 5, and a flowering date of the first decade of March. Leaf area index was found to be higher for new varieties that the old ones (El Hafid *et al*., 1996).

II.6 PARTITIONING, YIELD, AND YIELD COMPONENTS CHANGES UNDER DROUGHT STRESS

Using stability analysis, as well as drought susceptibility index to evaluate the responsiveness of yield components to stress, showed that cultivars' response to variation in environment occurred through adjustment of the different yield components (El Mourid 1988). The relationships between grain yield and yield components demonstrated that grain numbers per m^2 and HI were the two major components affecting cereal yields, irrespective of the soil water availability, although grain weight was also important and can be interchanged with the harvest index (HI). It has been argued that high grain weight of 'Yavaros 79', sister of (Karim' in Tunisia, 'Vitron' in Spain, 'Yasmine' in Morocco), may be a key contributor to its reported yield stability, since it has been shown that durum wheat cultivars characterized by high grain weight are more stable across environments (Royo *et al*., 2010).

The path to achieve high number of grains m^{-2} was mostly based on the number of spikes m^{-2} which was a very important yield component under dryland conditions as reported by Bouchoutrouch (1986). Grains per spike was less important than the spikes m^{-2} as shown by their correlation with grain yield, even though the former was very important for the variety "Nasma", suggesting that, to achieve a high yield in semi-arid conditions, each yield component has to increase. El Hafid (1996) revealed that greater WUE for varieties LA V17and Marzak across different levels of water stress appeared to be the result of high kernel number per spike, high spike number and more efficient dry matter distribution. The importance of spikes m^{-2} and grains m^{-2} as preponderant yield components indicates the importance of the pre-anthesis period when these two components develop (El Mourid, 1988). These results mean that, due to the importance of yield components such as spikes m^{-2} under stress, the performance of a cultivar in low-yielding environments is greatly influenced by its performance during pre-anthesis stages.

Grain filling phase is still of great importance to yield in this environment as shown by the importance of HI. Stable and drought resistant cultivars maintained a yield advantage in poor environment by maintaining higher numbers of grains m^{-2} through more spikes m^{-2} and high HI (or higher kernel weight) (El Mourid, 1988; El Hafid, 1996; Karrou, 2003).

II.7 BIOCHEMICAL AND METABOLIC RESPONSES

Ethylene gas has been shown to influence a diverse range of plant growth and developmental processes. It rises during a number of developmental events such as germination, leaf and flower senescence and abscission, and fruit ripening as well as in response to a diverse group of stimuli, including biotic and abiotic stress, wounding, and light. The biosynthesis of ethylene begins with the conversion of the amino acid methionine to S-adenosyl-methionine (AdoMet). AdoMet is converted to 1-aminocyclopropane-1-carboxylic acid (ACC), which is the first committed and in most cases the rate limiting step in ethylene biosynthesis. A further level of control on the production of ethylene is the conjugation of ACC to an inactive form, malonyl-ACC, 1- (malonylamino) cyclopropane-l-carboxylic acid (MACC).

Results showed that MACC accumulated in all cultivars under different moisture regimes. The quantities accumulated under stress regimes were higher by 1.4 to 5 folds than the quantities observed with non-stressed plants, depending on water stress severity and the plant development stage (El Mourid, 1988; Benichou *et al*., 1993). The cultivars studied accumulated MACC differently. Durum wheat accumulated higher amounts of MACC than bread wheat cultivar. There was a highly positive significant correlation between MACC accumulation and severity of stress, with an R^2 ranging from 0.49 to 0.59. However, there was no correlation between MACC and any physiological traits measured, namely stomatal conductance and leaf relative water content.on.

Reserch showed that, two weeks after stress alleviation, the levels of MACC decreased drastically. However, the stressed regimes maintained significantly higher levels (El Mourid, 1988). However, when the plants were rewatered, leaf water potential, stomatal conductance, and RWC changed and approached the watered treatment, indicating that these measurements cannot be used to evaluate water stress history. El Mourid (1988) reported that MACC accumulates in small grain cereals under water stress conditions and remains at high levels even after a long period of water stress relief (15 days), suggesting that the potential exists to use MACC as a water stress history index in comparative studies. Benichou *et al*., (1993) found that solutes (MACC) accumulation under drought might play an important role in genotype adaptation to drought and in the improvement of water use and water use efficiency.

III. RESPONSE OF CEREALS TO HIGH TEMPERATURE STRESS

Changes in the global climate, notably in regional spatial and temporal temperature patterns, are predicted to have important consequences for crop production. Both plant growth and development are affected by temperature (Ouabbou and Paulsen 2000). The most significant factors for heat stress-related yield loss in cereals include the high-temperature-induced shortening of developmental phases, reduced light capture over the shortened life cycle and perturbation of the processes associated with carbon assimilation (light reactions in the thylakoid membranes, transpiration, photosynthesis and respiration).

III.1. EFFECT OF HIGH TEMPERATURE ON LIGHT-REACTIONS

Injury and resistance to injury from high temperature differ substantially from one plant developmental stage to another. Studies reported by Ouabbou (1995) revealed that during the recovery process from high temperature stress in wheat plants, characterizing heat-stress effects in early stages of development has limited application in interpreting stress responses in mature tissue. Heat treatment of wheat plants up to 35/30°C reversibly inactivates the photosynthetic apparatus during tillering and elongation stage, while the same temperature regimes irreversibly inactivate the photosynthetic apparatus during anthesis and grain filling (Ouabbou 1995). The inactivation was more pronounced during grain filling stage. Damage during vegetative stages may be relieved by repair of organelles during the recovery process, whereas high temperature after anthesis accelerates senescence.

The greater sensitivity of photosystem II (PSII) presumably reflects the lability of the oxygen-evolving apparatus, which is easily damaged. Reversibility of impairment of the oxygen-evolving complex at the tillering and elongation stages and its irreversibility at post-anthesis stages suggest that restoration depends not only on the severity of heat stress but also on other factors (Ouabbou 1995). Inactivation of the electron donation from water to PSII, which is also evidenced by a depression of variable fluorescence (F_v) at 25 and 35°C, may indicate inactivation of electron transport through PSII and may limit overall photosynthesis.

III.2. EFFECT OF HIGH TEMPERATURE STRESS ON YIELD AND YIELD COMPONENTS

Heat stress during reproductive growth has a large effect on plant productivity, and grain weight is the most sensitive yield component during post-anthesis treatment. The evaluation of a collection of 189 durum wheat elite accessions bred in Mediterranean countries, showed that kernel weight is of a primary relevance for grain yield as shown by the significant and positive correlations in the low-to medium-yielding environments (Maccaferri 2010). According to El Mourid *et al*. (1991), the difference in canopy and air temperature (Tc-Ta) determined in post-anthesis explains respectively, 35% to 79% of the variability of grain yields in wheat. High temperature increases growth rate but decreases growth duration. The faster rate of transport of assimilates by the grain at higher temperature is usually balanced by greater respiratory losses. Loss by respiration may account for 25% of the reduction in grain weight at high temperature, suggesting a direct effect of respiration or other processes in the grain itself (Ouabbou 1995; Grass 1994). Plants that have the ability to recover from high-temperature stress during post-anthesis stage would be important for providing insights to the long-term physiological adaptation and increasing productivity in harsh environments.

III.3. EFFECTS OF SOWING DATES ON YIELD UNDER HIGH TEMPERATURE STRESS

To observe plant traits that were affected by heat stress and to identify genetic variability among durum wheat cultivars, the alteration of planting date can cause adequate differences in temperature during maturation (Ouabbou 1995). However, Cultivars planted on the first date reached anthesis on a mean date of 3 March and physiological maturity on 4 April. Those planted on the second date flowered on 28 March and matured on 18 April. Planting on the third date delayed mean dates of anthesis to 18 April and physiological maturity to 5 May. The mean daily high temperature from anthesis to physiological maturity was 25, 28, and 31°C for the first, second, and third plantings, respectively. In this study, two major factors were important determinants of grain yields of the durum wheat cultivars. Maintenance of photo synthetic activity favored yields of resistant cultivars as delayed planting increased temperatures during maturation. An association between relative photosynthetic rates and relative yields of the cultivars reflected the importance of the relationship. The highly significant correlation between photosynthesis and yields of the last planting relative to the first planting showed that current assimilation is as important under stress conditions as under normal conditions.

The magnitude of the coefficient (0.60), however, indicated that other factors were involved. Stomatal Conductance had no association with cultivar yields, probably because it was not limiting. Kernel weight and either or both of the two components of kernel number per area, spike density and kernel number per spike, contributed about equally to yield of all plantings. The significant correlations between kernel numbers and yield of the last planting relative to the first planting suggested that setting and retaining tillers and caryopses were important for productivity under stress conditions. Any of these measures would be appropriate for developing or identifying cultivars that are resistant to those conditions. Royo *et al*., (2010) reported that the only environmental variable that entered in the linear regression model, showing a negative relationship to yield, was the maximum temperature from emergence to heading, which explained a very high percentage (59%) of yield variation. The large negative impact of maximum temperature before heading on yield may reflect its effect on shortening the growth cycle, thus reducing the time available for accumulating biomass and resources for grain filling, hence reducing the yield potential (Ouabbou 1995; Royo *et al*., 2010).

III.4. EFFECT OF HIGH TEMPERATURE ON SEED GROWTH AND QUALITY

The influence of temperature on vegetative growth and reproductive yield components has been extensively studied, but less is known about the effects of temperature during seed growth, development, and maturation on seed quality in terms of germination and vigor. Seed germination alone does not provide sufficient information on the seed. Seed lots which show high germinability in the laboratory may demonstrate poor field emergence. A more sensitive measure of seed quality is provided by seed vigour tests.

A study by Grass (1994) indicated that high temperatures during seed development and maturation had no effect on wheat "Oum-rabia" seed germination but reduced seed vigor. High temperature treatment during seed desiccation resulted in mitochondria damage of wheat seed axes (Grass 1994). Adenosine triphosphate (ATP) is regarded as the main form of the available energy. However, dry seeds do not accumulate any ATP. Therefore, their production at the early stages of seed imbibition is essential for successful germination and in directing the growth and developmental processes. Grass (1994) reported that there was a decrease both in the nucleotide content and the adenylate energy charge of wheat embryos excised from seeds grown under high temperature conditions. Studies on seed quality suggest possible influence of temperature on the mitochondria activity and structure of seed embryo during its early stages of germination. The author (Grass, 1994) suggests that mitochondria may be one of the probable targets of heat stress injury to seed.

VI. RESPONSE OF CHICKPEA TO DROUGHT STRESS

Chickpea (Cicer arietinum) cultivars were identified as having different responses to water stress, based on Reltz's (1974) yielding classification. Based on this classification, Dahan (1993) reported that cultivars FLIP 83-48C and FLIP 84-182C are very desirable cultivars because their performance is uniformly superior, and they are stable. In contrast, FLIP 84-92C exceeds average performance only under very favorable environments. PC46, a landrace cultivar, has a relatively poor response and low yields in environments that are high yielding for other cultivars. Its stability comes from the fact that its variance among environments is small.

All cultivars accumulated dry matter to a similar extent independently of the water regimes. Therefore, differences in yield performance were not dependent on variations in mean crop growth rate (MCGR). Seed growth rate (SGR) and effective filling period (EFP) were greatly affected by cultivars and by water regimes. SGR and EFP were 83% and 68% less in the dry regime than in the wet regime (Dahan 1993). The largest effect of drought appears to be on seed dry matter accumulation. Results revealed that water stress reduced the number of pods and seeds per m^2. However, seeds per pod and the weight per seed were not affected as much by water stress. Significant differences among cultivars were found in all yield components except for single seed weight. It appears that differences in the number of seed set, i.e., sink size, in association with SGR and EFP, i.e., sink demand, accounted for most of the differences in yield potential among cultivars (Dahan 1993).

There were substantial reductions in total crop biomass (74%), seed yield (72%) and harvest index (88%) between the wet and the dry regimes. PC-46 has a low yield potential even under the wet regime, and it was the most affected by water deficit, although its total dry-matter yield was comparable to other cultivars. Its low productivity stems from the fact that it has a limited sink size and a limited capacity for partitioning assimilates from the vegetative source to the reproductive sink (Dahan 1993).

Shoot mass and seed yield have been used effectively in characterizing chickpea cultivar differences in drought tolerance based on empirical field screening methods in a receding soil moisture environment. These parameters integrate the total effects of drought over space and time. Drought inhibitory effects on growth are evident from the large yield reductions in all cultivars studied (Kamel and Solh, 1990). The question of whether the cultivars selected differ in relative sensitivity to drought, in terms of growth and development, is important in deciding genetic and agronomic management strategies to alleviate the effects of drought, and also in deciding which parents to use in a breeding program. Differential response among chickpea cultivars gave rise to important parameters associated with yield performance under drought. Good partitioning of dry matter to reproductive structures. In fact, cultivar FLIP 84-182C was able to extract water from a greater depth. Its deep rooting was exhibited under various water regimes. This is very desirable since it can make the best of any additional moisture supply (Dahan 1993).

Dry matter accumulation in a seed is the product of duration and rate of seed fill. Both of these components of seed growth were influenced by cultivar and water deficit. Duration of seed fill and rate of seed growth both had the greatest impact on differences in seed yield among cultivars. Similarly, the effect of water deficit involved consideration of both components of seed yield. These factors directly affected seed yield due to limitation of sink size.

Furthermore, they indirectly altered seed growth by effects on assimilate availability and translocation from vegetative organs to the seed, as reflected in the harvest index (Dahan 1993). Indeed, the process of seed growth involves partitioning of assimilates from the vegetative source to the reproductive sink. At all levels of water stress, the cultivar FLIP 84-182C was able to partition dry matter better than any other cultivar. It seems that as the gradient of stress progressed, sink size and demand and partitioning of assimilates to the reproductive sink became the major factors contributing to high seed yield. In these circumstances, grain yield was mainly sink

determined. Therefore, traits that were associated with high yield under drought were high harvest index, large number of pods and seeds, and a deep root system. FLIP 84- 182C was able to perform better under drought conditions but was still able to make full advantage of any additional moisture available (Dahan 1993).

There has been some success in identifying useful variability for drought tolerance in chickpea using empirical yield-based screening methods. However, a central issue in plant breeding for improved drought tolerance is the role of physiological attributes in supporting productivity under stress. The identification of such specific factors may help increase the efficiency of selection for improved performance under drought.

V. IMPACT OF DROUGHT ON PHYSIOLOGICAL PROCESSES

The physiological basis of adaptation to drought in chickpea revealed putatively important traits as they relate to yield performance. The landrace, PC-46, a highly stable cultivar, showed outstanding physiological performance under different environments compared with the other cultivars. PC46 constitutes a case for long-term viability and survival under natural conditions. These adaptive attributes, from which yield stability is derived, include the maintenance of high leaf water potential; osmotic adjustment;

stomatal behavior, i.e., stomatal response to increases in moisture stress; and mesophyll capacity for photosynthesis (Dahan 1993).

However, its yield potential is low due to limited sink size. It sets few pods, few seeds and ensures that those seeds are filled. This is inherent to the cultivar for survival. FLIP 84-182C, classified as the most desirable cultivar with wide adaptability, was by large the best yield performer over all environments. Its stability stems from its ability to maintain high leaf water potential under stress; good stomatal behavior; high mesophyll capacity for photosynthesis; a deep root system

and a large sink size. Its high yield under drought is affected not only by the specific physiological responses to stress, but also by the yield potential, which cannot be accounted for by physiological measurement of drought response. Seed yield was improved simply by partitioning a larger part of biomass into seed and by a larger sink size. The higher yield performance under drought of FLIP 84-182C compared with FLIP 83-48C was achieved by maximizing depth of extraction and controlling water loss, which resulted in maintenance of higher leaf water potential. It appears then that seed yield improvement has not resulted from any significant improvement in the physiological attributes of the plant. The high yields of the new cultivars are largely a result of higher yield potential attributable to a stronger reproductive sink (Dahan, 1993).

VI. BIOCHEMICAL AND METABOLIC RESPONSES TO DROUGHT STRESS

Houasli *et al*. (2013) showed that water stress in chickpea induced changes in concentrations of several of bio-chemical compounds. Results showed that there is a highly genotypic variability of the membrane stability. The average comparison test revealed that the ILC3182 genotypes were distinguished by a high membrane stability (11.4% damage) compared with other cultivars. Furthermore, water stress induced a decrease in relative water content (RWC) in all genotypes studied. The decrease varies between 7% (in both Mubarak genotypes and ILC 3182) and 50% in the susceptible genotype (ILC3279). Consequently, tolerant genotypes under field conditions, maintained a higher RWC under water stress. The evolution of the chlorophyll a content shows that all the genotypes studied respond negatively to water stress and show a decrease in chlorophyll content under water stress. However, this reduction is variable from one genotype to another (Houasli *et al*. 2013).

Application of water stress caused an increase in foliar proline content, total free amino acids, and total soluble carbohydrates. In addition, the majority of chickpea genotypes responded to water stress conditions by an increase in the level of total amino acids (61% to 86%). This increase seems to be an adaptation reaction of the plant to stress and can be explained by its osmotic adjustment effect to balance the osmotic potential of the soil (Houasli *et al*., 2013).

In recent study, genetic diversity of 70 Mediterranean lentil (Lens culinaris ssp. culinaris Medicus) landraces were assessed for variation in root and shoot traits and drought tolerance as estimated by relative water content (RWC), water losing rate (WLR) and wilting score (WS) (Idrissi *et al*., 2016). Results revealed a clear differentiation of Moroccan landraces from those from northern Mediterranean regions (Italy, Turkey and Greece). High genetic variation in root and shoot traits and traits related to drought tolerance was also noted. Landraces with higher dry root biomass, chlorophyll content and root–shoot ratio were drought tolerant as evidenced by higher RWC and lower WLR and wilting severity (Idrissi *et al*., 2016).

VII. RESPONSE OF CEREALS TO SALT STRESS

Extension of crops in the area affected by salinity have oriented researchers towards developing salt tolerant varieties. Results obtained by Alem *el al.* (2001a) showed the importance of membrane stability in assuring good leaf dry matter, maintaining a good ion selectivity, and tolerating high ion content in leaves.

All varieties showed a decrease in membrane stability with the increase in the stress intensity imposed by the different saline solutions. Three classes of varieties can be distinguished: the varieties Arig 8 and Asni which are little affected; the varieties Merzaga, Lannaceur and Rabat 071 are moderately affected, while the Aglou variety is strongly affected.

Good membrane stability seems to be a factor that allows the plant to limit the decrease in ionic selectivity under salt stress conditions. Nevertheless, in some varieties such as the Asni variety in the case of treatment with the (NaCl / CaCl) solutions, the good, displayed membrane stability values do not seem to be sufficient to maintain good ionic selectivity.

All varieties show an increase in ion content with increased salt stress. The classification of the varieties according to their ionic contents changed according to the intensity of the stress. For higher intensity stress, three groups are distinguished respectively by their ionic contents: the first group is composed of the Aglou and Lannaceur varieties. The second group consists of the varieties Merzaga 017 and Alig 8. The third group comprises the varieties Rabat and Asni. At the level of extreme stress, the Asni and Arig 8 varieties were the ones that increased their ion content the most, while the Rabat and Lannaceur varieties had the lowest increases. The Aglou variety shows an intermediate increase.

Regarding dry matter production, the variety Aglou showed a larger reduction in dry matter. When stress of extreme intensity is applied, the two varieties Aglou and Asni are the most affected. All varieties show good correlations between membrane stability and dry matter production. Both parameters undergo a decrease with increasing salt stress. The Aglou variety, which showed the lowest value of membrane stability, exhibited the greatest decrease in dry matter production (Alem *et al*., 2001a).

Although the role played by membrane stability in salinity tolerance seems to vary from one variety of barley to another and depending on the composition of salt water that has generated salt stress, overall, membrane stability under salt stress conditions plays a role in strengthening the barley inclusive behavior as well as in its ionic selectivity and consequently the maintenance of high dry matter production.

Results revealed that most of the varieties treated with the different saline solutions show an improvement in membrane stability compared to the non-stressed controls. Varieties Aglou and Arig 8 exhibited a significant drop in membrane stability at medium and high salt stress. Laannoceur variety has the best membrane stability for all degrees of salt stress. The Asni variety is remarkable for the consistency of the values of membrane stability at all levels of the salt stress.

In the case of treatment with NaCl/CaCl solutions, the increase in calcium content is negatively correlated with the decrease in membrane stability. This indicates that this salt stress simultaneously leads to an increase in calcium content and a decrease in membrane stability. In addition, the Asni and Laannoceur varieties with the largest increases in calcium content are also those with the lowest decreases in membrane stability. The Aglou and Arig 8 varieties which show the greatest decreases in membrane stability are among the varieties with the lowest increases. Calcium seems to play a role in maintaining a good level of membrane stability under salt stress.

Another study (Alem *et al.*, 2001b) revealed that the varieties with the greatest capacity to accumulate calcium, especially for the salt stress imposed by NaCl/CaCl solutions, have the best values for membrane stability. This is verified at the foliar and root level. Results suggest that the accumulated calcium can be used to maintain the stability of foliar and root membranes. However, the relationship between calcium content and membrane stability appears to be different depending on the plant tissue (leaf or root) and the chemical composition of the solution that imposes salt stress.

To further investigate the mechanisms involved in salt tolerance for some Moroccan barley varieties under NaC/$Cacl_2$ salt concentrations, the accumulation, of other chemical compounds were studied. Results showed a significant increase in proline accumulated in roots and leaves of all varieties under salt stress. This proline accumulation appears to be correlated with membrane stability at the root level but not in the leaf level. The increase of the foliar content in proline is accompanied by a decrease in membrane stability. It appears that the proline content plays no role in the improvement of membrane stability under salt stress conditions. The lack of correlation between proline content and membrane stability at the foliar level can be explained by the fact that at this level, proline levels are involved more in the achievement of ionic and osmotic equilibria than in the Cell membrane stability (Alem *et al.*, 2000).

VIII. FUTURE RESEARCH PERSPECTIVES

Research programs on crop physiology, as shown in this review, result in extremely interesting information. However, it is important to strengthen the links between discovery, deployment, and production, by combining and exploiting the information available. Crop productivity, the final goal of farmers, is the outcome of the Genetic x Management interaction in a particular range of environmental backgrounds. To produce reliable advances, in either breeding or management, the determinants of productivity must be taken it account. As shown in this review, the better the yield determination is understood the more likely the breeding or management strategies designed to rise productivity will efficiently apply. This is because yield is the final outcome of crop growth and development processes occurring throughout a growing season: yield is being formed all the time from sowing to harvest, and therefore virtually any trait may be considered yield-determining. However, in an agronomic context the idea is mostly restricted to two groups of attributes: those conferring adaptation (through phenological adjustment or tolerance/resistance to abiotic or biotic constraints for yield) and those related more directly to the productivity (attributes controlling either yield itself or attributes determining yielding advantages beyond tolerance to stresses). Some of the clearest examples of attributes controlling yield through the effect of major genes on adaptation are those related to phenology. Undoubtedly, the pattern of crop development is the single most important attribute largely determining its performance under field conditions. For instance, improving yield due to a better adaptation to different regions has been possible in wheat due to modifications in its pattern of development to outfit each particular combination of environmental conditions, being the key issue the fact that anthesis must occur when some water is still available during grain filling, for which the contributions of breeding and management have been both paramount. However, in most realistic situations, crops are exposed to a range of largely unpredictable combinations of stresses that requires the understanding of the attributes conferring higher productivity for a wide range of conditions.

Since roots are the agents of both water and nutrient uptake their activity is crucial. To be in a position to manage more effectively, an improved quantitative understanding of relationships between root traits and the use of water is required. The literature contains many suggestions of the type of root system likely to benefit capture during grain filling, but there are few researches done on root growth and activity. Future research should focus on developing a framework for optimizing roots in arid and semi-arid areas of Morocco, including an investigation of interactions between early and later events during crop development.

Any trait to be considered must be directly related to yield. The literature is filled with proposed traits dealing with the lower levels of organization (i.e. molecular, biochemical), which frequently show only poor and inconsistent relationships with crop yield in the field). In this category we can include metabolic traits such as enzyme activities, levels of substrates (e.g., proline, sugars, MACC). Yield is by nature a very integrative trait: through the plant cycle it takes in many levels of plant organization, from the molecular level to the canopy. Therefore, any trait consistently related to yield should also be integrative, either in time (by being determined through part, if not all, of the crop cycle), or in level of organization (by representing a level close, if not identical, to that of yield); or both.

From a breeding perspective there are, of course, specific requirements that any physiological trait should fulfil before it is included in a breeding program. Namely, the selected trait must exhibit enough genetic variability, a high genetic correlation with yield and a higher heritability than yield itself in genetic-populations representative of those being evaluated. Moreover, evaluation of these traits must be fast, easy, and cheap. The use of canopy temperature depression (CTD) is a striking example. Canopy temperature depression is therefore a good indicator of a genotype's physiological fitness, since a high value is indicative of good expression of all of those traits under a given set of environmental conditions. Moreover, leaf cooling contributes to improvement of the photosynthetic activity of leaves and prevents premature ageing. The surface temperature of a canopy in a field plot can be measured easily, cheaply and quickly (within a few seconds), with a simple infrared thermometer. Since the reading integrates the temperatures of plant organs over a small area of the canopy, error associated with plant-to-plant variability is reduced.

Another technique that may have application in screening for physiologically superior progeny is spectral reflectance in the visible and near infrared regions. This can be used to estimate a range of physiological characteristics, including canopy chlorophyll content, absorbed photosynthetic radiation (PAR), leaf area index and plant water status. Spectral reflectance indices (SRI) are formulations based on simple operations between the reflectance at some given wavelength, such as ratios, differences, etc. These indices measured at ground level are becoming a very useful tool for the assessment of many agro-physiological traits. Using SRI, all these traits can be estimated simultaneously in each sample, and in very narrow laps of time, while other methods are much more tedious and time consuming. This makes SRI a useful tool in breeding programs when screening either for potential yield or for resistance to different stresses.

When considering the adoption of physiological traits into a breeding program, it is necessary to establish the degree of genetic variability that exists for the trait(s) of interest. Instead of using commercial varieties that usually have a narrow genetic base, it is better to focus on using wild relaives that could carry some useful traits related to abiotic stresses.

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PART IV

SOIL FERTILITY AND NUTRIENT MANAGEMENT

SOIL FERTILITY AND NUTRIENT MANAGEMENT IN MOROCCAN DRYLAND AREAS

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SYNOPSIS

As the dominant constraints for crop production in dryland areas is due to limited water supplies, economic crop production is not possible without an adequate supply of nutrients. The soil fertility of dryland Moroccan regions is insufficient to support economic yields of crops. As fertilizer use in dryland areas is influenced by soil and climate conditions, best nutrient management implies the selection of the right source of nutrient at the right rate in the right time and the right place. Research during the past five decades showed that major research in dryland Moroccan areas was undertaken in the 80th and 90th. The few data produced were on the effect of major nutrients on cereals and pulses crops showed the essential need of fertilizer N as main nutrient component for crop production. Also the calcareous nature of most soils in the region showed low P fertility and thus addition of P fertilizer contributes in the improvement of yield. However, even if most of research in semi-arid areas reported that soils are sufficiently well supplied with K continuous soil mining of K leads to loss in soil fertility and in consequence low and high spatial variability of exchangeable K has been reported. While micronutrients deficiencies are common to calcareous soils, the dominant soil of semi-arid areas of Morocco, little or no information on these elements with respect to cereals and legumes is available in Morocco. The few information provided from soil survey reported the deficiency of Fe and Zn. In this chapter, the authors made a review of the main research findings of soil fertility and nutrient management in the context of dryland Moroccan conditions. The evidence concluded through this review showed that the domain of soil fertility and plant nutrition in Moroccan dryland areas need further research. there is a need to develop interpretation norms and new or adapted fertilizer formulations in order to provide farmers with tools and alternatives to improve nutrient use efficiency.

I. INTRODUCTION

Dryland agriculture covers main parts of Moroccan areas. It is largely subsistence farming with lower rainfed production. The farm holdings are often small with only a few hectares, many farmers in this region are poor and cultivate less than 10 ha. The main characteristics of dryland areas is the low and high variability of rainfalls and high temperatures. Drought, low soil fertility and land degradation are the major factors for low rainfall productivity that are challenging the rainfed agriculture in the dry areas. The improvement of livelihood in rural dryland areas of Morocco requires the improvement of agricultural production. Improving soil fertility and increasing fertilizer use are essential to advance global food security (Ortas and Lal, 2013). The fertilizer uses in Morocco still low and covers barely 50% of the real need (El Gharous and Boulal, 2016). The adoption of appropriate technical practices including adapted fertilizer management will contribute to appreciable yield improvement due that best nutrient management is one of the strategies to alleviate the effect of drought on crop production. Considerable fertilizer research has been done in semi-arid areas of Morocco over the 80th and 90th. Most of them were national research institutes in collaboration with international organizations or under Aridoculture project between Morocco and the Middle American International Agriculture Consortium. However, over the past 20 years there has been a tendency to less research on soil fertility and plant nutrition in dryland areas of Morocco. The present review is an overview of the most findings on soil fertility and nutrient management for crops in dryland areas of Morocco.

II. SOIL FERTILITY IN MOROCCAN DRYLAND AREAS

Dryland soils are generally characterized by a serious fertility decline (Rashid *et al*., 2004) and many soils are losing fertility that limit production and severely reduce water productivity (Wani *et al*., 2009). Research in semi-arid areas of Morocco showed that crop responses to fertilizer were not only related to rainfall variations but yield potential could differ two to threefold as a results of soil differences (Soltanpour *et al*., 1989). Major soils of Moroccan dryland areas are characterized by low SOC (Mrabet *et al*., 2001), and low nutrient reserves especially N (Ryan *et al*., 1990; El Mejahed, 1993) and in some cases phosphorus (Ryan *et al*., 1990) and in general soils are more provided in potassium (El Oumri, 1985; Stitou, 1985; Ryan *et al*., 1990). Soil fertility survey conducted in Chaouia region showed that nearly all the fields are N deficient, while about 50% were low in available P (Abdel Monem *et al*., 1990a). Even if most of research in semi-arid areas reported that soils are sufficiently well supplied with K (Ghanem *et al*., 1983; El Oumri, 1985; Stitou, 1985), however continuous soil mining of K leads to loss in soil fertility. Thus, in some sites such Doukkala and Chaouia regions low and high spatial variability of exchangeable K has been reported, with no correlation found between soil K fertility and soil type (Badraoui *et al*., 2003). The K fertility depend mostly on the parent material and the agricultural history of the land.

Given the low fertility of many dry area of semi-arid regions poor nutrient management can lead to consequences that are highly undesirable, environmentally, socially, and economically. Recognizing the need to recover soil nutrient depletion, INRA Morocco in collaboration with international organization started in the early 80th research on the effects of crop rotation, tillage and residue management on soil fertility (Bouzza, 1990; Kacemi, 1992; Mrabet, 1997). The main findings showed that rotation of cereals with crop legumes increases soil organic matter compared with continuous cereals or cereal-fallow system (Ryan and Abdel Monem, 1998). The decline of SOM in cultivated soil of Morocco, due to the tillage intensification, decreased soil quality and increased the risk of soil degradation. Switching from conventional tillage to conservation agriculture with crop residues retention can reverse degradation trends improving SOC (Mrabet *et al*., 2012) and total nitrogen (Mrabet *et al*., 2001; Laghrour *et al*., 2016).

Mrabet *et al.* (2001) showed over 11-year periods that not tillage system increases the accumulation of N, P and K in the topsoil compared to conventional tillage. Efforts to improve the adoption no-tillage in drylands areas of Morocco is became a new challenge for improving soils fertility in the region.

III. NUTRIENT MANAGEMENT IN SEMI-ARID CROPPING SYSTEM

III.1 ROLE OF NUTRIENTS IN CROP PRODUCTION

Cereals represents the major cultivated crops in Moroccan dryland areas with wheat in the more favorable rainfall zones (350-450 mm) and barley in the lower rainfall (<350 mm). The main cropping systems in semi-arid areas of Morocco are based on continuous cereals, cereals-legumes and cereals-fallow. Continuous cropping without application of fertilizers contributes in the decline of soil fertility.

Nutrient management is very complex under dryland areas due that economics, agronomics, and environmental aspects should be take into account. In this condition the effects of nutrient on yield depend on the available water. In semi-arid regions, the depletion of soil nutrient decrease soil fertility, limit crop production and reduce water productivity (Wienhold *et al*., 2000; Wani *et al*., 2009), and the efficiency of fertilization application depends on the amount and the distribution of rainfall. Several on-farm trials conducted in the semi-arid areas of Morocco showed that the use of fertilizer is highly profitable for wheat production (Soltanpour *et al*., 1987) and significantly improved grain yields (Shroyer *et al*., 1990; El Mejahed, 1993; Amrani, 1997). In absence of fertilizer some farmers practice fallow for mobilizing soil nitrogen for cereals crops or they involve legume crops such faba bean (*Vicia faba* L.), Pea (*Pisum sativum* L.) and chickpea (*Cicer arietinum* L.) in rotation with cereals. Significant N residues from previous legumes crops have been reported to be adequate for wheat (Abdel Monem *et al*. 1990b, El Mejahed, 1993). Without fertilization application Soltanpour *et al*. (1987) showed that the grain yield of wheat-legumes rotation was two to three times than wheat-wheat rotations (Soltanpour *et al*., 1987).

III.2 NITROGEN

Nitrogen is the most deficient nutrient in agricultural soil of dryland areas. Crop response to nitrogen fertilizer is highly variable depending on available moisture, soil type and crop rotation. N-deficient plants can be more marked when the N deficiency stress is combined with limited available water (Sadras, 2004) due that crop responses to nitrogen fertilization depend on seasonal rainfall (Mikhail *et al*., 2008) and soil water availability. Consequently, the application of N fertilizer under rainfed conditions is complex and needs proper management and the risk associated with applying N increases as rainfall declines. In presence of severe drought, no response of wheat to nitrogen was observed in semi-arid areas of Morocco (Ghanem *et al*., 1983; El Mejahed and Aouragh, 2005). Furthermore, when wheat grown in limited soil available water conditions, a large fraction of applied fertilizer nitrogen remains in the soil unutilized by the plant (Abdel Monem *et al*., 1987).

Most of research in Moroccan semi-arid areas reported an apparent nitrogen recovery less than 50% (Soltanpour *et al*., 1989; El Mejahed, 1993). Significant effect of N on grain yield were reported for wheat (Soltanpour *et al*., 1987; Ryan *et al*., 1997b; Karrou *et al*., 2008), barley (Ryan, 1994; Ryan *et al*., 2009) and triticale (Mergoum *et al*., 1992; Ryan *et al*., 1995). Also, nitrogen response was shown to be related to variety. Karrou and Nachit (2015) showed that early maturing wheat genotypes tend to be better adapted to use nitrogen more efficiently under limited water conditions (Karrou and Nachit, 2015).

Little attention has been given to food legumes which are grown in rotation with cereals. In some cases, residual N levels after legumes maybe adequate for maximum yield without any addition of N fertilizer (Soltanpour *et al*.,1987). However, despite their contribution to residual N soil, there is a net loss of N when all the biomass at harvest is removed.

III.3 PHOSPHORUS

Phosphorus (P) is the second most important nutrient in dryland areas. Due that phosphorus has an important role in crop production, P deficiency can lead to a reduced crop yield. The P availability is mainly governed by soil factors rather than crop (Soltanpour *et al*., 1987; Amrani, 1997). Soils of semi-arid area of Morocco are predominantly calcareous with high pH (> 7.5). In consequence a large part of P is fixed temporarily or permanently by the soil (Amrani, 1997). As a result, most dryland soils that have not been fertilized are P-deficient.

Most research conducted in semi-arid areas of Morocco demonstrated the need for P fertilizer (Ryan *et al*., 1993; Amrani, 1997). By testing in greenhouse, the effect of P fertilization on grain yield of wheat under 13 soil types of semi-arid areas of Abda, Chaouia and Doukkala, Amrani (1997) showed that P fertilizer increased grain yield under 9 soil types among 13. The previous results confirmed those of Ghanem *et al*. (1983) in the field in semi-arid area of Chaouia. The largest increase of grain yields was shown in soils with low P initial soil level where fertilization P, compared to no fertilization, increased P uptake by almost 7 times for very low P soils, 2 to 3 times for medium P soils, and less than one time for high P soils (Amrani, 1997). While most studies on P fertilization in Moroccan dryland focused on cereals (Ghanem *et al*., 1983; Soltanpour *et al*., 1987; Amrani, 1997), some research included other crops such Medicago spp. In their research in Chaouia region Derkaoui *et al*., (2004) showed that Medicago is highly responsive to phosphorus. Also, Amrani (1997) reported a small fertilizer P response of Chickpea compared to wheat. Given the results reported on P in dryland areas, there is a clear need of P for improving crop production in semi-arid areas of Morocco.

III.4 POTASSIUM

Potassium plays a key role in the resistance of water stress. The function of K in controlling the water relationships and stomatal movements gives the opportunity to improve the tolerance of plants to drought. Deficiencies of potassium for wheat production are not widespread in the dryland regions but are likely to become more prevalent where production is intensified (Ryan *et al*., 1997a). Few studies on K undertaken in semi-arid areas of Morocco showed that the response of cereals and pulses to potassium are generally low or negligible. In experimental trials in Chaouia region Azzaoui (1991) reported that the increase of K application from 0 to 200 kg/ha had no significant effect on grain yield of bread wheat. Bread wheat, as well as barley and vetch forage mixture did not respond when at least 150 K ppm is available in the soil (Azzaoui *et al*., 1993). Among 500000 ha of mapped soil in some regions of Morocco. El Oumri (1985) and Stitou (1985) reported that only 11% of Abda soils and 8% of Chaouia soils have less than 150 ppm of exchangeable K. However, high spatial variability of K status has been reported such in Chaouia region (Badraoui *et al*., 2003).

III.5 MICRONUTRIENTS

While micronutrients deficiencies are common to calcareous soils, the dominant soil of semi-arid areas of Morocco, little or no information on these elements with respect to cereals and legumes is available in Morocco. The few information provided from soil survey reported the deficiency of Fe and Zn (Ryan *et al*., 1990).

IV. NUTRIENT MANAGEMENT AND WATER USE EFFICIENCY

Best nutrient management showed positive impact for improving water use efficiency (WUE) in semi-arid rainfed areas for crops such wheat, barley, and food legumes (Jumaa *et al.*, 1999). Increases in WUE come from improved plant growth and yield that are a result of a proper soil nutrient status (Hatfield *et al.*, 2001). Extensive works in Morocco demonstrated the benefit of appropriate nitrogen (Karrou, 1992; El Mejahed, 1993) and phosphorus (Matar *et al.*, 1992) fertilization for improving WUE. When water becomes limited, little or no response to fertilizer was reported (El Mejahed, 1993) due to the fact that water availability has a dominant effect on the availability of N, P and other nutrients (Power, 1990).

V. FERTILIZER USE IN DRYLAND AREAS

V.1. FERTILIZERS USE

Fertilizers play a critical role in food security (Stewart and Roberts, 2012). Fertilizer use by Moroccan farmers started in the 60's through a program called "tillage operation" (Marthelot, 1961). Use of fertilizer represents one of the key factors in boosting food production in dryland system. Large spatial and temporal variation exists in fertilizer use in dryland areas. It's still very low and the quantities used in average are well below the recommended ones. Farm survey conducted in 2013 in Chaouia region showed that among a representative sample of 179 farmers, 79% of farmers responded using fertilizers, however fertilizer use decreases when rainfall decrease or when barley is the main cultivated crop (Abail *et al.*, 2014). The large percentage of fertilizer users apply N and P at planting time and top-dress with N (Abail *et al.*, 2014). However, limited K fertilizer are applied through the use of NPK component fertilizers. The choice of fertilizers and their rates of application by farmers were based on most cases on their self-experiences or the advice from their neighbors.

V.2. CONSTRAINTS OF FERTILIZER USE

One of the main limiting factors of fertilizer use by smallholder farmers in dryland areas is the limiting resources (Abail *et al.*, 2014). Other constraints for fertilizer use were reported by the farmers in dryland areas of Morocco such the no availability of fertilizers, the remoteness from fertilizer sales centers and the lack of awareness on the use and benefits of fertilizers.

VI. STRATEGIES FOR BALANCED FERTILIZATION

Balanced fertilization is the key for efficient utilization of fertilizer. Balanced nutrient management significantly increases yield of various crops compared to those with farmers' inputs in semi-arid region (Valizadeh and Milic, 2016).

VI.1. SOIL FERTILITY MAP

Soil fertility map use digital technologies for gathering data on soil characteristics to support decision-making on balanced fertilization. The availability of data on soil fertility map of an area will help to formulate site-specific fertilizer recommendations and to develop fertilizer formulas that are better suited to each region. In Morocco, most of lands described by soil maps have been concentrated in irrigated and favorable areas. Interest to semi-arid areas started in early 80th by developing the first soils maps in the regions of Abda (El Oumri,1985) and Chaouia (Stitou,1985). The last one has been used for developing the fertility status of the major mapped soil types of chaouia region (Abdel Monem *et al.*, 1990a).

VI.2. SOIL TESTING METHODS

Balanced fertilization depends on soil test values and crop removal. Soil testing methods is the bestmethod for detecting a nutrient deficiency in soil before its impact on plant growth and yield. Before a method can be used for soil analysis, it must be calibrated. The soil test calibration network, involving international organization and the national research systems, did much to stimulate awareness of potential value of soil testing as a basis for fertilizer recommendations (Ryan and Matar, 1990; 1992) and to improve the performance standards in laboratories that conduct those tests (Ryan and Garabet, 1994). Soil test calibration methods started in the early of the 80's in semi-arid area of Morocco (Soltanpour *et al.*, 1986). Several methods of soil testing for P (Amrani, 1997; Soltanpour *et al.* 1986) and N (Soltanpour *et al.*, 1989) have been assessed and developed in semi-arid areas of Morocco.

Using a series of on-farm trials to determine the critical levels of soils N and P in Chaouia region, Soltanpour *et al.* (1987) presented the norm of soil test calibration in dryland areas for wheat in Morocco. For the case of P, they classified soils in three categories: soils with less than 5 mg/kg extractable $NaHCO_3$-P are considered as deficient; between 5 and 7 mg/kg are considered unlikely, and greater than 7 mg/kg no response is expected. For the case of N, the critical level was 50 kg NO_3/ha for a grain yield of 2 t/ha, however crop grown on highly calcareous soil (20% lime) responded to P when critical values where between 5 and 8 ppm.

Despite the fact that soil tests are subsidized by about 50% in Morocco, its adoption by farmers still very low due to various constraints (Abail *et al.*, 2014) and most fertilizer recommendations still provided without soil analysis.

VII. 4RS NUTRIENT STEWARDSHIP APPROACH

VII.1 PRINCIPLES OF 4RS APPROACH

The 4R approach is a very important concept in ensuring efficient nutrient use with avoiding negative environmental effects. Using 4R nutrient stewardship guidance will enable growers to better match nutrient supply through adjusting source, rate, time and place to match the spatial and temporal demand of the crop. There is no standard fertilization for all regions and countries. This concept is highly specific to the crops and the environments where is applied.

VII.2. COMPONENTS OF 4R NUTRIENT STEWARDSHIP

Improved fertilizer technologies have in general little impact in dryland areas compared to favored areas. Best fertilizer management should take into account the four components of 4R nutrient stewardship (right source, rate, time and placement) to meet the crop needs and particularities of the specific sites.

RIGHT SOURCE

The most commonly fertilizer source used in semi-arid areas are based on cereals production. Fertilizer use in wheat are mainly based in priority on nitrogen at planting time and topdressing, followed by phosphorus at planting time and less or none use of potassium (IFDC, 2006). The range of recommended nitrogen sources is limited to ammonium nitrate (AN) or Urea in topdressing for cereals. Most research in dryland areas showed that ammonium nitrate is the most adapted N fertilizer source, however when Urea is top-dressed in wet cool conditions little less of efficiency occur in dryland Moroccan conditions (Ryan *et al*., 1994). In sowing after the 14-18-14 that has been widely recommended in the 80th and 90th, Diammonium Phosphate (18-46-0) was mostly recommended in the 2000. Many studies have demonstrated that application of nitrogen and phosphorus fertilizers can increase and stabilize grain yield of cereals in dry land areas and mainly in wetter season. However, decision on the best source of fertilizer to meet the requirement of crops is based on the availability of the source of nutrient and the combination between the rate and the cost of fertilizer. Little or no research testing the effect of fertilizer sources in dryland Moroccan areas. If N and P sources are commonly used for cereal, the negligence of potassium application is mainly due to the expensive prices of single K fertilizers such potassium sulfate and potassium chloride. By maintaining the equilibrium of nutrient balance, using K as fertilizer component NPK is the solution in dryland areas.

RIGHT RATE

Rates of fertilizer to be applied must optimize economic return to fertilizer inputs. As N fertilizer rates is a decision factor for obtaining high yield, numerous studies have been done in semi-arid areas of Morocco in order to determine the optimum rate of N application. The recommendation rates of fertilizer for wheat in the early of 80th were based on a rate of 20-80 kg N/ha for wheat and 30-60 kg N/ha for barley (Ghanem *et al*., 1983). However, this rate should be taken with precaution as it does not consider residuel N in the soil (Mikhail *et al*., 2008). Karrou (1992) and Mejahed (1993) showed that an application rate of 60 N Kg/ha is enough to significantly increase the grain yield of wheat (Table 28). If the crop has developed poorly due to poor rainfall, amounts of top-dressing fertilizer can be reduced and the remaining fertilizer set aside for the next planting season. Application of high levels of N fertilizer early in the cropping season can result in production of too much biomass and, hence, rapid depletion of soil moisture if early wet conditions are followed by prolonged periods of drought. In Morocco, under favorable rainfall season grain yield were maximized up to 100 kg N/ha for triticale (Mergoum *et al*., 1992) and 80 kg N/ha for barley (Ryan, 1994). However, N rates for achieving maximum yields depend on the previous crops. Thus, for the case of barley tolerable grain yield can be achieved by farmers after fallow or legumes without fertilizer application (Ryan, 1994). However, this depends on the type of legumes and how it is managed.

Table 28. Effect of nitrogen rates on grain yield of wheat in semi-arid areas of Morocco.

Karrou *et al.* (1992)		*El Mejahed et al. (1993)*	
N rates (Kg N/ha)	Grain yield (t/ha)	N rates (Kg/ha)	Grain yield (t/ha)
0	2.2 [a]	0	0.9 [a]
60	2.3 [b]	30	1.1 [b]
120	2.5 [b]	60	1.2 [c]
		90	1.3 [c]
		120	1.3 [c]

**Within columns, values with different letters are significantly different*

The investigations on the responses of wheat and Chickpea to cumulative P rates in calcareous soils of dryland Moroccan areas showed that 18 kg P/ha was sufficient to maintain the yields of wheat and chickpea near the optimum level (Table 29). Taking into account the crop rotation and fertilizer prices the recommended combinations of P rates were 18-18, 27-0, and 9-18 kg P/ha for wheat-wheat, wheat-chickpea, and chickpea-wheat rotation respectively.

Table 29. Effect of P rates on the grain yield of wheat (for two rotations: wheat-wheat and wheat-chickpea) and chickpea (wheat as previous crop) in semi-arid area of Morocco. (Adapted from Amrani, 1997)

P rates (Kg/ha)	Gran yield of wheat (t/ha)		Grain yield of chickpea (t/ha)
	Wheat-Wheat	Chickpea-Wheat	Wheat-Chickpea
0	1.75	1.90	1.50
9	2.55	2.20	2.15
18	2.80	2.40	2.45
27	3.10	2.50	2.50

Data by column are the average of two locations: Sidi El Aidi & Khemis Zemamra.

RIGHT TIME

The application of fertilizer at right time is to satisfy plant requirement. Early application of fertilizer in cropping season is the more common practice in nutrient management. Since P and K are relatively immobile in most soils, their application is at sowing time. Splitting the application of fertilizers is one way to avoid nutrient losses such nitrogen. Timing of fertilizer N application is a critical factor in nitrogen fertilizer management (Mossedaq and Smith, 1994). In early 80th the recommendations of fertilizer for wheat and barley were based on experimental research in the 60th and were based on one application of NPK fertilizers at sowing times (Ghanem *et al*., 1983). Split applications of N fertilizer for wheat are an important approach for improving nitrogen use efficiency (NUE). In general, two applications are recommended in dryland areas. The first application is generally at planting time and the second in tillering stage. Delaying N application at elongation and booting stages significant decrease of grain yield can occur under dryland conditions (Ryan *et al*., 1994). Karrou (1992) showed that the application of nitrogen fertilizer for wheat split into 50% at planting and 50% in tillering tends to increase grain yield and water productivity compared to the control (without N application). The efficiency of fertilizer N when applied in topdressing is influenced not just by timing application but also by fertilizer rate and rainfall.

RIGHT PLACE

Fertilizers need to be placed where they can be easily taken up by growing roots when needed. Various methods of fertilizer placement are used. Fertilizer can be broadcast on the surface, broadcast, and incorporated, surface banded, or deep banded. The goal of best fertilizer placement is to maximize the root-nutrient contact. Placement of the fertilizer in relation to the seed can also influence uptake and crop response to nutrients. In general, placement in a band below the seed and at some distance from it achieves the best results with nitrogen and potassium fertilizers. In dryland soils, the surface layers often remain dry where fertilizer are recommended to be placed deeper near the root zone. Under semi-arid conditions fertilizer placement may affect grain yield because nutrient mobility decrease with lower soil water content. Placement fertilizer methods have more influence in the case of P and K compared to N because nitrate is mobile in the soil. However, under semi-arid conditions placement of N may affect yield because nutrient mobility decrease with less water content. Fertilizer P from all the sources need to be incorporated with the soil or placed below the soil surface. By comparing banded and broadcasting methods of P fertilizers in Moroccan dryland areas, Soltanpour *et al*., (1987) showed that response of wheat to P in a shallow soil by applying more than 20 kg P/ha became highly significant with banded vs broadcast placement. This indicate that wheat response to P was not caused only by P rates but by the beneficial effect of banded placement (Soltanpour *et al*., 1987).

VIII. FUTURE PROSPECTS OF SOIL FERTILITY AND NUTRIENT MANAGEMENT IN DRYLAND AREAS OF MOROCCO

The evidence concluded through this review showed that the domain of soil fertility and plant nutrition in Moroccan dryland areas need further research. there is a need to develop interpretation norms and new or adapted fertilizer formulations in order to provide farmers with tools and alternatives to improve nutrient use efficiency.

As fertilizer sources based on N and P are now common in dryland areas of Morocco, more attention is needed for K. The common conception is that soils are rich in K and it is no need to apply K in semi-arid areas. However, soil analysis results and on- farm trial on omission K plots of wheat have proved recently that omission K has significant effect on grain yield of wheat (IPNI, unpublished data).

Little of research has been conducted with micronutrients in Morocco despite the fact that crops such legumes are sensitive to some micronutrients such Fe.

Particular attention should be given to the development of soil testing laboratories with the objective of the standardization of soil testing method for the nutrients studied in dryland areas. The recommendations according to soil analysis needs soil specific critical levels obtained from field experiments and for specifics crops. In each agro-ecological zone, different soil types and cropping systems should be considered in order to establish fertilizer recommendations for crops base on the cropping system.

In dryland areas farmers' strategy is to minimize fertilizer inputs at the installation of the annual crops. Therefore, Integrated plant nutrition seeks to improve nutrient-use efficiency. Facing the limitation of fertilizer use by farmers, developing genotypes that demand less nutrients but with higher potential of nutrient use efficiency is a challenge to reduce fertilizer use by plants.

Even if farmers are willing to use fertilizers to increase crop production, their knowledges on fertilizer management is largely based on their self-experiences. The role of the agricultural extension centers in making fertilization advice needs to be improved to help in promoting fertilization best management practices based on the 4Rs concept. The creation of website and social media pages that educate farmers and extension agents could contribute to increase the knowledges on the best nutrient managements. Also, as cell phone is prominent in rural areas, SMS or voice messages could be a useful method for transferring information from the extension agents or fertilizer dealers to the farmers.

Attention should be given to the selection of the source. Research on the selection of the best sources of fertilizer is needed according to the type of crops, type of soils and the variability of the rainfall during the season.

Research on the relationship between water and nutrient use efficiency have not well studied. Except some research on nitrogen, the other nutrients such phosphorus and potassium need further research to understand the interaction water x nutrient for a range of cropping system.

Use of yield goals in nutrient recommendations is an estimate method based on the association of the attainable yields in the regions taking into account climate or soil considerations. The efficacy of recommendation approaches employing yield goals is best accomplished using site specific nutrient management (SSNM) for increasing the efficient use of plant nutrients and net profit of farmers.

IX. CONCLUSION

Dryland agriculture is of such great importance in Morocco thus further efforts are needed for increasing crop production through best agricultural practices. The present review on soil fertility and nutrient management showed that most of research were developed in the 80's and 90's. Past research on nutrient management in dryland areas of Morocco has produced few data. In consequence it has not been possible to establish any rational basis on fertilizer use based on the 4Rs nutrient stewardship. Lack of information on nutrient dynamic in the soil, on crop nutrient uptake and how these are related to soil nutrient status, shows that it is a need on further research on nutrient management for specifics sites and crop related to water limiting factors.

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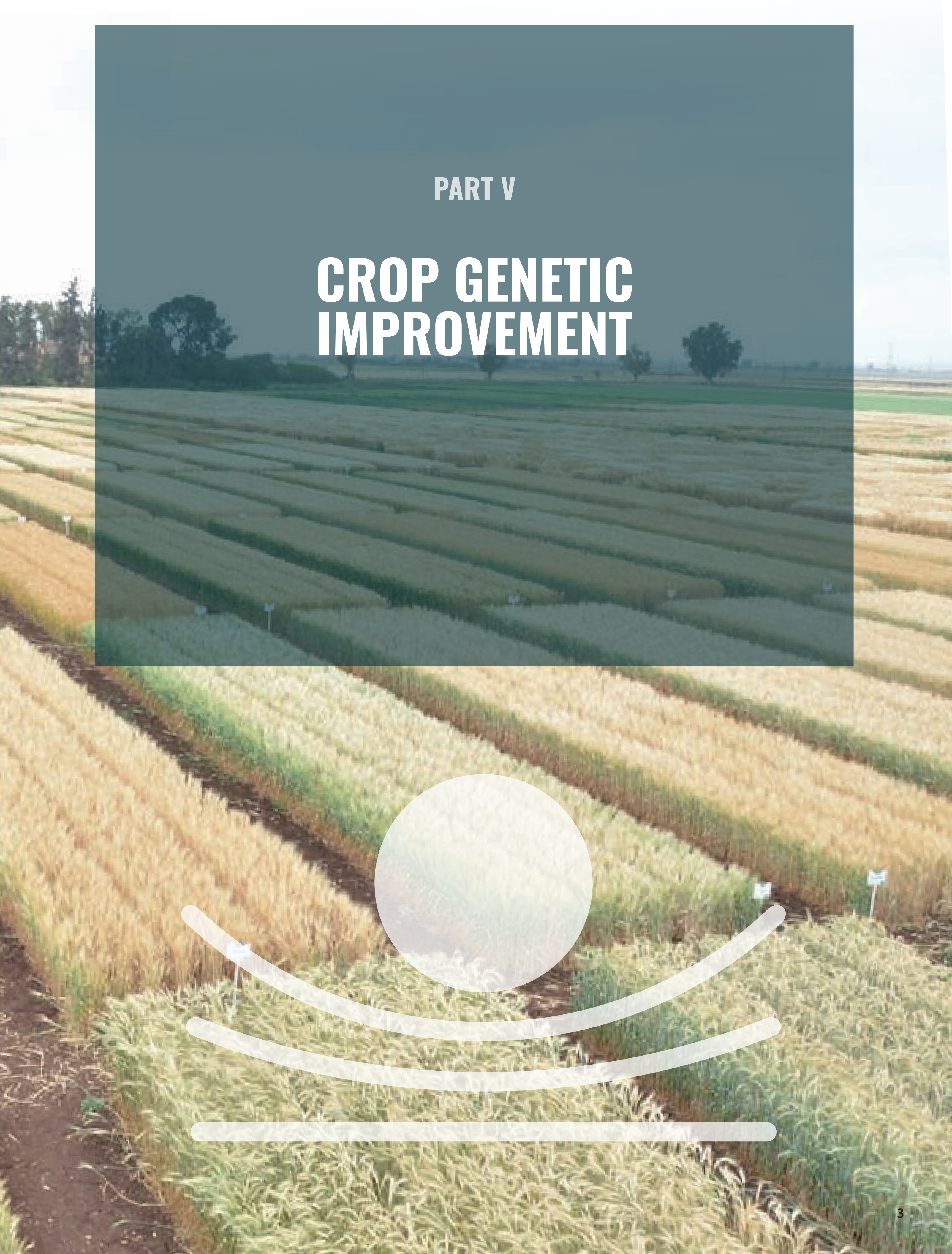
PART V

CROP GENETIC IMPROVEMENT



WHEAT GENETIC IMPROVEMENT IN MOROCCO

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SYNOPSIS

Bread and Durum wheat are important crop species in Morocco. From two to 2.5 million ha of bread wheat, and from 0.8 to 1 million ha of durum wheat are sown annually in this country. The average wheat consumption is about 190 Kg/cap-year of which 70 Kg per capita year of durum wheat. Main uses are bread and biscuit making for common wheat and, semolina products making for durum wheat. A variety of other homemade products is also common. The environment in Morocco is variable in time and space but Morocco is generally a drought prone country. Numerous biotic and abiotic constraints are usually encountered in wheat production. Drought, heat and Hessian fly are the major constraints in dry conditions.

Wheat breeding has produced significantly improved varieties in the 1980s, to the 2000s. These varieties were based on the semi dwarf, short season and widely adapted material that contributed to the world green revolution. Starting 1990s emphasis was made on biotic and abiotic constraints prevailing in the drylands and in the dry years. Hessian fly resistant varieties were produced since 1980s in bred wheat and 2000s in durum wheat. Drought tolerance was improved gradually in both crops. Advanced lines with multi–resistance to Hessian fly, yellow rust and Septoria are available. Advanced lines with resistance to Hessian fly, leaf rust, Septoria and root rot are available in durum wheat. Grain quality in both bread and durum wheat is greatly improved in these lines and yellow pigment content in durum semolina is doubled. The rate of certified seed use is still low (11–20%) but has been increasing recently. Several varieties were recently brought by the private companies from southern Europe and are being commercialized.

I. INTRODUCTION

Bread and Durum wheat are important crop species in Morocco. From 2 to 2.5 million ha of bread wheat and from 0.8 to 1 million ha of durum wheat are sown annually. The average wheat consumption is about 200 Kg/cap-year of which 75 Kg per capita year respectively of bread and of durum wheat. Main traditional uses are bread and semolina products making. A variety of other home-made products are also especially made from durum. The environment in Morocco is variable in time and space but Morocco is generally a drought prone country. Numerous biotic and abiotic constraints are usually encountered in wheat production.

Although substantial genetic gains have been achieved by agronomy and breeding, the national average grain yield is still low, due to cropping techniques, drought, and pest stresses. Improvements of wheat yields were less marked in the semi-arid areas. Improvement of grain quality is still needed for the favorable areas. Many improved varieties were registered at present by the national research system. The rate of certified seed usage is still low (11–20%) but has been increasing recently. Several varieties were recently brought by the private companies from southern Europe and are being commercialized.

II. WHEAT PRODUCTION IN MOROCCO

Wheat area in Morocco is variable from a growing season to another: This area is dependent on the rain pattern during the beginning of the season. Rains start in the end of September and may last until June, but the distribution is highly uneven, and periods of drought may occur in any time during the cropping season. Wheat is planted from Mid-November and is ready for harvest in end of May in the southern short seasons' environment, and in end of June or well in July in the northern longer seasons.

Wheat productivity remains lower than expected due to the uncertainty of the climate. Yearly rainfall has been diminishing in the last three decade and some areas have lost up to 30% of their annual rainfall. In some favorable areas, the rainfall is constant, but the variance of distribution is increasing.

Rainfall and temperature are the factors that best outline the environmental differences among zones. There is a constant gradient from the North west (well-watered and mild temperatures) to the south and to the east where rainfall decreases and temperatures increase.

Wheat production in Morocco is distributed across a wide range of agro-ecological zones. These include (i) High rainfall areas in the North western zones, (ii) favorable environments in the central zones north of the Atlas Mountains, (iii) semi-arid environments in the North Eastern zones, (iv) semi-arid or unfavorable rainfall in the west mid southern zones, and (v) Mountain zones which are also highly drought prone but offer a cool climate and a longer growing season. Irrigated zones are scattered in all the regions of Morocco and in the southern oases. The characteristics of wheat growing environment are dependent on the agro-ecological zones and the on the growing season (Tables 30 and 31).

Table 30. Relative Importance of wheat in Moroccan agro-ecological zones

Species	AEZ*	Area (ha)	Production (ql)	Area (%)	Production (%)
Durum wheat	Favorable	470 872	6 262 598	44.02	50.16
	Unfavorable	479 079	4 845 113	44.79	38.8
	Mountain	119 634	1 387 754	11.19	11.11
Bread wheat	Favorable	685 098	10 550 509	50.31	62.16
	unfavorable	589 557	5 272 436	43.29	31.06
	Mountain	87 230	1 186 328	6.41	6.99
Total	Favorable	115 5970	16 813 107	47.54	56.98
	unfavorable	1 068 636	10 117 549	43.95	34.29
	Mountain	206 864	2 574 082	8.51	8.72

**AEZ: Agro-ecological zone*

Table 31. Relative Importance of wheat in rainfed versus irrigated zones

Species	Regime	Area (ha)	Production (ql)	Area (%)	Production (%)
Durum wheat	Rainfed	1069 584	12 486 324	93.91	86.77
	Irrigated	69 381	1 903 544	6.09	13.23
Bread wheat	Rainfed	1 361 884	16 973 039	91.11	82.97
	Irrigated	132 939	3 483 002	8.89	17.03
Total	Rainfed	2 431 468	29 459 363	92.32	84.54
	Irrigated	202 320	5 386 546	7.68	15.46

II.1 THE FAR-NORTH WEST

The rainfall in these regions is the highest in Morocco It can reach 800 mm and this region is the least hit by drought. Temperatures are cold in the winter and mild in all remaining phases of crop growth. Soils are from sandy to heavy clay and offer good water retention. Water logging may be a problem as well as lodging and diseases related to high moisture. This zone is geographically limited at the east by the Rif Mountains and yields are less than what their potential would be according to rainfall.

II.2 CENTRAL NORTH AND WEST

The rainfall in these regions is usually exceeding 450 mm yearly. This zone is less hit by drought spells compared to southern and eastern areas. Temperatures are mild in most phases of crop growth, but high temperatures and hot winds occur usually at times where the maturing stages occur. Soils are variable and offer good water retention. Water logging is not a major problem. All diseases and insect pest are known to be important in this zone. Yields of both durum and bread wheat are the highest in Morocco.

II.3 THE DRYLAND

The zones described as drylands receives rainfall generally between 250 and 450mm yearly. The eastern dryland areas have colder winters while the southern zones have milder winters. Dry spells are frequent and may occur in any period of the growing season thus affecting crop growth in different manners. Temperatures are generally higher towards the end of the season, but hot spells may occur in the beginning or the middle of the season. Soils range from good to middle in term of water retention. Some soils are too shallow or eroded and with poor water retention capacity. Water logging may occur with short abundant rainfall.

II.4 THE MOUNTAINS

Mountainous areas may be well watered in the north and drought prone in the south and eastern sides. These areas provide longer growth cycle due to the colder winters. Irrigation may be applied where water is available. Temperatures may get to below freezing and spring frosts may be frequents thus damaging to wheat. Soils are variable and may have low water retention capacity.

II.5 IRRIGATED AND OASES

There are eight irrigation plans in Morocco totaling nearly one million hectares of land. These zones are scattered across all agro-ecological zones. The irrigation schemes are based on large water dams and were meant for crops other than cereals. Cereals are used in these areas as filler crop or for certified seed production. Cereals do not receive full irrigation in most of these zones. Soils are usually deep and offer a very good water retention capacity. There are differences among zones related to temperature and growth season length. These differences are apparent from north to south.

III. CONSTRAINTS TO WHEAT PRODUCTION IN MOROCCO

Constraints to wheat production in Morocco are numerous and variable depending on the production zones. The extent and economic effect of these constraints, as well as control measures were studied in the last decades. Most of the important constraints appear to be addressable by genetic improvement.

III.1 ABIOTIC CONSTRAINTS

DROUGHT

Drought is by far the most predominant stress for durum wheat production in Morocco. The country is drought prone, and rainfall is scarce by definition. Rainfall is irregularly distributed within and between cropping seasons. Even if it is generally accepted that the northern areas are more favorable than the others, drought may occur independently of the region. Drought can also occur in the early, middle or in the late season. Terminal drought is more common and usually limits yield of late flowering or maturing crops. Early and middle season drought are less frequent but can cause crop failure more easily. Inadequate cropping techniques: crop rotation, soil preparation, sowing, fertilization, and weeding are interacting factors that exacerbate the effect of drought.

TEMPERATURE EXTREMES

Durum and bread wheat are fall planted (End October/Mid December). In this time of the year temperatures start to go down and rain start to fall. The vegetative stages occur during consistently mild to cold weather that do not generally reach freezing point. Cold damage in this period is rarely a problem except in some mountainous areas. However, frost damage may occur during the months of March and April when plants have passed the flowering stage. Damage may be important in some higher altitudes.

Hot spells and Sirocco winds coming from the east and the south may occur and cause yield loss. Terminal drought are systematically associated with high temperatures. These constraints were partly alleviated by shorter cycle and heat tolerant cultivars. Seed shriveling resulting from high temperatures is disliked for both yield and marketing quality. For the mountain areas, wheat genotypes with semi-late flowering time still need to be sought.

III.2 BIOTIC CONSTRAINTS

Almost all biotic stresses known on wheat in the Mediterranean temperate areas were reported to occur in Morocco. The high variability in climate and environment of the country is probably a major cause for biotic stress diversity and importance.

FOLIAR AND STEM DISEASE

Stripe (or yellow) rust, caused by *Puccinia striiformis* is the most often observed on breadwheat. In the last ten years the change of resistance status provided by YR13 gene made bread wheat vulnerable to yellow rust. Durum wheat is less often attacked by this disease.

Leaf (or brown) rust, caused by *Puccinia recondita* is the widest spread rust disease on durum wheat in Morocco. Bread wheat is also affected but to a lesser extent.

Stem (or black) rust caused by *Puccinia graminis* f. sp. Is not usually a problem probably because the seasons are short, and wheat dries up before conditions are perfect for this disease.

Septoria spp diseases are often important on bread wheat. Recently however and at the occasion of cold and humid winters, durum wheat gets heavily attacked. These attacks are more frequent in the North.

Tan spot caused by *Pyrenophora tritici-repentis* is observed in all years and the yield losses were estimated to be 12 to 18%. Tan spot is considered as a relevant problem for durum wheat but not for bread wheat.

Barley yellow dwarf virus is observed in some years with variable extent of attack. The severity of infection was important in particular sites only and in some seasons.

Fusarium head scab is occasionally observed in wet seasons with late rains. It is mostly important for durum wheat. In durum wheat, the complex fusarium, helminthosporium and alternaria is known to be responsible for black point grain.

Powdery mildew was reported in some areas in Morocco. The extent of damage is not known. But genetic resistance and screening techniques were studied and are available.

ROOT DISEASES

Root rot may be an important disease under dry conditions for durum wheat. Bread wheat is more tolerant. This disease is caused by Fusarium Culmorum and Helminthosporium sativum pathogen complex. Chemical treatment is not effective, and all used varieties are susceptible. Root rot was also found under wet conditions and the isolated pathogenic agents were similar to those of dryland root rot.

III.3 INSECTS

Hessian fly, *Mayetiola destructor* say. is the most damaging pest in the rainfed areas. It consistently attacks the later planted wheat. In the dry years Hessian fly attacks are too heavy and complete crop failures are frequent. Recently, improved varieties with resistance to this pest were released in both bread and durum wheat.

Aphids from several species were identified as important. Some of them are vectors for the Barley yellow dwarf virus. Surveys in the early drought-stricken zone showed aphid infestations greater than under normal rainfall conditions. The Russian wheat aphid is a spreading pest in Morocco.

Effects of other insects (saw fly, gray fly) were investigated. But further research has not been undertaken. Mites may be important in some years under favorable conditions i.e., humid soil and mild weather.

III.4 GRAIN QUALITY

Bread wheat varieties planted in Morocco have medium to good quality grain for the purpose of bread making. For durum wheat, the first improved semi dwarf varieties from the 1970s and 1980s had a poorer quality in term of kernel size, virtuousness and susceptibility to black point. These defects were greatly corrected in the more recent varieties. The use of durum wheat grain for couscous requires the same quality traits as in the pasta processing; the requirements for bread making are different. Grain shriveling may be important for both durum and bread wheat. Yellow berry is disliked in durum wheat by end-users and occurs in susceptible varieties under low nitrogen fertilization in rain favorable and irrigated conditions. Black point caused by weakness fungi such as Helminthosporium sp. and fusarium sp. is consistently observed at variable degrees of severity.

Germination problems have been sporadically reported for durum wheat. Investigations on the cause of this problem led to suspect harvest and storage conditions.

IV. WHEAT BREEDING IN MOROCCO

IV. 1 HISTORICAL PERSPECTIVE

Institutions dealing with wheat production improvement in Morocco were created as early as 1921. The earliest reports from the French administration of Morocco illustrate some national durum wheat research activities that later led to formal research in agronomy and plant breeding. This research activity steadily evolved in organized and modern research. To date, research work related to wheat breeding may be divided in several phases.

The first phase is largely covered by the French administration of the country (ending in 1957). This phase was devoted to collecting and testing local durum wheat first and then of bread wheat from different regions of Morocco, North Africa, and the Mediterranean region. Testing was made for yield and grain quality essentially since wheat production was mostly predestined to exportation. Many well performing varieties were selected and proved very successful. All these varieties were low yielding by today standards, were late maturing, tall and susceptible to lodging. The durum wheat selection had very good grain quality traits and some of them were kept by farmers well after the semi dwarf wheat was brought in the country.

The second phase (1957-1968), research was characterized by crossing among the selected Moroccan varieties or selections. Interspecific crosses were heavily used as an additional mean to improve yield and adaptation, for both durum wheat and bread wheat in order to improve yield potential and adaptation. This phase was unsuccessful due to the lack of significant genetic variability.

The third phase (1968 -1980) was characterized by the Involvement of CIMMYT (Centro International de Mejoramiento de Maiz Y Trigo, Mexico.) and later on of ICARDA (International Center for Research in the Dry Areas, Syria.) in the region. The introduction of high yielding, early maturing and semi-dwarf wheat material had reduced lodging susceptibility and improved escape or tolerance to drought common at the end of the season. The three varieties were either crossed with local material or were released. Yield potential, yield stability and wide adaptation and rust resistance were improved. In durum wheat, grain quality of the new varieties was inferior to that of the old cultivars in use. In consequence, these varieties were not as widely accepted by farmers as expected.

The fourth phase (1980 until present): The efforts were directed to review and rebuild a new national program, using a multidisciplinary and impact driven approach. It aimed at reviewing the constraints and the objectives and methodologies of all breeding programs (among which was wheat). The further, objective was to correct the main problems encountered with the varieties of the previous phase.

The breeding program methodology and the catalog testing program were reviewed in 1980 and 1981. The number and the locations of testing sites for the release tests were changed in order to improve the cost and effectiveness of the breeding program. A "planning by objective" process was also used to plan anew the research process. A multi-year survey of biotic and abiotic constraints as well as technical and socio- economic constraints were undertaken. These surveys were used to define better breeding objectives.

The cooperation with the international centers in germplasm development was improved and joint work was started on numerous fields of germplasm development.

For the dryland areas, it was accepted that new objectives should tackle adaptation to drought, Hessian fly, leaf, and stripe rusts and Septoria. In addition, root rot was to be tackled for durum wheat.

Concerning the genetic material and newly released varieties, it was accepted that: (i) New varieties brought genetic improvements in terms of agronomic adaptation to the main rainfed wheat producing zones in Morocco. The improvement was specially made in the area of earliness, plant height, yield potential, adaptation...; (ii) These varieties still lack genetic resistance to Hessian fly insect - mainly associated to drought - but generally found in most of the regions of Morocco; (iii) There is need for improved varieties for the high altitude and northern areas; and (iv) A renewed interest should be given to durum wheat grain quality especially under irrigation in the different zones. For wheat in general quality aspects and the relevant laboratory tests to evaluate breeding material should be elucidated and sufficiently equipped for.

IV.2 CURRENT OBJECTIVES OF THE WHEAT BREEDING PROGRAMS

The current objectives are certainly the results of an evolution in which the dryland project had an important input. The objectives for each of the target areas in Morocco are listed herein in order of decreasing priority for the breeding program: (i) The low to moderate rainfall areas: priority objectives are adaptation to drought conditions, stability, resistance to Hessian fly, to stripe and leaf rust, Septoria, root rot grain quality and yield potential. (Tan spot and tolerance to heat were added for durum wheat); (ii) The high-altitude areas: the ideotype for this environment is a taller and later maturing plant, with tolerance to drought, cold and to micro-nutrient deficiencies. Flowering should be later than in the previous zone but time to maturity should be minimal. Resistance to important diseases such as Septoria, tan spot, rusts, BYDV, Russian wheat aphid, is necessary. Grain quality should be improved in parallel with all the former plant traits as well as adaptation and grain yield; (iii) In the high rainfall (North western areas), Yield potential, short stature and resistance to lodging and medium earliness in maturity as well as a good level of resistance to Septoria, stripe and leaf rust, tan spot, and powdery mildew are needed. Heat tolerance is also needed for some seasons when hot sirocco winds occur. In addition to grain quality for both bread and durum wheat, resistance to yellow berry and black point and specific durum wheat quality is needed for the later; (iv) The irrigated areas: The ideotype is similar to rainfed areas with the additions higher yield potential, of later maturity for the northern irrigated areas, shorter plant stature and greater tolerance to heat. Grain quality, stripe and leaf rust, Septoria, tan spot resistance, are very important. Two sub environments may be distinguished the northern and southern areas mainly because of temperatures and in which the growing season lengths are different.

VI. 3 METHODOLOGICAL APPROACHES

Both durum and bread wheat breeding programs use conventional approaches. The parents are chosen based on the needed traits and crosses are made in respect of the needed combination. All F1 and F2 generations are planted in the greenhouse for advance. F3 to F7 or later generations are planted in experiment sites representatives of the target environment and are subjected to field selection. Advanced lines nurseries comprising national and international material are planted in Three to seven stations representing all agro-ecological zones. Yield and adaptation trials are performed for three seasons for each genotype. A substantial number of entries managed by the program are introduced from the CIMMYT and ICARDA wheat programs

IV. 4 CHOICE OF PARENTS

In the eighties, the recipient parents used in crosses had to have a wide range of earliness and a smaller range of variation in plant height, good adaptation, yield potential and as many as possible of the biotic and abiotic stress tolerance and resistance traits. The Donor parents most used in those times were those carrying genes for Hessian fly resistance introgressed from bread wheat and other related species. As traits were successfully introduced, the choice of parents and of crosses changed to combining multiple traits from both parents.

IV. 5 Selection method

The selection method most utilized is the pedigree method. Selected bulk is also used if differences among families are not obvious. Modified backcross method was used in the last decade for the production of Hessian fly resistant lines.

Doubled haploid method is used for bread wheat. And backcross with embryo rescue is used for wide crosses.

IV. 6 TOLERANCE AND RESISTANCE TO BIOTIC STRESSES

Screening for tolerance and/or resistance to the important pests on wheat is made in hot spots. Rearing the Hessian fly and artificial infestation under controlled conditions are used in routine screening. Field and laboratory inoculation and evaluation of root rot disease, tan spot, and rust are occasionally used for special germplasm. There are two major constraints for laboratory or greenhouse screening: The first is related to the number of entries to be evaluated and the second is the difficulty to screen for multiple resistances.

IV. 7 YIELD POTENTIAL, ADAPTATION, AND GRAIN QUALITY

Field selection remains the only screening technique used in in early generations. Plant characteristics such as early vigor, tillering capacity, plant height, plant structure, earliness in heading and maturity are used as visual indicators for adaptation and predictors for yield potential. For grain quality, and in the early generations, selection is based upon visual attributes (size, color, freedom from shriveling, for all wheat and black point and yellow berry for durum wheat).

In the advanced generations: Other plant traits with a more complicated genetic determinism but possessing a more direct effect on yield are: yield potential, yield stability, drought and heat tolerance. Advanced lines are tested in 5 sites with yield trials of four blocks and for three seasons. Evaluation of yield and related plant attributes as well as stability and adaptation by sub-environment are made. Grain quality is evaluated in the final selection and include protein content and final product making suitability.

IV. 8 TESTING SITES

Testing sites utilized by the Moroccan breeding program are chosen as representatives of the targeted environments. Also, the dispatch of the different breeding material categories is made according to the zonal representation of the station and to the potential of seed increase or safeguarding the breeding in case of catastrophic drought. The segregating material is conducted in four stations (Annoceur, Marchouch, Sidi El Aydi and Jemaa Shaim). The advanced lines are evaluated in the same stations in addition to four others (Fes-douyet, Sidi Allal Tazi, Tassout and Deroua). Yield trials are evaluated in five stations (Fes-Douyet, Annoceur, Marchouch, Jemaa Shaim and Tassaout). The location, the general characteristics and the dispatch of the different breeding material categories is described in table 32.

Table 32. Characteristics of the experiment sites.

Agro-ecological Zones	Experiment Site	Site characteristics for the breeder.
Favorable Rainfed	Fes Douyet	North central, favorable, heat stress, leaf and yellow rusts, tan spot, Septoria, Hessian fly.
	Marchouch	Central, medium favorable, Yield potential, Heat, drought, yellow and leaf rust, septoria, root rot, tan spot, Hessian fly.
Unfavorable part irrigated	Sidi El Aydi, Settat greenhouse	West dryland, supplemental irrigation, greenhouse. Drought, heat, Hessian fly, root rot, yellow and leaf rust, septoria, tan spot,
Unfavorable	Jemaa Shaim	West and southern dryland, extreme drought, heat, extreme Hessian fly infestation. yellow and leaf rust, septoria, Tan spot.
Northern Irrigated	Sidi Allal Tazi	North west, irrigated, heat, leaf and yellow rust, extreme septoria, tan spot, lodging.
Irrigated South	Tassaout	South central, Fully irrigated dryland, heat, leaf and stripe rusts, tan spot, Septoria, Lodging.
Mountain	Deroua Annoceur	North central, medium high altitude, cold, long season, yellow and leaf rusts, septoria, tan spot, Russian wheat aphid.

V.MULTI-DISCIPLINARITY AND INTERNATIONAL COLLABORATION

The national research institutions have developed expertise in several areas that confers a multidisciplinary status to plant improvement. But the use of these capacities were only sporadic in the areas of screening and virulence studies in leaf rust, tan spot, root rots hessian fly and Septoria, Physiological characterization and drought stress tolerance.

Biotechnology tools are evolving in every research institution and are meant to speed up and improve the efficiency of the genetic improvement of crops. Work on *In vitro* techniques (doubled haploid, embryo rescue and interspecific crosses, molecular markers for drought tolerance. Links to breeding and genetic material are in the development stage. These methods are likely to be routinely utilized in the future. Globally, links between biotechnology and breeding are still to be stably established and improved.

The largest part of the international collaboration and the national research system is made with the CIMMYT and wheat project. The collaboration is based on germplasm and information exchange. The material shared by these centers becomes part of the Moroccan breeding program. Several other sources of collaboration are also tried, and these are the Mediterranean and North American research institutions in USA and Canada.

VI. MAJOR ACHIEVEMENTS

The varieties released by the wheat-breeding program since 1980 are shown in Table 33 and 34. In bread wheat, eleven varieties were released in the 1980s; these varieties were bred in the seventies and brought improvement in yield and adaptation. Among these varieties Saada was the first resistant to

Hessian fly and was a response to the massive damage to this insect pest observed in the dryland areas. However, Saada lacked yield potential and grain quality. In the Nineties, six varieties were registered, they brought better yield and adaptation and grain quality. Arrehane and Aguilal were two new varieties that brought Both, Hessian fly resistance in addition to yield potential and grain quality. Disease was also improved (Septoria and yellow rust).

As Yellow rust virulence changed in the last decade, three new varieties that were resistant to Hessian fly, Septoria and yellow rust were released in 2010 (Kharoba) 2012 (Khadija) and 2016 (Malika). These varieties were produced by using interspecific crossing coupled with embryo rescue and doubled haploid method.

In durum wheat, twelve varieties were registered in the 1980s. Two of these (Marzak and Karim) had a large success and are still being planted nowadays. The other varieties were grown for short periods of time (Table 33). Most of these varieties had medium grain quality. In the nineties, 8 varieties were registered, they brought good yield and adaptation with improved grain quality and disease resistance. These varieties were used by farmers and most of them are abandoned nowadays. In 2002 and 2005, five varieties were registered and were the first durum wheat ever to be resistant to Hessian fly. They were very adapted to the dryland conditions but lacked resistance to leaf rust. It was advised that these varieties be restricted to the dry areas. The variety Faraj registered in 2017 was resistant to Hessian fly, leaf rust Septoria and was tolerant to drought. In 2011 and 2016, Two varieties, Louiza and PM9 were released for having high yield potential, adaptation and especially high grain yellow color and quality. These varieties were selected in response to the millers' associations demand.

Major achievements were made in the area of disease resistance or tolerance in collaboration with the CIMMYT and ICARDA wheat programs. These achievements concern root rot tolerance, leaf rust resistance, yellow rust resistance and Hessian fly resistance. Contribution to studies on drought and heat tolerance as well as the identification of germplasm were made in the last two decades.

Table 33. Durum wheat varieties registered since 1980

Name and year of release	General traits
H. Mouline, 1982 ACSAD 65, 1984 Marzak, 1984 Karim, 1985 Isly, 1988 Massa, 1988 Oum Rabia, 1988 Sarif, 1988 Sebou, 1988 Tensift, 1988 Tessaout, 1988	Large adaptation and grain yield
Anouar, 1993 Jawhar, 1993 Yasmine, 1993 Tarek, 1995 Amjad, 1995 Ourgh, 1995 Marjana, 1996 Tomouh, 1997	Improved adaptation and yield, improved grain quality, Improved disease resistance
Amria, 2003 Irden, 2003, Nassira, 2005 Chaoui, 2005 Marouane, 2005	Adapted to drought, Hessian fly resistant.
Faraj, 2007	Large adaptation, Hessian fly, leaf rust
Louiza, 2011	Large adaptation high yield, high grain yellow
PM9, 2016	Large adaptation high yield, high grain yellow

Table 34. Bread wheat varieties registered since 1980

Name and year of release	General traits
Jouda, 1984 Marchouch, 1984 ACSAD 59, 1985 Sais, 1985 Sibara, 1985	Large adaptation and good yield
Kanz, 1987 Saba, 1987 Achtar, 1988 Baraka, 1988 Khair, 1988	Large adaptation and high yield
Saada, 1988	Large adaptation and high yield, Resistant to Hessian fly
Tilila, 1989 Massira, 1993 Amal, 1993 Mehdia, 1993 Rajae, 1993	Large adaptation and high yield, improved disease resistance
Aguilal, 1996 Arrehane, 1996	Large adaptation and high yield, Resistant to Hessian fly
Kharoba, 2010 Khadija, 2012; Malika, 2016.	Resistant to yellow rust, leaf rust and Hessian fly.

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BARLEY GENETIC IMPROVEMENT IN MOROCCO

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SYNOPSIS

Barley, the best nutraceutical, multiuse and widely adapted cereals in the world, is considered as an alternative crop to climate change. Moroccan barley is covering more than 20% of the Useful Agricultural Area, mostly located in dry areas. From twenties till now, Its breeding program tackles many issues linked to biotic and abiotic stresses for better performance. Currently, the climate change associated with the quality requirement and yield gap, push to take drastic measures in modifying barley strategy program to deliver more and better products with time, space and money saving.

I. BARLEY IMPORTANCE

Barley is the best nutraceutical, multiuse and widely adapted cereals in the world. It was domesticated more than 10,000 years ago in the Fertile Crescent. Renowned for its strengthening power to the Romans Gladiators called " hordearii " or "barley eaters". Barley is a rustic cereal in all continents thanks to its adaptability in extreme environments such as the Himalayan plateau in 4800m above sea level, the Iceland and Scandinavia islands at longitude 60° North and arid areas below 250 mm of rainfall. Barley, cereal with low short-cycle inputs, is distinguished from other cereals by its tolerance to drought, cold, salinity, soil acidity and alkalinity and to photoperiod. Thanks to its multiple uses in animal feed, human consumption and other industrial uses, barley has played a strategic role in food security and social stability. For climate change, barley grain is considered as a good alternative.

II. BARLEY IN MOROCCO

In Morocco barley occupies, on average, 2 million hectares (2000-2016) representing 40% of the total area planted with cereal crops and 21% of the utilized agricultural area (UAA) (MAPM, Statagri 2016). Seventy percent of the barley area is in the arid and semi-arid zones, 10% in the highlands and 20% in more favorable areas, but in poor soils with little or no inputs. The annual production of barley is 2 million tons (2000-2016) representing 31% of the total cereal production (2000-2016). Barley straw provides 30% of required animal feed. Barley grain is used for both animal feed (80%) and human food (20%) with the latter being common in arid areas and in the mountains (traditional use). It is considered as a low-risk crop. As depicted in Figure 29, the quinquennial evolution of barley in Morocco for the two decades shows feeble production and yield increase of 23% and 44% respectively and an acreage decrease of 15%.

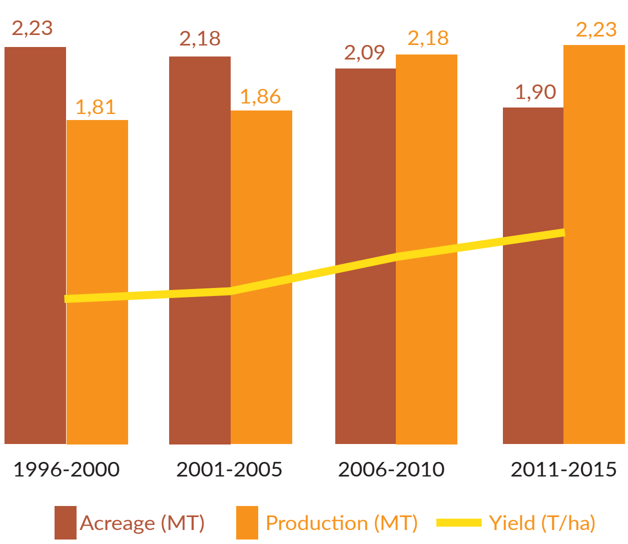

Figure 29. Quinquennial evolution of barley in Morocco

III. BARLEY BREEDING HISTORY

Breeding for barley, Hordeum vulgare L. one of the most important cereal crops in the world (Baik & Ullrich, 2008), represents the characterization of agronomic, grain and malt quality attributes of potential new cultivars. In Morocco, barley breeding began in 1924 with the selection of lines from introduced two row barley accessions from the US, Australia, and Europe as well as selection among sex row domestic landraces. The first selection has concerned Chevalier, Hannchen, Combesse, Guldkorn, Princesse and Prior (Ulrich, 2011). The later program led to selection and release of two cultivars "077" and "071" among local populations which are widely grown up today by most farmers. This clearly shows the importance of the genetic diversity in Morocco (Saidi *et al*, 2005). Several accessions have been introduced afterward and a new breeding program was initiated since 1970 for improving two-row barley which led to release of several cultivars among which Brasserie Maroc, Tamellalt and Asni. This type of genotype was not easily accepted by farmers who prefer the six-row barley though there is now evidence of their superiority. Since 1980, new accessions were introduced from the US in order to improved earliness and harvest index. Several accessions were also introduced from ICARDA with the main objective of improving forage and grain yields and disease resistance for leaf rust Puccinia hordei, powdery mildew Erysiphe graminis f. sp. hordei, net blotch Pyrenophora teres f.sp. teres and BYDV virus (Saidi *et al*, 2005).

During this period there was a renewed interest for barley as a food component for human consumption. Its high soluble dietary fiber and β-glucan content compared with other cereals as well as the new prospect of hulless barley genotypes that can be easily separated from the hulls after threshing could facilitate the use of barley grain for bread making and other nutritional foods. An additional program to develop hulless food barley varieties was initiated in 1985. Hulless barley helped initiated a wide food processing program for diverse dietary uses. However, the difficulty of handling the seeds and their reduced seed germination capability limited their inscription in the national catalogue (Amri and Saidi, 2005). Since 2003 a new breeding program was initiated with two major components, one for marginal rainfed land (dry lands and high elevations areas), the second for favorable conditions. For the first production system, participatory breeding of local land races population (Nassif *et al.*, 2003), in situ- conservation and on farmer seed production are the main features of the breeding program. For the second, the objective is to develop pure lines through conventional breeding methods within a long-term strategy aiming at the introduction of male sterility for production of synthetic varieties (Saidi *et al*, 2005).

Production of varieties with increased mineral and vitamins contents is another recent area of research lunched with collaboration with ICARDA. A new breeding project on bio fortification aiming to mitigate the problem of micronutrients deficiency by improving zinc and iron contents was recently initiated. But this program remains relatively limited though its importance.

As illustrated in Figure 30, the century-events of Moroccan barley breeding program has recognized a great period of progress between the 80s and 90s and new goals recently focusing on the specific end uses.

IV. CONSTRAINTS

Barley crop in Morocco faces several constraints. Indeed, the vast majority of farms (80%) have an area less than 5 hectares; they are landlocked, fragmented, in debt, providing low and random income. In addition, production is strongly related to the climatic condition (essentially the rainfall), the disrespect of the appropriate technical practice, the underuse of fertilizers and lack of control against weeds and diseases fungal and also production methods which are still traditional essentially with a limited use of modern tools and mechanization. There is also a lack of means and strategies, including aspects related to management (extension, training, awareness, alerts) and the transfer of technologies on technical practice. Another major constraint is related to the poor use of the seed certified barley which is less than 2%, this rate is still below the standard recommended by the FAO which is 30%.

Breeding for wide adaptation during the registration of varieties in the official catalogue is considered as being the salient factor of low yields and development of varietal mapping for elite varieties and not average performance of 12 regions of the Morocco varieties. The National Institute of agronomic research (INRA) is the only national organization that undertook breeding programs. While the introduction of foreign varieties, for homologation in the official Catalogue, is performed annually by thirty of seed companies. Pre basic seed production is carried out by INRA while the production of basic seed and certified is carried out in a contractual framework between the seed companies and multipliers (700 seed growers for 50,000 Ha). Despite these different stakeholders, certified seed of barley supplies remain below the needs.

Barely is grown in stressful environments, poor soils, with low or no inputs (fertilizers, herbicides, fungicides...). Among the barley diseases frequently developed in all Moroccan barley area, there is Net Blotch (NB) which could cause yield losses range from 14 to 29% and reach 39% on susceptible cultivars (El Yousfi and Ezzahiri 2001) and Powdery Mildew (PM) with yield damage close to 26%. BYDV has been estimated to cause yield reduction between 16 and 23%. Barley stem gall midge is the most important insect pest all over Morocco, while Russian wheat aphid (RWA) can cause serious damages in the highlands. The arid and semi-arid areas are characterized by low and unpredictable annual rainfall (200-400 mm) associated with heat stress at the end of the cycle, shallow soils affected by wind and water erosion and salinity, with low content of organic matter. Barley yields are low in these areas (70% barley acreage), under severe risk of desertification. In the highlands, that include the Rif in North Morocco, the Middle Atlas, and the High Atlas, barley can be affected by severe frost damages until early May, and immediately after, by hot winds. Lodging contributed also to yield loss while using machine harvesting.

V. IMPROVEMENT OBJECTIVES

Barley breeding program, through multidisciplinary efforts, in Morocco aims to (Figure 31): (i) Produce more (high yield) and produce better (high quality for specific end use) in the target environment; (ii) Disseminate varietal package and best technical practice to stakeholders through barley platforms, field days and workshops; et (iii) Develop and valorize barley products whether for food or feed.

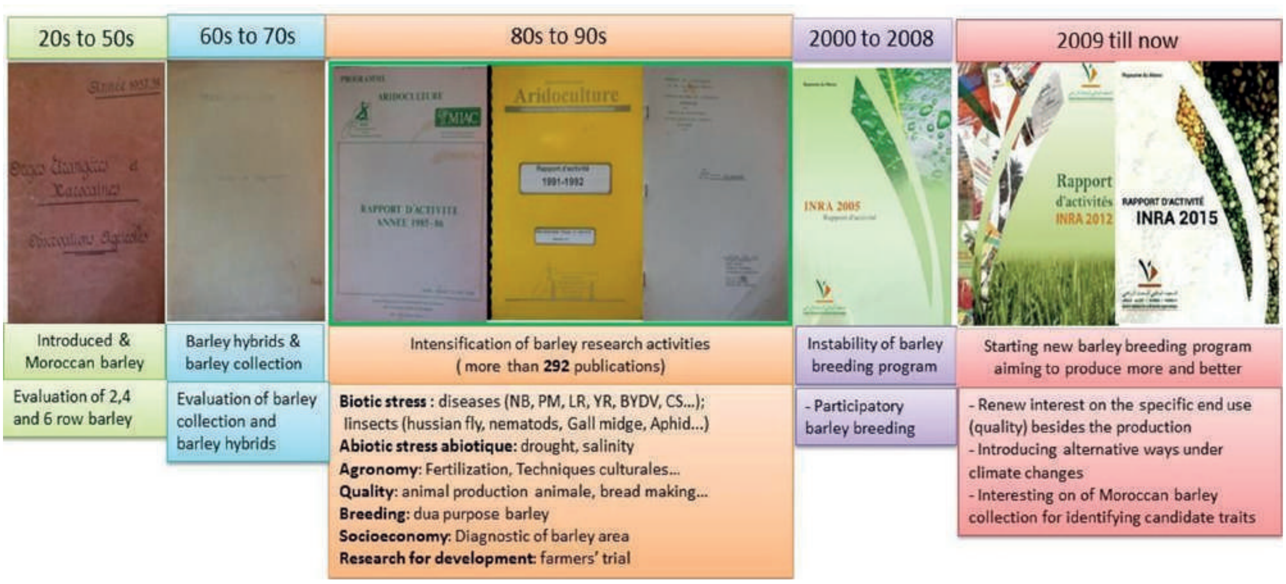

Figure 30. Century events of Moroccan barley breeding program

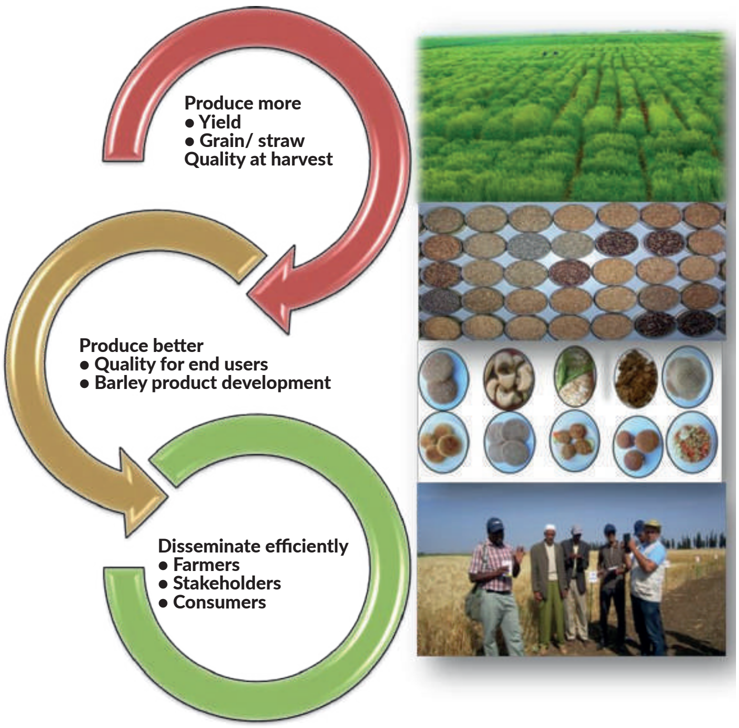

Figure 31. Scheme of Moroccan barley breeding program

VI. METHODOLOGY

In Morocco, barley breeding program is split into three subprograms according to agro climatic zones (arid zone, favorable zone, and highland) representing respectively by their three experiment stations Jemmat shaim, Merchouch and Annoceur. In each zone, separate goals have been made:

ARID ZONE: in this area, we look for high average yield with a stability through vigor and earliness, and tolerance to early and final drought. In addition, resistances to NB, PM and Hessian fly are taken into account in selection.

FAVORABLE ZONE: in this zone, high potential yield with resistance to biotic stresses and lodging were subject to selection.

HIGHLAND ZONE: with the use of winter, spring and facultative barleys, barley breeding subprogram tackles frost resistance after heading, resistance to biotic stresses, resistance to Russian Wheat Aphid and short grain filling stage.

ALL ZONES: grain quality and straw production are considered to insure a large adoption of the released varieties. Grazing technique, in arid and favorable zones, in tillering stage stimulates grain yield in good conditions and when using varieties with double end use (grain and straw).

SOURCE OF RAW MATERIAL FOR CROSSING (CROSSING BLOCK)

The barley crossing block is composed of the Moroccan release varieties with high performance lacking resistance to biotic and abiotic stresses and the elite lines already tested in our experiment stations coming from Moroccan barley landraces, introduced materials from ICARDA, ACSAD and CIMMYT. Since the discovery of the quality richness of Moroccan barley landraces in terms of minerals like iron and zinc and the dietary fiber (beta glucans) and in order to guide the end use of our released varieties either for food, feed or malt, an important focus on grain quality is ongoing through assessment of barley landraces and promoting lines.

VI. SELECTION METHOD

Pedigree method is used for barley breeding program in Morocco, after crossing the elite lines with our good released varieties lacking resistance or quality parameters; the F1 is planted separately in space to give F2. Each F2 spike is planted in a row to disclose the segregating material joined to the introduced F2 materials from the international centers listed above. F3 families were subject to selection according to the target objectives same as F4 and F5. The selective F5 families bulked represent observation nurseries were selected again and the chosen pure lines will initiate the yield trials.

Starting from preliminary trials with 2 replications to intermediate trials with 3 replications and finally the two advanced trials with 4 replications will allow assessing yield performance of the elite lines. The introduced material from ICARDA, ACSAD and CIMMYT will be incorporated in the appropriate generation scheme. In multi-farmers' fields testing, these lines with the released varieties as checks, will inform us on the G*E interaction and the stability of these upcoming varieties. A screening for quality will be joined to Moroccan barley breeding program to guide the end use of released varieties (Figure 32).

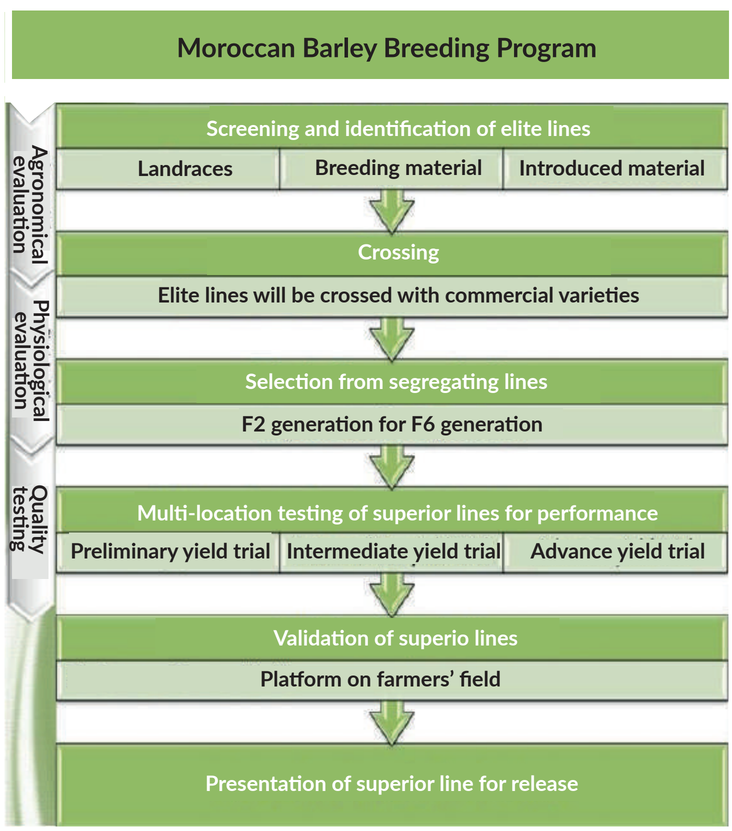

Figure 32. Moroccan barley breeding program scheme

VIII. MAJOR RESULTS AND ACHIEVEMENTS

The released varieties have been subject to specific traits identification (cereal varietal guide, under edition). The major output related to barley grain and straw of this guide for barley is illustrated in Table 35. Specific adaptation for specific varieties has been also illustrated in the guide (Figure 33).

Table 35. Specific traits identification of barley released varieties

Traits	1st Choice	2nd Choice	3rd Choice
Grain yield	Amalou	Amira	Oussama
Grain yield under direct drill	Tissa	Oussama	Firdaws
Grain yield when late sowing	Oussama	Taffa	Amalou
Grain protein	Amalou	Amira	Oussama
Biomass	Taffa	Amira	Amalou
biomass under direct drill	Firdaws	Taffa	Amira
straw protein	Amira	Oussama	Taffa
Diseases	Amalou	Amira	Oussama
Lodging	Amira	Amalou	Oussama
Nitrogen use efficiency	Taffa	Oussama	Amalou
Grazing	Laanaceur	Oussama	Amira
Hydroponic barley	Taffa	Amira	Amalou

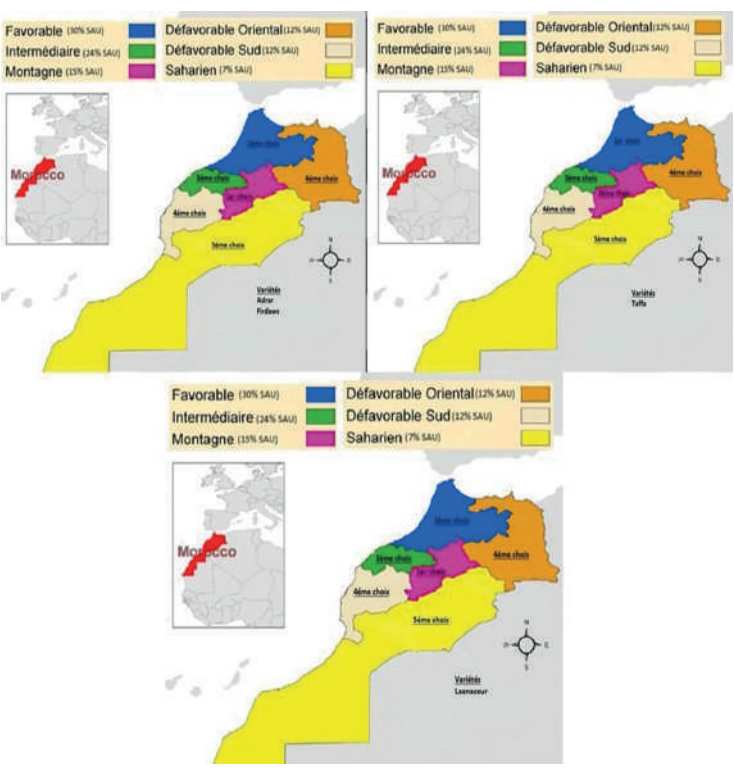

Figure 33. Commercial barley varieties for specific agro-ecological zones

XI. RELEASES AND GERMPLASM

Twenty-four varieties have been released from Moroccan barley breeding program characterized by its large adaptation and its significant production compared to checks with disease resistance (Said *et al*, 2005). Two naked barley varieties have been recently released for the first time in Morocco (Table 36).

Table 36. Barley released varieties at INRA Morocco (Possessor : INRA Morocco)

Variety	Row type	Year of release
MERZAGA	6	1982
RABAT	6	1982
TRIPOLI2	2	1982
BARLIS	6	1982
BRASSERIE	2	1982
ARIG8	6	1982
ASNI	2	1984
TAMELLAT	2	1984
TISSA	2	1984
ACSAD 176	6	1995
ACSAD 60	2	1996
ACSAD 68	6	1996
AGLOU	2	1997
TIDDAS	2	1998
AZILAL	2	1998
LAANACEUR	6	2016
MASSINE	6	2016
TAFFA	6	1984
OUSSAMA	6	1984
AMIRA	6	1985
IGRANE	2	1988
AMALOU	6	1988
ADRAR	2	1989
FIRDAWS	6	1991
INRA 1791	6	1994
INRA 1793	6	1994

X. FUTURE PROSPECTS

The main perspectives related to Moroccan barley are: (i) A multidisciplinary and multi-institutions federative research program on barley needs to be launched. It consists of releasing varieties, conserving genetic resources, applying technical practice at low cost, effectively valorizing barley products for animal feed, human food and industrial use, and socio-economic studies of barely sector; (ii) Establishing a re-launching strategy of barley sector development with an integrated approach; (iii) Barley needs to receive a particular attention in the Green Morocco Plan and by all institutions and stakeholders involved in research, development and valorization (iv) Strengthening the collaboration of the stakeholders with the National service of Agricultural consulting (ONCA) for a large adoption of developed technologies, with ICARDA on the new CGIAR research program in dry areas (CRP DC) and with the others partners along barley sector; (v) Norms for releasing barley varieties need to be targeting the different environments and different end uses; (vi) Encouraging the use of certified or quality seed and valorization of this input; (vii) Formal and informal seed sector of barley need to be reinforced and supported for responding farmers' demands; and (viii) Capitalizing on agricultural oriented maps for targeting actions of technology transfer using participatory approached.

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CHICKPEA GENETIC IMPROVEMENT IN MOROCCO

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SYNOPSIS

The chickpea breeding program at INRA Morocco aims to develop and release varieties that are well adapted to different agro-ecological areas, processing high yield potential, resistant to Ascochyta blight and others diseases and pests prevalent in the target areas. Tolerance to drought and making the new varieties suitable for mechanized harvesting are also other important objectives. Other traits related to seed quality such as large size, cooking time and high nutritional value, are also being introduced in the breeding program. Since 1994, seven winter chickpea varieties were released and registered by the breeding program. Those new high yielding varieties are resistant to blight. However, seed increase and commercialization is still needed to make those varieties available to farmers.

I. INTRODUCTION

Chickpea is the second most important food legume crop in Morocco, after faba bean. It plays an important role in population diet and it is often referred to as 'poor man's meat'. It is an important source of protein, fibre and micronutrients, and plays a vital role in cropping cycles due to their ability to fix atmospheric nitrogen (El-Enany *et al.*, 2013; Mantri *et al.*, 2013).

The chickpea cultivated area during the past two decades is around 67,854 ha and annual production is 37,883t (DPVCTRF, 2013). In 1994, Morocco produced 70,000 tons, however, in 2013 the production has gone down to 25,000 t. This decline of around 65% has been due to climatic and parasitic conditions, no-use of certified seed and low investment in production techniques (improved varieties, weed management, mechanization...).

Most of the chickpea cultivated land is located in the north and west regions of the country which includes the provinces of Taza-Alhoucima-Taounate (27%), Meknes Tafilalet (16%), Fes-Boulemane (12%) and Gharb-Chrarda-Benihssen (24%). Nearly 80% of the total chickpea production comes from these regions.

II. CONSTRAINTS

Major biotic and abiotic stresses are the most serious production constraint for global pulse production and are projected to worsen with anticipated climate change.

In Morocco, Chickpea is affected by biotic stresses like Ascochyta blight, Fusarium wilt and Leaf miner and abiotic stress (drought and extreme temperatures), which ultimately lead to huge economic losses on the national scale. Efforts are yet to be invested toward improving stress tolerance in chickpea.

II.1. ABIOTIC CONSTRAINTS

Drought: in the rainfed areas, particularly in the semi-arid zone, yields of spring chickpea are low due to terminal drought during flowering and pod filling stages. Advancing the sowing date to winter (November/December) increases yield. In global chickpea production, the loss due to drought stress is severe and is estimated as 33%.

Heat: it is a constraint to late sown spring chickpea in areas where the crop is exposed to risk of hot summer winds blown in from the east (chergui). It is a common constraint in most chickpea growing areas both in the favorable and semi-arid zones.

II.2. BIOTIC CONSTRAINTS

Several pests and diseases affect chickpea in Morocco. Ascochyta blight is the most important disease followed by wilt (Fusarium oxysporum). Yield losses due to these diseases range from 10% to complete crop failure.

Leaf miner (*Liriomyza cicerina*) is the most important insect pest on chickpea in Morocco. During storage, bruchids cause significant economic losses.

II.3. WEEDS

Weed infestation in spring chickpea range from low to moderate. But, in winter sown chickpea, they are a major problem and can cause heavy yield losses.

III. IMPROVEMENT OBJECTIVES

The objectives of chickpea breeding are to improve yield potential and stability, drought tolerance/avoidance, disease resistance (Ascochyta blight and Fusarium), plant erectness for mechanical harvesting, and seed quality (size, proteins, cooking time, etc.). The specific objectives of the chickpea breeding program are: (i) Enhancement of yield potential; (ii) Improvement of new spring varieties adapted to different agro-ecological areas; (iii) Development of disease and pest resistance (especially Ascochyta blight, fusarium wilt and leaf miner); (iv) Improvement of plant erectness for mechanical harvesting; and (v) Improvement of grain size and quality (large seed size, cooking time and high nutritional value).

III.1. METHODOLOGY

Since chickpea is predominantly self-pollinated, development of true breeding homozygote genotypes with desirable traits are the main objective methodologies in the breeding program. Like other plant species, the breeding process in chickpea consists of four stages: (i) Creating genetic variation through hybridizations and introduction of cultivars/segregating material from other sources within or outside the country; (ii) Selection in segregating early generations; (iii) Evaluation of selected lines; and (iv) Release of varieties (Toker & Mutlu, 2011). To date, a majority of the varieties released represent selections from ICARDA materials. Several limited hybridization programs are underway to generate diverse materials through pedigree selection and bulk population methods.

A combination of the pedigree and bulk methods is generally used for selection after hybridization in chickpea. The early segregation generations (F2 and F3) are invariably grown in Sick nurseries and surviving plant are harvested in bulk. The selection of single plant starts from F4 or later generation. Progeny evaluation is carried out in F5- F7 generations. High yielding and nearly uniform progenies are bulked for replicated yield tests under multi-annual and multi-location yield trials (preliminary, advanced, and national trials). Yields trails are conducted at different locations represented by INRA's experimental stations representing different agro-environments: Dry areas (Jemâat Shaim and Sidi El Aidi Stations), irrigated area (Khmiss Zmamra and Sidi allal tazi) favourable areas (Merchouch station) and high-altitude areas (Anneucer station). These trials are repeated for two to three years, at the end, the best lines are selected.

Promising lines are conducted in on-farm trials or demonstration trials with one or two improved lines and the local variety or cultivar. The objectives of the trial are to grow the new lines under farmer conditions to assess the yield and to obtain the farmers' views. If the line is superior in yield and acceptable to farmers, it is considered for release.

The biotechnological approaches of resistance breeding have provided several improved varieties of food legumes with tolerance to abiotic stresses. There is no substitute for these approaches, and they will continue to be the mainstay in the future. However, efforts are needed to improve the effectiveness of these approaches by further refining screening methods for resistance to stresses and identifying new sources of resistance genes in both cultivated and wild species. There is a need to use diverse sources of resistance in breeding programs and to develop cultivars with tolerance to multiple stress factors.

IV. MAJOR RESULTS AND ACHIEVEMENTS

Early breeding program, initiated since 1920, put more emphasis on germplasm collection of spring chickpea of large seeded Kabuli types. Breeding work was strengthened in 1943 with germplasm collection of both kabuki and specific Desi Types maintained during winter season for Ascochyta blight evaluation. Were plant breeder at that time, aware of the potential of winter chickpea, there were no evidence for this; nevertheless, winter hardy types were maintained at this collection and two spring chickpeas of Kabuli type, “PCH34” and “PCH 37”, were released from such program. The requirement of larger seed size and competition of Mexican and Spanish types in the commerce, were a serious handicap for any further progress in the breeding program. In 1978, INRA initiated a new breeding program on horizontal resistance of spring chickpea to Ascochyta blight (*Ascochyta rabiei* (Pass.)) with FAO collaboration.

Extensive works on screening and breeding methodologies were developed within the framework of such program. About 26 lines with durable resistance were selected from this program. However, the specific nature of blight pathogenic variability in Morocco, limited the release of such breeding material. It is worth mentioning that such program was afterward extended to cover durable resistance of Faba bean to Orobanche and tomato to Fusarium wilt, but this program was not continued. The renewed interest for chickpea became however very clear through collaboration with ICARDA-ICRISAT program posted at ICARDA since 1979. The introduction of the concept of winter chickpea completely changed the configuration of the breeding program. Winter planting in November of winter hardy genotypes was suggested as an alternative option for increasing yield and stability in semi-arid environments. Resistance to Ascochyta Blight became a prerequisite in such situation because of the major blast of the disease during the winter season. Potential yield of winter chickpea was increased to more than 2.0 t/ha as compared with 0.6 t/ha of spring chickpea. This represents an overall increase of nearly 210% with an earliness of 25 to 45 days (Kamal, 1990). Two varieties ILC 482 and ILC 195 were released in 1987 but their seed size was too small to be accepted by farmers. Further collaboration with ICARDA led to release since 1992 of 7 new winter chickpea cultivars with larger seed size among which are: Rizki, Douyet, Farihane, Zahour, Moubarak, Arifi, Bochra (Table 37).

The average yield potential of these varieties ranges from 1700 to 2300 kg/ha against Moroccan’s average of 589 kg /ha (DPVCTRF, 2013). There is a large gap between farmer’s yield and research experiments. This gap is largely due to a lack of the appropriate package of practices at farmer’s level and the inadequate supply of quality seeds of the new improved varieties. The unavailability of seed of these cultivars has been one of the main handicaps for any use of this genetic material by farmers. The dissemination of newly released cultivars was in most cases through informal channels of farmers to farmers' seed production. Large imports from Canada and Turkey, however, have a significant impact on local chickpea production and will seriously affect the overall impact of INRA's achievements.

V. RELEASES AND GERMPLASM

Research work on chickpea breeding aims development of chickpea varieties for high yield, disease resistance and tolerance against abiotic stresses.

Continuous breeding efforts resulted in the release of 7 improved chickpeas (*Cicer arietinum* L.) varieties with improved yield, seed quality, disease resistance and better adaptation to different production zones within Morocco.

Also, several chickpea breeding lines appear to be promising candidates for future release as improved germplasm or new cultivars based on their performance in advanced yield trials. During 2015 approximately 50-100 single plants were selected for three promising breeding lines noted in Table 37. These lines may be proposed for release as a new cultivar in 2017.

Table 37. Chickpea varieties released in Morocco since 1992

Varieties	Year of registration	Important traits
Rizki	1992	AB resistant
Douyet	1992	AB resistant
Farihane	1994	AB resistant
Zahour	1994	AB resistant
Moubarak	1995	AB resistant
Arifi	2007	AB resistant, large seed size, erect plant
Bochra	2016	AB resistant, large seed size, erect plant, early maturing
Promising advanced lines		Early maturing, high yielding, resistant to AB, extra- large seed size

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VI. FUTUR PROSPECTS

The chickpea research and developments efforts need to focus on the following areas for further increasing and sustaining chickpea production and further increasing income of farmers from chickpea production and value addition: (i) Development of varieties with enhanced resistance/tolerance to stresses and wider ecological adaptation; (ii) Development of varieties with tall and erect growth habit which will be suitable for mechanical harvesting; (iii) Development of extra–large seeded kabuli varieties which attract premium price in the market; (iv) Development of herbicide tolerant varieties for promoting resource conservation (zero or minimum tillage) technologies and reducing cost of cultivation as manual weeding is becoming very expensive; (v) Development of varieties preferred by agro-processing industries; (vi) Development of competitive market products from chickpea; (vii) Integration of molecular markers in chickpea breeding programs for improving efficiency and precision; (viii) Germoplasm of cultivated and wild species need to be evaluated systematically for identification and utilization of sources of resistance to emerging diseases.

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LENTIL GENETIC IMPROVEMENT IN MOROCCO

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SYNOPSIS

Lentil contributes to sustainable farming by biological fixation of nitrogen in soils and enhances nutrition thanks to its proteins and micronutrients- rich grains. It is an important crop of the wheat-based cropping system in Morocco. Unlocking yield potential of this cropping system involves clear review of the achievements, specific constraints analysis and improvement objectives definition that could allow operational design of future prospects. Breeding towards high yielding, biotic and abiotic resistant and adapted varieties that correspond to farmer's needs are at utmost importance to enhance and sustain the crop productivity. For this purpose, this chapter is a review of lentil genetic improvement in Morocco.

I. INTRODUCTION

Lentil (*Lens culinaris* Medik.) is one of the most important food legumes worldwide. It contributes to reduce hunger and malnutrition thanks to its grains consumed as staple food rich in proteins, vitamins and some important micronutrients like iron and zinc (Carbonaro *et al*. 2015; Grusak 2009; Grusak and Coyne 2009) especially with low- income people in developing countries. Furthermore, the crop provides a number of additional agronomic, environmental and socio-economic benefits. As a leguminous crop, lentil is able to enhance soil fertility and thus contributes to farming sustainability by fixing atmospheric nitrogen thanks to the symbiotic association of its roots with *Rhizobium leguminosarum bacterium*.

In Morocco, lentil is currently grown as a rain fed crop in rotation with cereals occupying around 14% of the area yearly cultivated by food legumes in the country. Within the legume group, it ranks third, after faba bean (42%) and chickpea (20%) contributing to the productivity and sustainability of the cereal-based cropping systems (Ministère de l'Agriculture et de la Pêche Maritime 2015).

Despite its importance in Morocco, lentil faces a number of constraints lowering its grain yield and profitability. To overcome these constraints and increase the production, a national breeding program aiming to develop improved cultivars has been deployed by INRA-Morocco few decades before.

II. CONSTRAINTS

Lentil production in Morocco is limited by several biotic and abiotic factors that result on low profitability causing serious decrease in cultivated areas dedicated to this crop.

On a global scale, drought is a major constraint for crop production, especially in arid and semi-arid areas. As lentil is often cultivated in rainfed regions of Morocco, its productivity is frequently limited by irregular rainfall and thus drought. Moreover, traditional farming based on poor adoption of efficient production techniques (sowing date, fertilizers, and improved seeds) limits the potential of this crop and results on low production. Also, weak adaptability of available populations and cultivars used by farmers to the use of machines, thus the extensive needs for costly labor-workers for weeding and harvesting contribute to reduce the profitability of lentil. In addition, locales populations and cultivars being used by farmers have long cycles in which flowering and pod onset occur under end-cycle low soil water availability and high temperature reducing grain yield.

Among biotic constraints affecting lentil in Morocco, several diseases, parasitic plant and insects were reported to be important considering their effect on yield. Rust [caused by *Uromyces viciae fabae* (Pers.) J. Schröt], wilt (caused by *Fusarium oxysporum* Schlecht. emend. Snyder & Hansen f. sp. *Lentis Vasudeva* and Srinivasan) and Ascochyta blight (caused by *Ascochyta fabae* Speg. f. sp. lentis) are the major damaging diseases. The parasitic plant Orobanche is a major threat for lentil as well as for other food legumes such as Faba bean and pea causing heavy damages. Complete crop failure due to Orobanche has been reported under sever infestations. To date, no accessible genetic resistance is available. Treatment based on total herbicide (glyphosate) showed some success but problems of toxicity on lentil plants remain. On the other hand, weak chemical weeds control especially those from dicotyledonous class result in highly infested fields where both lentil biomass and grain yield are low as a result of high competition. Bruchids cause substantial damages on lentil grains limiting seed quality in storage.

III. IMPROVEMENT OBJECTIVES

The overall objective of INRA-Morocco lentil breeding program has been to develop high-yielding cultivars with improved characteristics. High grain yield, rust and Ascochyta blight resistance, early flowering and maturing, drought and cold tolerance as well as ability for machinery harvesting were the main improvement objectives that have been targeted during first decades of the program.

Important results especially regarding high yield, rust and Ascochyta bligh resistance, early flowering and maturing have been achieved (see the section below, Major results and achievements). However, a number of constraints that still limit lentil production need further breeding efforts to identify source of resistance/tolerance. Thus currently, priority is being given to such objectives while keeping breeding for all other important characteristics as: (i) High yield; (ii) Tolerance to abiotic stresses (High temperature, Drought, Cold); (iii) Tolerance to biotic stresses (Orobanche, Rust, Fusarium, Anthracnose, Sitona and bruchids); (iv) Seed quality: Nutritional (more proteins, Iron, Zinc…), less antinutritionnal factors (Tannin…) and reduced cooking time; (v) Quality requested for better valorization of lentil seeds (profession new demand: seed shape, dimension, cotyledon color, ability of flour for making pasta, mixing with wheat and other cereals…); (vi) Ability for mechanical harvesting (Erectgrowth habit, Plant architecture (less biomass, more pods), and Height of the first pod to soil); (vii) Specific adaptation to different agro-climatic zones of Morocco; and (viii) Herbicidetolerance.

Among these objectives, tolerance to drought, high temperature and Orobanche as well as ability to machinery harvesting are of utmost importance in the coming years. Combining these traits in high yielding, extra-early and diseases resistant cultivars with good seed quality will contribute to enhance the potential production and profitability of lentil in Morocco.

IV. METHODOLOGY

Conventional techniques have been used in Moroccan lentil breeding program. The breeding program is based on both modified pedigree and mass selection methods. The first step is germplasm development by collecting and introducing new genetic resources from international institutions (such as ICARDA, and other gene banks and research institutes). These genetic resources are tested under specific nurseries (diseases, adaptation, and biotic and abiotic stresses). Selected lines from these nurseries could be used as parents in crossing blocks or directly introduced under yield trials after development of pure lines. After crossing, selection on segregation materials (F_3-F_7) based on single plant/row selection in superior families is carried out following specific objectives. Advanced lines with fixed characters depending on targeted specific objectives from nurseries and segregating material are tested under multi-annual and multi-location yield trials (preliminary, advanced, and national trials). Ultimately, few promising lines with confirmed improved characteristics compared to a local check are identified and tested with farmers in demonstration trials before being suggested for registration as cultivars.

Three main contrasted agro-environments where lentil is being cultivated in Morocco were characterized: semi-arid areas (Abda-Chaouia region, western and north-central Morocco), favorable areas (Zair-Sais region, north-western Morocco) and high-altitude areas (middle Atlas Mountains, central Morocco) (Sakr 2005). These environments are represented by INRA's experimental stations that were used for screening and advancing genetic material under contrasted agro-climatic conditions: Dry areas (Jemaat Shaim and Sidi El Aidi Stations), favorable areas (Marchouch station) and high-altitude areas (Anneucer station). Prevalent biotic and abiotic stresses affecting lentil in each area were identified over 10 years of observations and survey (Sakr 2005). Thus, drought, heat stress and rust were frequent in semi-arid areas. While drought, rust, anthracnose and Orobanche were frequent in favorable areas. Cold stress and viruses were found to be present in high altitude areas.

In addition to conventional breeding and characterization of genetic resources, it should be pointed out that recently, efforts have been deployed to incorporate the use of DNA markers for tagging economically important traits and for the characterization of landraces in order to initiate marker-assisted selection protocols and enhanced use of genetic resources for breeding goals in the future (Idrissi *et al.* 2015 a, 2015 b, 2016 b).

V. MAJOR RESULTS AND ACHIEVEMENTS

Considerable efforts on INRA Morocco have resulted on a strong national breeding program for lentil with wide international collaboration. Research activities under this program have yielded a number of improved varieties and advanced lines. Several selection criteria have been targeted under the three agro-environments (semi-arid, favorable and high-altitude areas) in the field and under greenhouse to overcome specific constraints.

Rust and ascochyta resistance have been successfully incorporated to the developed cultivars and advanced lines through crossing and selection in prone environments. High yield and early maturity compared to local populations used by farmers were also combined with resistance to these diseases (Sakr *et al.*, 2004 (a, b); Sakr 2005). Drought escape through early maturing cultivars contribute to complete pant cycle (pod and seed filling) before the soil water decrease frequent in Morocco especially in semi-arid areas. On the other hand, preliminary results regarding developed root systems, correlated above ground characteristics and associated genomic regions obtained by Idrissi *et al.* (2015 a, 2016 b) could help to enhance screening for root traits-based drought avoidance in the breeding program in the perspectives of development of adapted cultivars. Preliminary results about host differentiation and variability of *Orobanche crenata* populations showing the specificity for lentil by lentil- grown *O. crenata* was reported by Ennami *et al.*, 2017. This could be used in the future when designing screening studies.

VI. RELEASES AND GERMPLASM

VI.1. REGISTRATION OF CULTIVARS

Continuous evaluation and screening activities under INRA Morocco lentil breeding program have resulted on 9 improved cultivars and several promising advanced lines. These cultivars and their main characteristics are listed in table 38.

Table 38. Lentil cultivars registered in the official catalogue of plant varieties

Cultivars	Year of registration	Important traits
L24	1989	Small seeds, late maturing, yellow cotyledon
L56	1989	Large seeds, late maturing, yellow cotyledon
BAKRIA	1989	Rust resistant, Early maturing, large seeds, yellow cotyledon
BICHETTE[1]	2000	High yield, moderate winter-hardy, resistant to rust, Ascochyta blight and wilt, yellow cotyledon
HAMRIA[2]	2000	High yield, moderate winter-hardy, resistant to rust, Ascochyta blight and wilt, red cotyledon
ZAARIA	2003	High yielding, rust and Ascochyta blight resistant, red cotyledon
ABDA	2004	Early maturing, high yielding, rust resistant and semi erect growth habit, yellow cotyledon
CHAOUIA	2004	Early maturing, high yielding, rust resistant and semi erect growth habit, yellow cotyledon
CHAKKOUF[3]	2009	High yielding, Early maturing, rust and Ascochyta blight resistant, iron and zinc rich seeds, yellow cotyledon
Promising advanced lines	-	Extra early high yielding, resistant to rust and Aschochta blight with various seed characteristics

[1] Sakr et al. 2004 a; [2] Sakr et al. 2004 b; 3 Idrissi et al. 2012.

VI.2. CHARACTERIZATION AND VALORIZATION OF LOCAL POPULATIONS

National Moroccan Gene Bank held in Settat maintains a collection of Moroccan lentil landraces. Fifty-three landraces from this collection together with 20 from other Mediterranean countries were characterized using DNA markers (Simple Sequence Repeat and Amplified Fragment Length Polymorphism). Genetic differentiation according to agro-environmental origins (dry areas versus favorable and high-altitude areas) and preliminary marker-trait associations with drought tolerance were reported (Idrissi *et al.* 2015 a, b, 2016 a, b). Some of these local populations are being used as parents in crossing blocks of the breeding program. This allows oriented selection of genotypes to be included in breeding programs depending on specific objectives. Landraces from dry areas especially those originating from Jemaat Shaim (one of the driest and warmest location in Morocco where lentil has been grown) would result in greater genetic gain for drought and high temperature tolerance, while landraces from highlands (middle Atlas Mountains) would result in greater genetic gain for cold tolerance. Furthermore, genetic evidence for the differentiation of 'lentils of Ain Sbit', a small rural area known ancestrally for lentil cultivation, as a local product quality mark (produit de terroir) were obtained, thus offering efficient tools for enhanced valorization and for the protection of this landrace for the benefits of local farmers.

VII. PERSPECTIVES

Breeding programs are basically medium and long-term research programs that need designing appropriate working plans to solve current problems as well as future challenges. Thus, breeding objectives depend on present and expected constraints and demands. So far, lentil breeding efforts have made resistance/tolerance genetic resources and varieties to a number of biotic stresses available in Morocco. Moreover, these varieties have high yield potential that could help to reduce gaps between demand and production and contribute to ensure national food security. Efforts on extension and seed increase of these varieties for their valorization are urgent in order to make them available for farmers could increase lentil production in Morocco. Furthermore, lentil is mainly grown by smallholder farmers in Morocco. Thus, seeds of improved variety are a key production factor for this category of farmers that use often very little of other factors. Therefore, yield advantage that they could take from improved varieties could significantly increase their incomes. Thus, contributing to rural development.

In the other hand, continuous evolution of constraints in the context of climate change and global warming, recalcitrant abiotic and biotic stress and emergent seed quality and end-use requirements make continuous breeding at utmost importance. The frequency and intensity of drought and heat stresses are expected to increase in the coming years. Thus, drought and heat tolerance are important traits to be considered in the future. Giving the complexity of these traits, multidisciplinary approaches taking in consideration physiology, agronomy and genetics will be adopted. Orobanche is still causing substantial damages limiting lentil production in Morocco. Among registered varieties, none has confirmed resistance. Furthermore, resistance mechanisms are currently under study. Thus, breeding for tolerance/resistance to this parasitic plant is also an important objective that should be targeted with high priority. Another biotic stress causing considerable damages in seed stores that should be investigated is bruchids attacks. Exploring genetic solutions in breeding programs may help, in an environmentally friendly way, to solve this problem. Seed quality (nutritional richness, cooking time, shape and color…) should be also taken in consideration when developing new improved varieties that could correspond to consumers and food industry demand.

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FABA BEAN GENETIC IMPROVEMENT IN MOROCCO

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SYNOPSIS

Faba bean is a major food and feed legume because of its high seeds nutritional value. Used in crop rotation, it plays an important role in improving productivity of cereal crops through the biologically fixed nitrogen and decreased buildup of pests and diseases. In Morocco, faba bean is the most important cultivated food legume crop. With more than 200.000 ha grown area, it represents about 45% of the total food legume cultivated area. The analysis of the current status of faba bean production highlights that drought is by far the most important constraint on the production of faba bean. In addition, Orobanche, cryptogamic diseases, nematodes, viral diseases, and insects are the major biotic constraints limiting the development of this crop in many potential regions in the country. The objective of faba bean improvement program is the development of high yielding varieties of small and large seeded faba bean with high and stable yield potential with respect to climatic changes and tolerant to the main abiotic and biotic constraints. The selection scheme followed by faba bean improvement program is based mainly on the pedigree method. However, this method has a significant limitation due to the effect of consanguinity. Recently, progress has been made for producing synthetics in addition to pure lines.

I. INTRODUCTION

Faba bean is an important food legume crop of Morocco with a multitude of uses. Among the food legumes grown in Morocco, faba bean tops with respect to area and production. However, the country is not self-sufficient in faba bean production and therefore imports for its domestic consumption. This crop is being grown in marginal area by small farmers, mostly using local landraces and under rainfed conditions. The number of improved varieties currently available is very limited and cannot adequately meet the demands of different agro-ecological zones. Production of these landraces and varieties are susceptible to major biotic and abiotic constrains for the production.

The main objective of faba bean improvement program is to develop high yielding varieties of small and large seeded faba bean with high and stable yield potential with respect to climatic changes and tolerant to the main biotic constraints (Orobanche, chocolate spot, Ascochyta, rust). To achieve this objective, the program adopts an approach based on the use of conventional breeding methods such as creating genetic variability, selection within segregating material, Preliminary Screening Nursery, yield testing and finally on-farm verification trials. These methods are applied directly under the edapho-climatic of the target environments, thus effectively taking into account the ecological differences between these environments and their specific varietal requirements.

Three varieties of large seeded faba bean were registered in the official catalog in 1985 and re-registered in 1995 (Lobab (F269), Karabiga (F 213) et Defès (F111)) and Three small seeded varieties were registered in the official catalog in 1986 (Alfia 05 (F305), Alfia 17 (F317) et Alfia 21(F321)). They are moderately susceptible to botrytis and Ascochyta and susceptible to Orobanche and stem nematode.

Several promising faba bean lines were identified (especially 3 small seeded faba bean and 3 larges seeded) These lines are highly productive and are medium resistant to chocolate spot. In 2017-2018, one small seeded and one large seeded faba bean lines are being tested in the second year Official Catalog trials in the purpose for inclusion in the Official Catalog. A total of 117 local populations (*V. faba* L. var. minor, equina and major) were collected from 2012 to 14 from the faba bean growing region of Morocco. They were morphologically characterized through ICARDA/IPGRI descriptors and evaluated for principle agronomical traits. They were also screened for biotic stresses and identified tolerant landraces for chocolate spot. Concerning drought, the tested landraces showed large variability in tolerance to drought. Molecular analysis using microsatellite markers indicated substantial diversity among these local landraces.

The identified useful variability is being deployed in conventional breeding for genetic improvement of faba bean in national breeding program.

As prospects, this improvement program should move more on producing synthetics in addition to pure lines. Two faba bean synthetics are being produced and will be proposed for registration for inclusion in the Official Catalog in 2018-2019 season.

II. CONSTRAINTS

Faba bean is an important food legume crop of Morocco with a multitude of uses. The grain has a special place in the diets of people in Morocco. The green immature seed is also favored as a vegetable. It is grown as rainfed crop in many parts of the country. Faba bean provides much needed dietary proteins in the nutrition and also plays an important role in improving soil fertility (through biological nitrogen fixation) in marginal areas and in cereal based cropping systems. Among the food legumes grown in Morocco, faba bean tops with respect to area (200 thousand ha) and production (109 thousand tons). However, the country is not self-sufficient in faba bean production and therefore imports for its domestic consumption.

This crop is being grown in marginal area by small farmers, mostly using local landraces and under rainfed conditions. The number of improved varieties currently available is very limited and cannot adequately meet the demands of different agro- ecological zones. Production of these landraces and varieties are susceptible to major biotic and abiotic constrains for the production.

II.1. ABIOTIC STRESSES

Drought is by far the most important constraint on the production of faba bean. Other abiotic stresses are winter cold and spring frosts, heat at the end of the growing season, and salinity in some areas.

II.2. BIOTIC STRESSES

Among the biotic factors affecting faba bean, we can mention in order of importance: Orobanche, cryptogamic diseases, nematodes, viral diseases and insects.

The orobanche can be considered as the first threat to faba bean production causing yield losses of up to 100%. As for cryptogamic diseases, it should be noted that the most prevalent is chocolate spot disease (*Botrytis fabae*), anthracnose (*Ascochyta fabae*) and rust (*Uromyces fabae*). Nematodes, in particular the giant stem nematode (*Ditylenchus dipsaci*), also affect the yield of this crop.

Several viruses can attack the bean and cause significant losses of yield especially when the attack occurs at the seedling stage. Among the major viruses are faba bean yellow necrotic virus, Broad Bean Mottle Virus (BBMV), Broad Bean Wilt Virus (BBWV), Necrotic Virus (Broad Bean Stain Virus or BBSV) and the Yellow Mosaic Virus (BYMV).

Several insects are important pests of the bean. These include aphids which affect the bean directly by attacking the top of the plant before covering the entire aerial part or indirectly by serving as vectors in the transmission of viral diseases mainly faba bean yellow necrotic virus. Bruchus rufimanus cause significant losses in storage. Sitona can cause significant damage especially in the nodules. In addition, Lixus is a beetle becoming a danger to faba bean (Lhaloui et El Bouhssini, 2015).

This situation leads to crop loss if pesticides are not applied at appropriate stage and rate. Most farmers don't use these inputs or misused them, resulting in further aggravation of the above stresses and crop losses.

II. IMPROVEMENT OBJECTIVES

The main objective of faba bean improvement program is to develop high yielding varieties of small and large seeded faba bean with high and stable yield potential with respect to climatic changes and tolerant to the main biotic constraints (Orobanche, chocolate spot, Ascochyta, rust).

IV. METHODOLOGY

To achieve this objective, the program adopts an approach based on the use of conventional breeding methods (Collection, Introduction, Hybridization, Bulk, Pedigree). These methods are applied directly under the edapho-climatic of the target environments, thus effectively taking into account the ecological differences between these environments and their specific varietal requirements.

The selection process is schematized below (Figure 34). This program has two components that is large and small seeded faba bean. The Douyet Experimental Station is the site for creating variability and selection. Performance tests are carried out in Douyet, Jemaa Shim and Khemiss Zemamra Experimental Stations.

In this process, the genetic material of faba bean follow these steps:

IV.1 PHASE I: CREATING GENETIC VARIABILITY

The breeder uses genetic recombination as the main tool for the creation of new genotypes in his search for new improved varieties. The crossing is a primary tool of genetic recombination.

On the basis of the pursued goals, a parent male and a parent female are retained according to their characteristics and then crossed.

The crossings are carried out under cages at the Douyet Experimental Station in order to avoid allopollinisation.

IV.2 PHASE II: SELECTION WITHIN SEGREGATING MATERIAL

GENERATIONS F 1-F6:

The seeds from crosses are advanced without selection during up to generation F 3. They are sown in rows at the Douyet Experimental Station under a

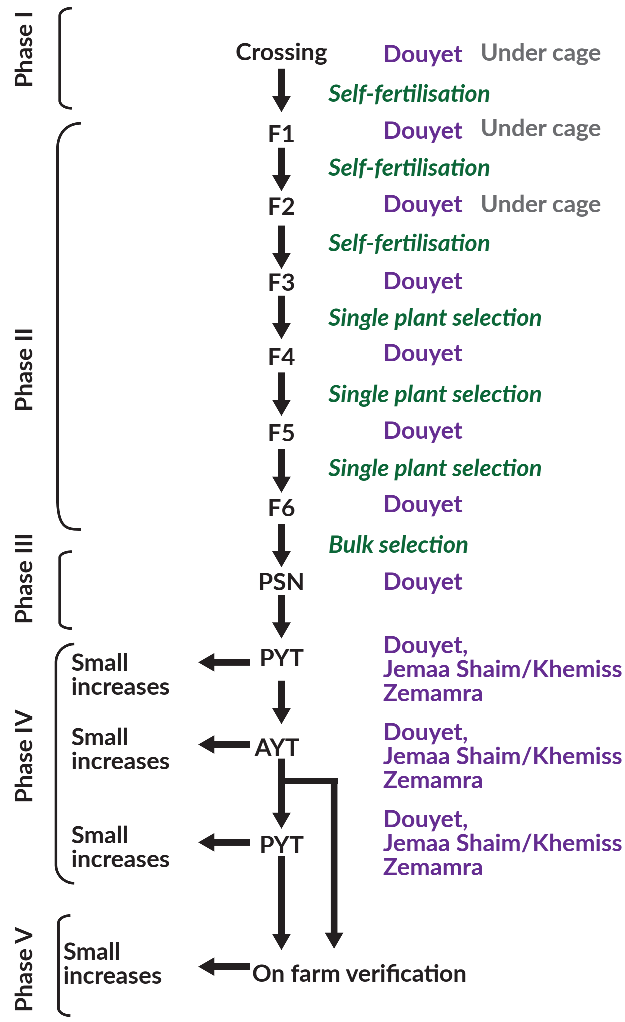

Figure 34. Faba bean improvement methodology

cage under the same conditions as above., then selection is performed within F3, F4 and F5 outside the cage at the the Douyet Experimental Station. The selection is based on the choice of individual plants that appear superior to the targeted characteristics (such as early maturity, resistance to disease). At F6, and since at this stage most of the target traits are almost stable, the F6 plants, sown at the Douyet Experimental station, are selected in bulk. At this level, the selection index must be severe in order to reduce the number of lines selected for the Preliminary Screening Nursery.

PRELIMINARY SCREENING NURSERY:

The F6 lines harvested, each in bulk, are evaluated in observation nurseries for the main agronomic traits and for resistance to major diseases. This preliminary screening step is carried out before yield testing. Each line is planted in two lines. Also, to better understand the performance of tested lines, they are compared to two checks: one large seeded and one small seeded faba bean.

The lines, newly introduced into the breeding program, are tested in an observation nursery. This nursery is conducted in the same manner as the preliminary screening nursery.

IV.3 PHASE III: YIELD TESTING

The yield trials are used to test the yield potential and performance of different lines selected under conditions of target environments. These environments have been selected on the basis of the distribution of bean production, which is concentrated in the central-north zone (Taounate, Taza and Fez) and in the region of Settat, Ben Slimane and El Jadida. According to this, two sites were selected: (i) Douyet Experimental Station for the north-central zone; and (ii) Experimental Stations of Jemaa Shim and Khemiss Zemamra for the region of Settat and El Jadida.

PRELIMINARY YIELD TRIALS:

The lines selected in the preliminary screening nursery are tested for their performance in preliminary yield trials in the Experimental Stations of Douyet and Jemaa Shim or Khemiss Zemamra to test their performance. The preliminary tests are conducted in a complete randomized block design with three repetitions. Lines that exceed the checks are tested in advanced yield trials. These trials are also conducted in a complete randomized block design with three repetitions. The seeds of the best lines tested in these trials come from the small increase plots in isolation. Similarly, the selected lines from advanced yield trials are tested in elite yield trials. The latter are also conducted in a complete randomized block design with three repetitions for at least two years and in several locations.

IV.4 PHASE IV: ON-FARM VERIFICATION TRIALS

The lines selected from elite yield trials are tested in farmers' fields. In parallel, these lines are increased in isolation.

V. MAJORS RESULTS AND ACHIEVEMENTS

Three varieties of large seeded faba bean were registered in the official catalog in 1985 and re-registered in 1995 (Lobab (F269), Karabiga (F 213) et Defès (F111)) and Three small seeded varieties were registered in the official catalog in 1986 (Alfia 05 (F305), Alfia 17 (F317) et Alfia 21(F321)). These different varieties generally have a broad adaptation for different agro-ecological zones of Morocco. Early varieties such as Karabiga or Alfia 21 are more suitable for areas with risk of water stress at the end of the cycle. They are also moderately susceptible to botrytis and Ascochyta and susceptible to Orobanche and stem nematode (Fatemi *et al.*, 2005).

Several promising faba bean lines were identified (especially 3 small-seeded faba bean and 3 large-seeded) (Table 39). These lines are highly productive and are medium resistant to chocolate spot.

Table 39. Promising faba bean lines

Promising faba bean lines		Origin
Large seede faba bean	FH 1031	National Collection
	FH 1032	National Collection
	663-4	INRA selection
Small seeded faba bean	Sel. 88 Lat. 18105	INRA/ICARDA selection
	S 87182-6-m-4	INRA/ICARDA selection
	S 87182-8-m-4	INRA/ICARDA selection

In 2017-2018, one small seeded and one large seeded faba bean lines are being tested in the second year Official Catalog trials in the purpose for inclusion in the Official Catalog.

A total of 117 local populations (*V. faba* L. var. minor, equina and major) were collected from 2012 to 14 from the faba bean growing region of Morocco.

These populations were morphologically characterized through ICARDA/IPGRI descriptors and evaluated for principle agronomical traits. Large genetic variability has been identified in terms of leaflet characteristics (size, shape and number), plant height, pod characteristics (angle at maturity, shape, surface reflectance, distribution on the stem, length and number of seeds per pod). Moderate variability was observed for leaflet size and shape, flower color. No variability was observed for growth habit, branching from higher nodes, wing petal color, pod color at maturity and hilum color. Based on morphological traits, principal component analysis leaded to grouping these landraces into nine gene pools.

These Moroccan landraces were also screened for biotic stresses and identified tolerant landraces for chocolate spot. Concerning drought, the tested landraces showed large variability in tolerance to drought and performed well in both environments.

Molecular analysis using 7 microsatellite markers revealed polymorphism.

However, extent of polymorphism detected as by the individual markers varied. The number of alleles observed at each locus microsatellite loci varied considerably from 4 alleles (VFG 19 and VFG 89) to 7 alleles (GB-SSR VF 115 and VFG 55). The average genetic diversity observed in the microsatellite loci also varied from 0.3550 to 0.6381 (VFG 55) respectively for the GB-SSR and VF 52 loci.

Allelic distribution among three major groups also did not vary, indicating that there is substantial gene flow across the three major groups through cross pollination. Based on the prevalence of specific alleles, we could not able to distinguish the three groups. This observation was further echoed by cluster analysis, in which no relationship was observed between the UPGMA groupings and the 3 major groups. Furthermore, no relationship was also observed between the genetic diversity and geographical origin of the accessions. (Krimi Bencheqroun *et al*. 2012, Fatemi *et al.* 2014 a, b, Fatemi *et al.* 2016).

The identified useful variability is being deployed in conventional breeding for genetic improvement of faba bean in national breeding program.

VI. RELEASES AND GERMPLASM

Three varieties of large seeded faba bean were registered in the official catalog in 1985 and re-registered in 1995 (Lobab (F269), Karabiga (F 213) et Defès (F111)) and Three small seeded varieties were registered in the official catalog in 1986 (Alfia 05 (F305), Alfia 17 (F317) et Alfia 21(F321)).

Several promising faba bean lines were identified (especially 3 small-seeded faba bean and 3 large seeded).

In 2017-2018, one small seeded and one large seeded faba bean lines are being tested in the second year Official Catalog trials in the purpose for inclusion in the Official Catalog.

A total of 117 local populations (V. faba L. var. minor, equina and major) were collected during 2012 to 2014 (Figure 35) from the faba bean growing region of Morocco. These populations were morphologically and genetically characterized and evaluated for principle agronomical traits.

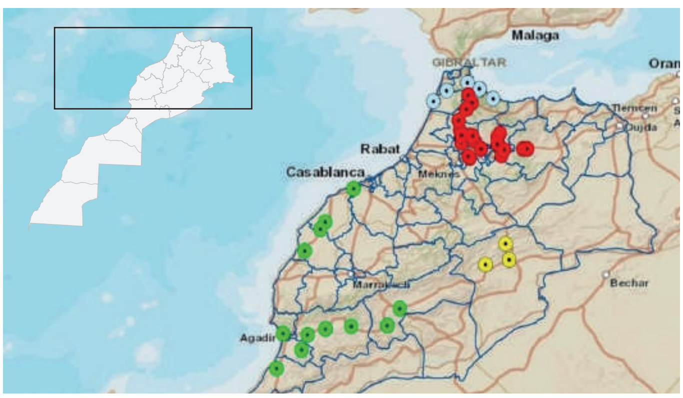

Figure 35. Faba bean collection missions (2012 to 2014)

VII. FUTURE PROSPECTS

The selection scheme applied by the bean improvement program is based mainly on the pedigree method. Moreover, Duc (1997) reported that the pedigree method is the most widely used breeding method for faba bean. But this method has a significant limitation due to the effect of consanguinity (Duc, 1997). Researchers avoid this effect by exploiting the heterogeneity and effect of heterosis by producing synthetic or hybrid varieties (Duc, 1997). Indeed, the superiority of the populations or synthetic varieties compared to pure lines of faba bean has been largely reported (Bond, 1982, Rowland *et al.*, 1982 et 1986; Rowland, 1987; Gallais, 1992; Stelling *et al.*, 1994a et 1994b). Thus, this improvement program should move more on producing synthetics in addition to pure lines. Two faba bean synthetics are being produced and will be proposed for registration for inclusion in the Official Catalog in 2018-2019 season.

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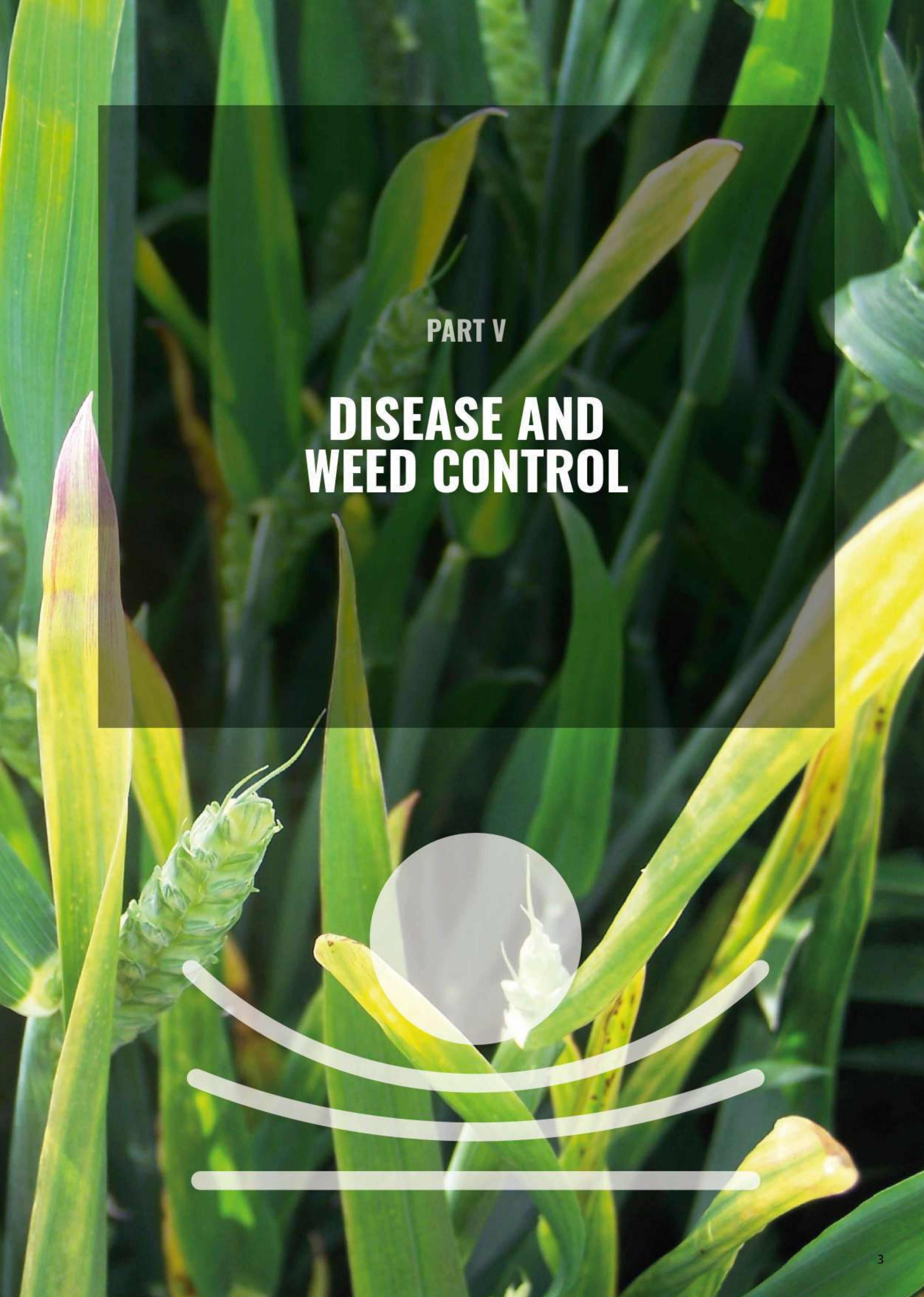

PART V

DISEASE AND WEED CONTROL

BIOTIC CONSTRAINTS OF CEREALS AND PULSES IN ARID AND SEMI-ARID REGIONS OF MOROCCO

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SYNOPSIS

Cereal crops are becoming more in demand due to a significant Moroccan population increase. To sustain production and keep up with national food security, wheat and barley production must be doubled in time. Concern about quality and production is mainly related to biotic stress such as rusts, powdery mildew, Septoria, BYDV and wheat crown rot. Different studies have been achieved, such as disease diagnosis, chemical control, biological control, essential oils, cultural methods and epidemiology, are approached to bring these major biotic constraints under control. These techniques are developed herein for each pathosystem and draw scientist attention to focus on new methods for plant disease diagnosis and new research on epigenetics including host pathogen interaction. Extensive knowledge of pathogen population is a key point in evaluating resistance. This information should be guidelines for breeders to incorporate identified resistance genes into useful background.

I. INTRODUCTION

Rapidly increasing world population, global climate change and agricultural land degradation are major problems and challenges that increase the demand of improving grain production in rainfed regions. Some specific challenges also lie on estimating the size of the yield gap, identify factors limiting average yield production and designing cost-effective and appropriate strategies for these agro-ecological regions. The extent of the yield gap is mostly site specific and varies according to agro-climatic region under study, but it is greater in higher rainfall areas and in developing agriculture where it is difficult to deploy known and available crop management remedies (Sadras *et al*., 2015, Anderson *et al*., 2016).The existence of major yield gaps indicates that there is still hope to increase the average yield of crops in rainfed cropping systems, especially in developing countries where available technologies for growers are scarce.

Fungicide application in a disease management is among various approaches developed to close the gap. Such approaches are tactical and strategic cop management practices and plant breeding. Identification and testing of factors that limit yield grain production can lead to rational techniques that will enhance crop production in specific agro-ecological or field situations and therefore close grain yield gap.

A decision to apply or not a fungicide on cereals is one of the more difficult decisions to be taken by farmers under Moroccan conditions. This difficulty is due to many factors that affect directly the adoption of foliar fungicides. First of all, fungicides should be applied at early stages of disease development; therefore, time of scouting is of a great importance. Fungicide application should take place before any foliar disease takes epidemic proportions.

In addition, this decision has to take into account cereals growth stage at which the disease is diagnosed. If the disease is diagnosed early, weather conditions are forecasted to be favorable and disease development is rapid, two applications are needed to bring the disease under control. In general, these conditions may not give Moroccan farmers some scope to adjust their disease management according to seasonal conditions and available resources.

Applying fungicides very early in advance of an epidemic or too late to take a decision automatically results in a poor disease control. Similarly, when farmers' knowledge and their level of performance are low, the risk of no economic return becomes very high from the use of fungicides. Under Moroccan conditions, some rust diseases give a time laps of only one week to take a decision between a warning and action thresholds. A warning threshold is where the pathogen or injury level is below the "action threshold" that alerts a farmer to prepare for action. The action threshold is the pathogen or injury level at which action must be taken to prevent the pathogen or pest population from exceeding the "damage threshold," which is the lowest pathogen level at which some damage is expected (Nutter *et al*., 1993).

Finally, it must be understood that application of foliar fungicides may only control some foliar diseases, especially those caused by fungi. However, foliar treatments of cereals do not control diseases of bacterial and viral origin and could not have any effect on certain telluric diseases. Herein a summary of the work undertaken on major biotic constraints to cereals and pulses in semis arid region.

II. BROWN RUST (PUCCINIA TRITICINA)

The causal agent of this disease overwinters mainly on cereals residues and on alternate host. The inoculum is windborne, and infection is favored by cool conditions of 15 to 22 °C with a relative humidity of 100%. Usually, disease incidence (Figure 36) is favored by spring rainfall. But under climate change, mild winters and hot springs became frequent and induced favorable conditions for the emergence of the disease at very early cereal growth stage. Estimated grain yield reduction compared to one single application of a fungicide was 16%, while two applications provided evidence that yield losses were of 19% and significantly different from those of one application.

Figure 36. Symptoms of leaf rust (Puccinia triticina) on bread wheat

The early work on this disease was mostly focused on varietal selection and resistant gene identification (Taoufiq, 1986 and 1988).

The estimated yield potential of 2010/11 cropping season was around 3.8 t/ha and 2.9 t/ha at Sidi El Aidi and Jemaat Shaim experimental stations respectively, while for 2012/2013 it was about 3.4 t/ha at Sidi El Aidi. Gain yield prediction can be achieved through a model that relates grain yield to measure of healthy area of flag leaves (Pr = 0.0304, R2 = 65%), and this model validation overestimated grain yield by 0.2 qx/ha which represented a 0.6% average error (El Wazziki *et al*., 2015).Disease management is based on an appropriate application of foliar fungicide at heading stage. This application should be coupled with a resistant variety when it is available (Table 40), because the emergence of new strains of virulence can overcome varietal resistance. In general, a single treatment at this growth stage is sufficient. However, previous approaches were only based on single inputs, practices or genotypes which always resulted in partial solutions. Understanding epidemiology of this disease shows the need to delay infection in order to reduce the rate of disease development, where this cannot be achieved, fungicide applications may be needed (Cook and Yarham 2006).

Recently, one foliar application of an essential oil (*Thymus satureioides*) was found to significantly control brown rust by 15% and consequently increased yield by 55% (Habiballah and El Yousfi 2016).

Table 40. Disease susceptibility and infection types of barley, durum, and bread wheat varieties to brown rust epidemic in 2016 cropping

Durum wheat		
Variety name	Disease severity	Infection type
Karim	2	MR
Carioca	5	S
Tomoh	1	MS
Cocorite	1	R
Isly	5	S
1805 nassera	0.1	RR
1807 Chaoui	2	R
Massa	1	R
Sarif	1	R
Irden	0.1	
1809Marwan	5	
Marzak		
2777		
Ouad zenati		
Amjad		
Rg 0027 Pionner		
Icamor		
Acsade 6		
zeram		
W		

Bread wheat		
Variety name	Disease severity	Infection type
Aguilal	20	
Rihane	0	
Saba		
Khair		
Saada		
Tilila		
M		

Barley		
Variety name	Disease severity	Infection type
Igrane	0.5	MR
1776 Amira	0.5	MR
Tissa	0.5	R
Orge 628	0.5	R
Aglou	15	MS
Amalou	10	MR
Azilal	5	MR
Acsad 176	15	MR
Ac 68	25	MR
Asni	85	S
Rabat 071	15	MS
Massine	75	S
Arig 8	60	S
Annaceur	25	MS
Acsad 60	10	MS
Taffa	80	MS
Tamellalte	1	R
Marzaga	10	MR
Tiddas	1	R
Oussama	60	MS
Nd 112	15	MR
Heart land	70	MS
Oulad said	80	
Ferdaws	80	
Orge nue	5	
L. Ourika		
Tobkale		
Hispanic		
Or Mutation		
Floremon		
Tiche		
V		

III. SEPTORIA BLOTCH (SEPTORIA TRITICI, SEPTORIA NODORUM)

Septoria is caused by two different pathogens, one of which is responsible for the septoria of the leaves known as *Septoria tritici*, which is most abundant on bread wheat. Its symptoms are in the form of elongated spots of varying sizes. These spots are at first chlorotic and become necrotic. In very humid and at early seasons, these lesions are observed on the basal leaves and are detectable from the tillering stage. The inoculum is either in the form of pycnides on infected residues that survive 2-3 years or as mycelium in stubble. Inoculum is dispersed by rain and windborne. Infection is favored by very mild conditions of 15 to 20 °C. Foliage that remains wet for six hours ensures maximum infection conditions within 48 hours.

Recently, this disease is also encountered on durum varieties (Table 41). In 2004 where favorable conditions were met, most of wheat fields are largely affected by septoria: 61% for bread wheat and 57% for durum wheat. In the Gharb region, a maximum incidence of 77% was found on bread wheat, while in Zemour-Zaër durum wheat was the mostly infected (63.6%). The infection is more frequent and severe with *Septoria tritici* on bread wheat and with *Stagono sporanodorum* on durum wheat (Zahri 2008). Depending on the variety used, disease incidence of septoria varies between 0 to 100% on bread wheat and from 0 to 70% on durum wheat (Figure 37).

Table 41. Wheat varieties reaction to septoria disease

Durum wheat variety	Disease severity (%)	Durum wheat variety	Disease severity in %
KARIM	2	KEYREROUNDA 2777	1
CARIOCA	3	ICAMORE	0
TOMOH	0	AMJAD	3
COCORITE	40	YASSMINE	4
ISLY	5	VITRON	20
NASSIRA	5	PIONER	2
BELBACHIR	3	SEBOU	4
OUMRABIA	6	JAOUHAR	2
JORI	10	ANOUAR	10
CHAOUI 1807	50	OUED ZENATI	20
MASSA	0	ACSAD 65	5
SARIF	5	ZERAMIK	0
IRDEN 1804	70	WAHA	3
MARWAN	90	MARJANA	5
OURGH	3	BLE DUR LOCAL	0
TAREQ	2	RIAD	2
MARZAK	4		

Bread Wheat variety	Disease severity (%)	Bread Wheat variety	Disease severity in %
AGUILAL	0	BARAKA	1
ARRIHANE	10	TILLILA	15
ACHTAR	7	MASSIRA	45
MARCHOUCH	90	RAJA	0
ACSAD 59	45	MEHDIA	0
SAIS	0	NASMA	0
SABA	0	WAFIA	0
JOUDA	80	RADIA	0
KHAIR	90	KENZ	0
POTAM	60	SIETE CEROS	0
AMAL	0	SIBARA	0
SALAMA	70	PYNITE	0
SAADA	0	FAIZA	0

Figure 37. Symptoms of septoria disease on bread wheat leaves and spikes

Losses caused by septoria can be as much as 35% (Zahri *et al.*, (a), 2008) with regard to chemical control, the use of fungicidal pesticides registered in Morocco remains the most effective option (Alaoui, 2004). Estimated grain yield losses measured from one single application of a fungicide were 19%, while two applications provided evidence that those losses were of 28% and were significantly different from those of one application. Furthermore, Grain yield can be predicted from measures of severity on flag leaf through a model relating grain yield and average disease severity (Pr=0.0003, R^2=67%), and its validation over estimated grain yield by 2.90 qx/ha and represented a 10% average error (El Wazziki *et al.*, 2015). Control measures rely on use of certified and treated seeds, foliar treatment with an appropriate fungicide, adoption of resistant varieties, use a rotation of at least 2 years (at least one treatment at heading stage, and in case of sever attack, a second treatment just after flowering is needed) are measures for disease control.

Genetic resistance (Table 42) is the most efficient and cost-effective control measure, but breeding is often complicated by the negative correlation between host resistance, plant height, and early maturity. In spite of this, resistant genotypes were Saada, Tegyey, Nasma x 2/I4-2 and Vee's'/Snb (El Bouami and Jlibene, 1996).

Several fungicides provide effective control if used properly, and triazoles such as tebuconazole considerably reduce disease severity permanent action in the plant and to their broad spectrum of activity (Zahri *et al.*, (b) 2008). However, the most satisfactory results were obtained by a combination of triazol and carbendazim because pathogens are targeted at different biochemical sites and stages of development and, and therefore are less likely to develop resistance (Zahri *et al.*, 2008). Furthermore, a combination of triazole (epoxiconazole) with a strobilurin (pyraclostrobin) is highly effective in controlling septoria disease.

IV. STRIPE RUST OR YELLOW RUST (PUCCINIA STRIFORMIS)

This disease can infect wheat, barley, triticale and other grasses. The pustules are in a striated form along leaf blades, giving it its name. The pustules formed of urediospores are yellow or orange-yellow in color and may cover the entire surface of the leaf sheet. Infections are induced by long-distance wind-borne urediospores to reach susceptible leaves, sheaths and spikes, and may even be inside the spikelets. As the season progresses, these urediospores are transformed into teliospores with increasing temperature. It should be noted that a simple favorable temperature during the night would suffice for this disease to take epidemic proportions, even if this temperature becomes unfavorable during the day.

The causal agent is *Puccinia striiformis*, and crop damage depends on host growth stage and severity. Under an outbreak, the disease could cause a complete crop loss especially on very susceptible varieties (Figure 38). Very cold winters and cooler temperatures in late February favor disease epidemic. The pathogen mainly overwinters on cereal debris and can survive more than 2 years. The inoculum is transported by wind, and infection is favored by 100% relative humidity on the leaves for 4 to 6 hours and temperatures of 5 to 12 °C. However, disease progression stops when air temperature exceeds 22 °C.

Table 42. Bread wheat and durum susceptibility to yellow rust

Durum wheat variety	Yellow rust	Bread wheat variety	Yellow rust
Tomoh	R	Aguilal	S
Cocorite	R	Rihane	TS
1805 nassera	R	Achtar	TS
Massa	R	Merchouch	MR
Sarif	R	Acsad 59	MR
1809Marwan	R	Sais	S
Keyperounda2777	R	Saba	S
Ouadzenati	R	Jouda	S
Amjad	R	Potam	R
Yasmine	R	Amale	S
Vitron	R	Salama	R
Rg 0027 Pionner	R	Baraka	MR
Jawhar	MS	Saada	R
Icamor	R	Tilila	R
Acsade 65	R	Massira	S
Zeramik	R	Raja	S
Waha	R	Mahdia	S
Marjana	R	NESMA	S
BD Local Chaouia 2012	MS	Wafia	S
Riad	R	Radia	TS
Kanakisse	R	CieteSeross	TS
		Sibara	TS
		Pynite	TS
		Faiza	R
		Blini	S
		Najia	R

Figure 38. Symptoms on leaves and field foci of yellow rust disease

Disease management first pointed to adoption of resistant varieties. However, emergence of new virulent races can overcome varietal resistance. Foliar treatment with appropriate fungicides is another option (Table 43). Once the disease is diagnosed, treatments should be triggered immediately and within one-week period. When the disease is diagnosed early in the season (late February to early March), two fungicide application are needed, one at the booth stage and the second at the flowering stage.

On the other hand, the more severe the initial disease severity is at the time of a fungicide application, the less effective a disease control is. Therefore, disease must be controlled as soon as the first symptoms are noticed in the field. If the application is more or less late, disease control is generally ineffective for reducing the spread of the disease.

Triazoleas tebuconazolemay reduce yellow rust disease and significantly increase grain yield, and a combination of a morpholine (tridemorph) and triazole (triadimefon) to tebuconazole, would be even more effective. On the other hand, stribulinazoxystrobin would improve the yield by 19%.

Recently obtained results demonstrated that the use of fungicides of two or three active ingredients is not justified for the time being, because treatments against cereal leaf diseases are not very widespread in Morocco. This low use of chemicals on cereals results in a low selection pressure on causal agents of foliar diseases that leads to a low likelihood of resurgence of chemical-resistant isolates.

Alternative control measures provided evidence that one foliar application of an essential oil (Thymus satureioides) significantly controlled yellow rust by 17% and increased yield by 26% (Habiballah and El Yousfi 2016). This performance was found to be similar to one foliar application of the fungicide (Spiroxamine + Tebuconazole + Triadiménol).

V. POWDERY MILDEW (BLUMERIA GRAMINIS)

In Morocco, this disease is a major constraint to barley production and can be severe under drought stress. The disease can also infect wheat. The causal agent is Blumeria graminis with different forma species. Symptoms are of the form of a white to gray powder (whitish fluff). Symptoms begin on the lower leaves, and then spread to stems, upper leaves and ears. Late symptoms are characterized by small black pycnidia (fruiting bodies) which contain spores (ascospores), Figure 39. The disease is favored on barley by a humid and cool climate but not rainy. It can take turn to an epidemic when the growth period between tillering and stem elongation is characterized by a moderate water stress. Whenever the crop receives rain, disease development stops, but disease persists. For barley, yield components that are mostly affected are number of tillers and number of grains per spike. Generally, the effect of this disease goes unnoticed, because it is mostly confined to tillering, and stem elongation but under drought stress, this disease enhanced the effect of dry root rot disease.

Table 43. Mean yellow rust disease severity after one fungicide application and its comparison to a respective untreated check taking into account the initial severity evaluated of the disease at three experimental stations and for the 2014 cropping season.

Fungicidea.i	Jamaat Shaim	Khemis Zemamra	Sidi El Aidi
Tebuconazole	41*	33*	31
Chlorothalonil			
Cyproconazole	30	30*	36
Propiconazole			
Spiroxamine			
Tebuconazole	34*	34*	36
Triadimenol			
Metconazole	32	31*	35
Epoxiconazole			
Pyraclotrobine	26*	36*	39
Epoxiconazole	28	34*	39
Cyproconazole	28*	38*	38
Trifloxystrobine	33	31*	36
Epoxiconazole	31*	28*	33
Kresoxim-methyl			
Azoxysstrobine	29	31*	33
Cyproconazole	35*	31*	43
Epoxiconazole			
Tebuconazole	32	32*	36
Fluquiconazole	31*	41*	39
Propiconazole	26	82*	43*
Azoxystrobine			
Cyproconazole	32*	72*	35*
Propiconazole			
Standard error	1.98	4.8	4.1

*Note: *Significantly different from the check. Check is Wafia at Sidi El Aidi with disease severity (DS) of 41% and Check Salama with DS of 58%; Check Wafia with DS of 50% at Khemis Zemamra and check Salama with DS of 80; Check Ourgh with DS of 31% at Jamaat Shaim.*

Figure 39. Symptoms of Powdery mildew on barley leaf

Infested residues represent a major source of inoculum, on which the pathogen as pycnidia or as mycelium in the stubble, survives from 2 to 3 years. The inoculum is dispersed by rain and wind, and infection is favored by fresh conditions of 15 to 20 °C. Six hours of 100% relative humidity within 48 hours are sufficient for this disease to turn into an epidemic.

Isolates, from cultures of single spore, inoculated to a differential set showed that virulence genes Va1, Vh, Vat, Vra, Va6, Va14, Va10, Vla, Vk, Vp, Va are very common in Morocco. The Va3, Vo5, Va12, Va13, Va9Vk, V1402, Va7 (LG2) genes are of a rather remarkable rare, whereas Va7 and Va7Vk genes are totally absent (Magida, 1994). Pathogen populations are very diverse.

Yield increase through one single application of Triadimefon was greater in susceptible varieties than in resistant ones. When disease onset is early on susceptible varieties, losses were estimated to 40% for Merzaga and 37% for ACSAD176 (Magida, 1994).

Disease management requires a use of certified and treated seeds with appropriate fungicides, treatment with an appropriate foliar fungicide, such as ZENIT 575 EC (Fenpropidine/Propiconazolea nd adoption of resistant varieties (Table 44). At least one treatment at stem elongation is obvious, but in case of a severe attack a second treatment at flowering is justified.

VI. TAN SPOT (PYRENOPHORA TITICI-REPENTIS)

This disease attacks wheat, rye and other grasses, it is mainly found on durum wheat. However, bread wheat variety Arrihane has been identified in the field as susceptible to this disease. But other varieties may very well be added to the list of sensitivity to this disease. The causal agent is Pyrenophora tritici-repenti. Symptoms appear as oval lesions and the central part of which is light brown, often bordered by a yellow halo (Figure 40). At maturity, the fungus invades the stems and results in a formation of pseudothecia, a form of conservation and overwintering organ. A relatively high humidity and temperature are conducive to the development of the disease. This disease develops from lower leaves onwards to

Table 44. Barley reaction to powdery mildew, barley yellow dwarf virus and barley mosaic virus along with growth stage at Sidi El Aidi in 2014 cropping season.

Barley	Powdery Mildew %	BYDV	BMV	Growth stage
Igrane	0	R	R	EH
Amira	25	R	MR	B
Tissa	15	MS	MR	EB
Orge 628	20	R	S	EB
Aglou	10	R	R	EH
Amalou	10	R	MS	MI
Azilal	15	R	MR	Grain at 1/2
Acsad 176	30	S	MS	B
Ac 68	25	MS	MS	B
Asni	25	R	MS	Grain at 1/2
Rabat 071	35	MR	MR	SE
Massine	25	MR	MS	LB
Arig 8	35	R	S	B
Annaceur	10	R	R	B
Acsad 60	0	R	R	EH
Taffa	15	R	MR	SE
Tamellalte	0	R	MS	B
Marzaga	0	R	MR	EH
Tiddas	0	R	MS	B
Oussama	30	MS	MR	B
Nd 112	5	MS	MS	B
Heart land	40	MR	MR	SE
Oulad said	40	R	R	SE
Ferdaws	5	MS	MS	MI
Orgenue	25	MS	S	SE
L. Ourika	30	MS	S	SE
Tobkale	35	S	S	SE
Hispanic	30	R	R	SE
Or Mutation	25	S	S	SE
Floremond Despres	0	R	R	SE
Tichedarte	0	R	MR	B
Vermogales	0	S	S	B

BYDV= Barley yellow dwarf virus; BMV=Barley mosaic virus; B= booth stage, EH= early heading, SE= stem elongation, MI=milk stage, the grain filling, which adversely affects the grain yield. Under severe infections, produced seeds are shriveled and may turn red. In case of mild infection, the disease may go unnoticed due to the reduced number of leaf spots.

Figure 40. Symptoms of Tan spot on durum wheat leaf

The main source of inoculum consists of ascospores that harbor in residues of previous crops. A wet period of 24 hours or longer leads to germination of spores and initiate infection on lower wheat leaves. Disease development depends on the frequent spring rains as the inoculum is dispersed by rain and wind and initial infection is favored by cool, cloudy, and wet weather.

Yield losses range from 12 to 18% under moderate field infection using current moderately susceptible cultivars, and even though tan spot is favored by wet climate it is important in dryland areas as it develops steadily throughout the season (Nasserellah and Mergoum 1994, Nsarellah *et al*., 2000).

Disease management is based on use of certified and treated seeds for reducing initial inoculum. Upon disease onset with conducive climatic conditions a fungicide treatment is necessary. Adoption of resistant varieties when available is another option (Nsarellah *et al*., 2000, Nsarellah *et al*., 2011). In general, a fungicide treatment at heading stage is sufficient, but in event of a severe attack, a second treatment would be scheduled immediately after flowering.

This disease may increase in intensified cropping systems and adoption of stubble retention/reduced tillage. Usually and under Moroccan condition a single application of triazole fungicides, such aspropiconazole and tebuconazole at 62 g ai ha^{-1} applied at flag leaf emergence, can provide economic control.

VII. BARLEY NET BLOTCH DISEASE (PYRENOPHORA TERES F TERES, PYRENOPHORA TERES F MACULATA)

This disease is mainly found on barley, but can infect triticale, corn, especially durum wheat as it can be found in other grasses. The symptoms first appear as brown spots on lower leaves and are distinguished in the early stages of their evolution by a net form or a spot form corresponding to the progression of the mycelium inside the limb. These lesions are generally bordered by a yellow halo according to host susceptibility. Moreover, grains may also be infected by this fungus, but the disease is essentially foliar.

Mediterranean climate is very favorable to the spread of this disease and it is found in semi-arid and humid regions. This prevalence is favored by cool temperatures and relative humidity of 100%. Early infection results in an early senescence of lower leaves which leads to a significant yield loss in quantity and quality. The causal agent of this disease is *Pyrenophora teres* f. teres inducing the reticulate symptoms and *Pyrenophora teres* f. maculata which is responsible for oval spot or spot form). The disease is found on leaves, sheaths and glumes, and infection starts from initial inoculum harbored in stubble or on contaminated seed. The disease starts on the basal leaves and progresses onwards to upper leaves (Figure 41). Yield losses depend on disease severity and host growth stage.

Figure 41. Net blotch disease symptom on barley leaves

The main source of inoculum consists of hyaline conidia which are harbored by crop residues and/or contaminated seeds. The disease requires a temperature close to 20°C and a relative humidity of 100%. The inoculum is dispersed by rain and wind and disease onset starts from tillering stage and persists until maturity depending on the frequency of the rainy period within the growing season.

Estimated yield losses due to net blotch varied between 14 and 29% with resistant varieties out yielding susceptible varieties by 39% when there was no disease control and by 56% under fungicide treatment. However, varietal resistance is essential to the control of barley net blotch (El Yousfi and Ezzahiri 2002). Grain yield losses are mainly related to yield potential of the growing season.

The increasing rate of biomass production of barley, at tillering stage, coupled with the relationship between initial disease severity and area under the disease progress helped to recommend seed treatment and/or verity seedling resistance as an initial means of disease control. It was demonstrated that a single application of foliar fungicide is necessary at boot stage, with a second application needed toward the end of ear emergence when weather conditions favor disease development (El Yousfi and Ezzahiri 2001).

Populations of these two forms of net blotch pathogen were dissimilar in terms of classes of virulence. For *P. teres* f. maculata, avirulent, moderately virulent and highly virulent isolates represented one-third of the population, whereas 90% of *P. teres* f. teres population was composed of avirulent to moderately avirulent isolates (Jebbouj and El Yousfi 2010). Relying only on resistant cultivars as sources of resistance to control net blotch disease would fail to control all pathotypes, however an alternative was proposed as a breeding strategy to control net blotch effectively (Jebbouj and El Yousfi 2010). Very resistant varieties were also very performing in terms of grain yield (Joraifi 2000). However, drought stress may hamper the effect of chemical disease control. Another strategy for controlling this disease can rely on crosses between varieties in Table 45 to come up with varieties having both quantitative and qualitative resistance all along the growth cycle of the host. For example, we can first cross Laanaceur with 1778, then Laanaceur with Massine or Arig 8 or Oussama. Resistant progenies from the first cross can be crossed with the resistant progenies from the three later crosses.

Disease management measures focus on the use of certified and treated seeds to reduce initial inoculum. Furthermore, and when climatic conditions are very conducive to disease development, treat with an appropriate foliar fungicide and ideally coupled with resistant varieties. At least one single application of fungicide at the beginning heading stage is sufficient. The use of a rotation of at least 2 years' period should be of great help in this disease control measures.

VIII. WHEAT AND BARLEY CROWN ROT DISEASE (FUSARIUM CULMORUM)

The causal agent of this disease is mainly Fusarium culmorum, and durum wheat is more susceptible to this disease, followed by bead wheat, triticale, and barley (Lyamani 1988). Disease symptoms are mainly observed on the base of infected stems. First, infected stem base turns brown and end up being pink at the end of crop cycle. These symptoms often extend upward to 2 to 4 lower stem nodes. Some tillers can escape the disease and towards heading, severely infected tillers produce white heads, especially during alternating dry and rainy periods within the cropping season. This alternation of drought and precipitation predisposes cereals to the infection due to water stress. The signs of the fungus can be seen at ground level and on the first nodes, and even inside the tillers. Pinkish fungal growth may occur on lower nodes especially in wet weather. At harvest, shriveled seeds are apparent during severe infections (Figure 42).

Table 45. Quantitative and qualitative resistance of Moroccan varieties to *Pyrenophora teres* f teres relative to host growth stage

Seedling resistance		Adult plant resistance		
Growth stage				
Seedling	Tillering	Stem elongations	Booth	Heading
Taffa	1778	Laanaceur	Laanaceur	Massine
Tissa		Arig 8	Atlas	Arig 8
1776			Acsad 60	Oussama
Arig 8			Rabat 077	
Laanaceur			Orge 628	
Massine				
Oussama				
Rabat 071				

Figure 42. Symptoms of crown rot disease on durum wheat stems showing white stuff that turns pink later in the season

The main source of inoculum is in the form of hyaline conidia or pinkish mycelium, which is found in crop residues or on seeds. The disease, to develop, requires a temperature near 20°C and a relative humidity of 100%. The inoculum is dispersed by rain and wind, and disease on set starts at tillering stage and persists until maturity. The development of the disease depends on the alternation of prolonged dry period with wet phase.

Survey of the 1984 cropping season demonstrated that wheat and mainly barley crops in fields with shallow and sandy to silty soils and under water stress was completely destroyed by a complex of powdery mildew and root rot (Lyamani, 1989). The one of 1987 found that 85% of wheat fields in Abda and Doukkala regions, had severities ranging from 0 to 20%, and *F. pseudograminearum* had been less frequently isolated. In 1988-89, root rot disease was present in most of the fields surveyed and average disease incidence was 24 to 40% in Doukkala and Abda, respectively, while disease severity was mild and around 9% (Lyamani, 1990). The last surveys of 2008 to 2012 showed that dry root rot disease was found to increase in intensity especially in the Gharb region where a very susceptible variety (Amal) was widely adopted in a cereal-food legume rotation. In Doukkala and Chaouia regions, disease increase was mainly due to a large adoption of a cereal-maize rotation.

Disease epidemiology studies showed that Disease evolution had logistic growth patterns in most cases and especially under fertilized conditions. Number of white heads was highly correlated to area under disease progress curves of disease severity. Yield losses were 13-18% based on metam-sodium treatment. Durum wheat was the most susceptible followed by bread wheat, while barley was the least susceptible when compared for disease progression. Yield losses due to F. culmorum to be 99, 78, 76 and 62%, for the varieties Cocorit, Kyperounda, Karim and Marzak, respectively. While for *Bipolaris sorokiniana*, losses were 56, 44, 31, and 7% for Cocorit, Kyperounda, Marzak, and Karim, respectively. Two recent studies revealed that durum wheats; Karim, Carioca, Tomoh, Ourgh, Sebou, Annouar and Jawhar, bread wheats; Jouda, Radia, Khair, Wafia and Bezostaya; and barley varieties; Heart Land, Ferdaws and Tobkale were tolerant to both *F. culmorum* and *B. sorokiniana*.

A lowest disease severity was recorded for rotations wheat/fallow either ploughed or not and wheat/medics. *F. culmorum* was mostly dominant in rotations wheat/vetch+oats, continuous wheat and fertilized continuous wheat subjected to hand weeding.

The behavior of wheat grain yield and its characteristics to root rot field inoculations (*Fusarium culmorum*) under various levels of nitrogen and waters tress were studied for six wheat cultivars at Sidi El Aydi and Tassoute stations in Morocco during 1988-89 and 1989-90. Significant root rot effects coincided with the severe drought of February through April in 1989-90 induced by seed inoculation. Nitrogen had no significant effect on the development of the disease at all environments. In 1989-90 inoculation of wheat cultivars significantly reduced grain yield up to 60% and kernel weights by 34% and increased white heads. However, previous studies estimated yield losses of 12-17% under normal condition (El Yousfi 1984). Durum wheat varieties were more affected by inoculation than common wheat for all studied traits. Four varieties had significant differences in their reaction to root rot inoculums. Cocorit was highly susceptible to *F. culmorum* and slightly susceptible to *H. sativum*, while Kyperounda (2777) was moderately susceptible to both. On the other hand, Marzak and Karim were moderately susceptible to F. culmorum and fairly resistant to *H. sativum* (Lyamani, 1988). In another study, durum wheat varieties; Marzak and Cocorit were found to be the most susceptible, and bread wheat Teguey-32 was the most tolerant (Mergoum *et al*., 1994).

Recently in two cropping seasons (2014-2015 and 2015-2016) and aiming to control this disease through management of soil fertilization including nitrogen, phosphorus, and potassium. Results showed that root rot is much more favored by severe drought and can cause total crop failure, and no fertilization management can overcome root rot negative impact. However, and under wheat crown rot stress, use of nitrogen as DAP + urea in the presence of mild water stress can significantly increase disease severity. But the use of ammonium nitrate (33% N) instead of urea (46%) was found to significantly reduce disease severity. Durum grain quality was highly dependent on nitrogen application, especially when potassium was added at sowing in the soil that is rich in this element (Bahaa-eddine, 2016).

Biological control studies of cereal root rot disease started in 2007, and the disease is controlled with the use *Bacillus subtilis* as seed bacterization. Six biological agents were identified as three isolates of Enterobacter cloacae, one isolate of *Klebsiella oxytoca*, and two isolates of *Rahnella aquatilis*. *Enterobacter cloaca* provided better protection against root rot.

Under conservation agriculture, different rotations affected differently disease severity, and a continuous wheat rotation with 38% disease incidence (DI) had a profound effect on the development of root rot disease. Wheat/fallow rotation decreased disease severity with 16% DI. In 2011 study, a four-year period of CA adoption, disease index was 44% in conventional agriculture, while it was 32% in the conservation agriculture, and *F. culmorum* isolates from conservation agriculture system were more virulent than those of the conventional one.

IX. BARLEY YELLOW DWARF VIRUS (BYDV)

This virus induces one of the most severe cereal diseases. It is caused by a RNA luteovirust hat is transmitted by aphids mostly by *Rhopalosiphum padi*. Disease impact on host growth and yield is more drastic when the plants are under dry conditions. The join effect of drought and the virus increases amino acid contents within the host which are important elements of aphid diet. The virus increases leaf turgor, which facilitate aphid reproduction under dry conditions. Virus multiplication within host cells is mostly controlled by the yd2 barley gene of Ethiopian origin.

Research has included virus strains present and their relative importance, the vectors, the grass hosts, and the survival and maintenance of the virus-vector complex (El Yamani and Hill, 1990). Crop yield losses, germplasm screening for resistance to the virus and use of insecticide to control vectors were also studied. Purification of the virus and preparation of an antiserum to one isolate of the virus were achieved (El Yamani 1989, El Yamani and Bencharki, 1997). Results demonstrated the relative spread and occurrence of virus strains using field surveys and trap plants due to an abundance of the vector-nonspecific (PAV) strain, followed by the *Sitobion avenae* - specific (MAV), and Rhopalosiphum specific (RPV) strains (El Yamani and Hill 1991).The predominance of the PAV strain constitutes a major threat to Moroccan cereal crops since it represents the most virulent strain, and is known to be vectored nonspecifically by many grass aphid species (El Yamani 1989), and virus vectors in the country are up to ten. *Rhopalosiphum padi* appeared to be the most abundant and efficient vector responsible for virus transmission and maintenance. Severity of infection of Moroccan barley yellow dwarf virus PAV isolates was correlated to variability in their coat protein sequences (Bencharki *et al*., 1999).

The periods of maximum disease incidence are during the spring months (Figure 43) especially within late sowing crops. Once the virus is in the phloem of the host, root growth stops, and dwarf symptoms are evident. Virus antigen could be detected by ELISA in Rp-S and Sa-S for up to 11 days of serial transfer. However, it was shown that aphids could retain and transmit BYDV-PAV for at least 3 weeks (Bencharki *et al*., 2000).

Figure 43. Barley yellow dwarf virus symptom on a susceptible accession (spring time).

Artificial inoculation induced losses such as 19 to 38% decrease in head weight, 9 to 25% decrease in thousand kernel weight, 38% to 24 % decrease in biological yield and 61% to 51% decrease in the grain yields of the cultivars Nesma 149 and Saada, respectively. Under natural infection, grain yield losses were only 15% and 26% for Nesma 149 and Saada, respectively.

Assessment of varietal resistance to BYDV showed that bread wheat varieties were more tolerant to BYDV virus, followed by durum wheat varieties. However, most of barley varieties had no appreciable virus resistance. Some tolerance to the virus was found in spring bread wheat ACSAD 59 and Jouda, and in durum wheat Cocorit, ACSAD 65, and Marzak. Two winter bread wheat Caldwell and Elmo had very little color change following inoculation and therefore may be good cultivars for use at high elevations in Morocco or for sources of resistance genes to incorporate in well adapted spring type varieties. Only one barley variety ACSAD 60 was found to be resistant to BYDV. Integration of resistance should be accomplished very easy since resistance in barley is controlled by a major Yd2 gene that can be easily backcrossed into well-adapted local genotypes (El Yamani, 1989). However, BYDV disease is an intricate subject for which results and conclusions are somehow hard to generalize and extrapolate to numerous other geographical or ecological areas.

X. PROSPECTS

Vulnerability has been defined as the capacity to suffer from harm or to react to adversity (Timmerman, 1981). In considering the vulnerability of crops to climatic elements, surface hydrology, soil processes, and systems of exchange between the atmosphere and biota also need to be considered. An approach that will obtain reasonably good yields under adversity and optimum yields if favorable conditions prevail is probably best. A production system using modified cultivars, cropping systems and management practices should confer stability to the productivity of cropping systems across a range of geographic areas and climatic regimes arid and semi-arid regions of Morocco.

Changes in agricultural practices, sometimes with great phytopathological and economic consequences, are triggered by human activities or imposed by changing climate, social, economic. Furthermore, technical changes in cropping system lead to changes in crops and cropping methods, and affect the scale and pattern of plant diseases. Methods have been developed for short-term warnings and for long-term projections about diseases. For the short term, strategic (pre-planting) and tactical (in- season) forecasts should be developed. For long-term approach, three methods should be investigated such as time-series analysis, which relates disease and weather phenomena over a number of years, geo-phytopathology, which analyzes climatic maps and delineates areas where conditions are optimal for a particular disease and extended surveys of large numbers of fields grown under a variety of conditions that should be analyzed to predict future trends (Zadoks, 1989).

A higher quality phenotypic analysis and screening methodologies is a priority, and field-based studies are likely to remain of signal importance in the foreseeable future (Mundt 2014). Opportunities for improving the precision of fungicide application by forecasting when disease epidemics are likely to occur should be looked for (Cook and Yarham 2006).

Furthermore, I propose that genetic improvement should rely on multiple disease resistance in developing resistant variety. For barley any variety should include resistance to powdery mildew, net blotch, brown rust, yellow rust, and scald diseases. For durum wheat, resistance should have resistance to root rot, brown rust, yellow rust, and tan spot diseases. Bread wheat variety has to have resistance to Septoria, yellow rust, brown rust, root rot and tan spot. Chickpea varieties need resistance to ascochyta blight, and wilts diseases, lentil varieties should harbor resistance to wilt and aschochyta blight diseases. Finally, faba bean varieties need resistance to Orobanche, chocolate spot, aschochyta blight, brown rust and powdery mildew.

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DISEASE MANAGEMENT RESEARCH STATUS IN FOOD LEGUMES IN MOROCCO

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SYNOPSIS

Fungal diseases are considered as an important biotic stress that can lead to significant yield losses on food legumes in Morocco. In this review, attempts have been made to summarize the progress made in identifying the situation of major diseases that affect yields of chickpea, lentil and faba bean. Genetic and pathogenic variations among the population of some important pathogens have been reported. Research on resistance host plant and other disease management options have also been discussed. It appears that the adoption of appropriate integrated disease management and other pests' management can help farmers to improve production efficiency and to achieve maximum economic return.

I. INTRODUCTION

The production of grain legumes in Morocco is limited by a number of biotic constrains. Fungal diseases are among the main biotic constrains that reduce yields and can cause severe crop losses. The importance of fungal diseases and their effect on yield vary among years and depend on environmental conditions. However, some diseases are persistent problems in wide geographic areas in Morocco such as Ascochyta blight and Fusarium wilt on chickpea and chocolate spot on faba bean. The crop can be completely devastated by these diseases in epidemic years. Severe Ascochyta blight epidermis had been registered on chickpea during 1971, 1991 and 1997 and yield losses reached 97% in some regions (Ameziane, 1976; Kamel, 1984; Lamnouni, 1994 and Akem *et al*., 1999).

Adoption of integrated disease management practices is essential for economical and effective control of food legume diseases and to mitigate yield losses. It involves several approaches that help reduce pathogen populations to a level where higher yields can be obtained and enables the farmer to achieve maximum economic return. This review intends to summarize the progress made in major food legumes disease studies and in developing integrated disease management strategies in Morocco.

II. MAJOR DISEASE CONSTRAINTS OF FOOD LEGUMES IN MOROCCO

II.1. DISEASE STATUS AND THEIR YIELDS IMPACT

Surveys were carried out for several years in different bioclimatic regions in Morocco to identify the major biotic stress that affect grain legumes crop production.

On chickpea, different studies had revealed the presence of many pathogens that can infect the crop in Morocco such as *Ascochyta rabiei*, *Fusarium oxysporum*, *Rhizoctonia solani*, *R. bataticola*, *F. roseum*, *F. solani*, *Verticillium albo-atrum*, *Macrophomina phaseolina* and *Pythium sp*. (Anonym, 1976; Tahtah, 1976; Ghenbib, 1979; Hidan, 1985; Mabsoute, 1988; El Hadi, 1997 ; Mabsoute *et al*., 1996; Akem *et al*., 1999; Lamnouni, 2004; Krimi Bencheqroun *et al*., 2014). Among these pathogens *A. rabiei* and *F. oxysporum* were the most widespread and caused severe losses (Figure 44). Yield losses due to these pathogens were ranged from 10 to 100% (Ameziane, 1976; Kamel, 1984; Akem *et al*., 1999; Amine *et al*., 1996). Ascochyta blight is a devastating disease mainly on susceptible varieties and yield losses were estimated to be up to 100% when conditions are humid. Therefore host- plant resistance is essential. Whereas Fusarium wilt can cause hard losses mainly on spring sown chickpea or when there's a dry condition (Akem *et al*., 1999).

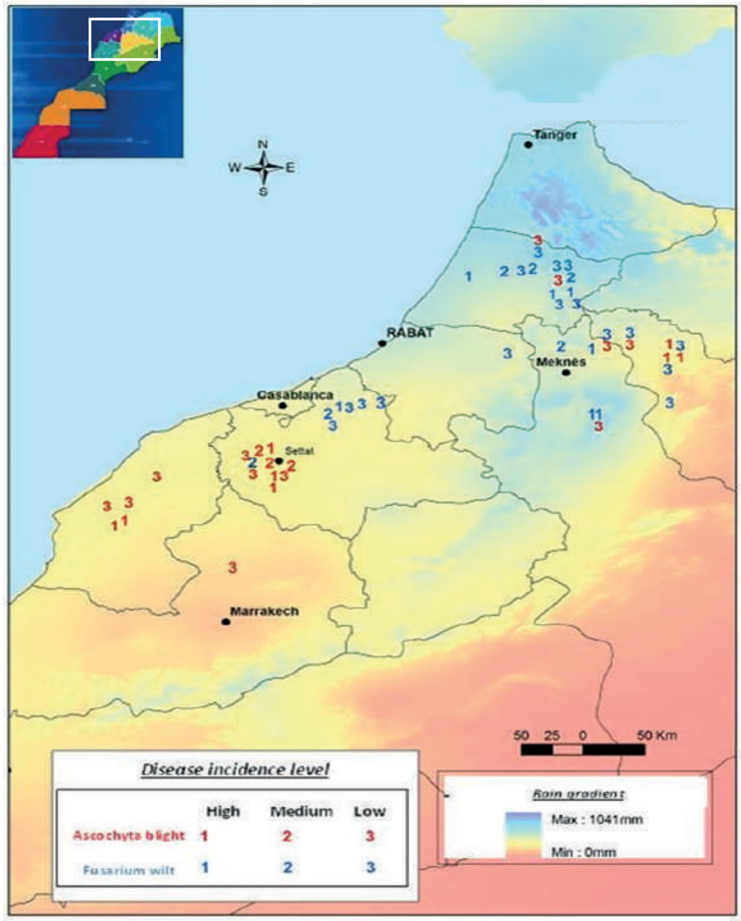

Figure 44. Distribution map of incidence of major chickpea diseases in some regions of Morocco (Krimi Bencheqroun *et al*., 2014)

On lentil, several pathogens had been identified to cause foliar diseases (*Uromyces vicia-fabae*, *Ascochyta fabae* f.sp. lentis, *Botryts cinerea* and *Alternaria sp*.) and root rot diseases (*F. solani*, *F. oxysporum* f.sp. lentis, *S. sclerotiorum*, and *R. solani*) in different works (Rieuf, 1960; Mabsoute, 1988; Mabsoute *et al*., 1996). However, rust caused by *U. vicia-fabae* was found to be the most important disease on lentil and can cause yield losses arranged from 20 to 32% in some years (Sakr, 1990).

On faba bean crops, Chocolate spot (*Botrytis sp*.), Rust (*Uromyces fabae*), Ascochyta blight (*Ascochyta fabae*), Downy mildew (*Peronospora viciae*), *Alternaria sp*. and Root rots were common diseases in different regions (Janati et Schluter, 1976; Mabsoute, 1988; Sakr and Lamnouni, 1996, Krimi Bencheqroun *et al*. 2014). Other pathogens were also identified by some authors such as *Erysiphe polygoni*, *Stemphyllium sp*. and *Cercospora zonata* but without a high importance (Janati et Schluter, 1976; Anonyme, 1976; Mabsoute, 1988). Chocolate spot was the most widespread disease in all prospected regions and Rust was particularly destructive in some humid regions like Gharb area (Mabsoute, 1988; Krimi Bencheqroun *et al*., 2014).

II.2. DIVERSITY OF SOME MAJOR PATHOGENS IN MOROCCO

The study of pathogen variability is an important step to understand the population structure of disease agents and their potential of adaptation that allow the pathogen to evolve increased virulence on resistant cultivars and to develop resistance to fungicides. It's a tool to elaborate suitable strategies of integrated disease management and to develop durable host resistant plant.

II.2.1. ASCOCHYTA RABIEI ON CHICKPEA

A. rabiei shows a high degree of pathogenic and genetic variability, and Ascochyta blight resistant chickpea cultivars have become susceptible in some countries (Peever *et al*., 2004; Vail and Banniza, 2009). It's assumed that the sexual recombination of *Didymella rabiei* ascospores could increase genotypic diversity in *A. rabiei* populations and evolve increased virulence that can overcome resistant cultivar (Barve *et al*., 2003). A study of the pathogenic variability of Moroccan population of *A. rabiei* was started by Lamnouni (1998) and had revealed a high diversity and a presence of physiological specialization in the system *A. rabiei* x *Cicer arietinum* L. A new study of pathogenic variability of *A. rabiei* populations collected from different chickpea growing regions in Morocco had allowed classifying isolates into three pathotype groups according to their level of virulence against a set of differential genotypes. Pathotypes PI and PII were the most prevalent; however, the most aggressive pathotype PIII was present in the majority of surveyed regions (Krimi Bencheqroun *et al*., 2016a). Genetic analysis with SSR fingerprinting of these isolates distinguished high variability within and among identified pathotype groups of *A. rabiei*, indicating low correlation between their virulence and the genetic pattern (Krimi Bencheqroun *et al*., 2016b).

The genetic diversity and population structure of *Ascochyta rabiei* in Morocco in comparison with other isolates from Syria were also investigated. A high level of genetic diversity among Moroccan *A. rabiei* isolates with the majority attributed to diversity within subpopulations. Small genetic differentiation and a significant gene flow were detected among pathogen populations originated from Morocco and Syria suggesting limited geographic delimitation and a high pathogen migration probably due to seed exchange (Krimi Bencheqroun *et al*., 2015a).

The identity and the distribution of mating types of *A. rabiei* were determined using a MAT-specific PCR assay to assess the risk of sexual reproduction of *A. rabiei*. This study revealed the presence of both mating types (MAT1-1 and MAT1-2) of *A. rabiei* under Moroccan conditions (Figure 45). The distribution of these groups showed that random mating could occur under natural conditions in some regions in Morocco and can contribute to enhance virulence

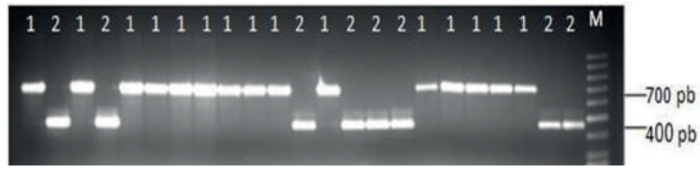

Figure 45. Multiplex PCR amplification of mating types of some Moroccan isolates. The fragment "1" represent MAT1-1 with 700bp and the fragment "2" represent MAT1-2 with 400bp. The lane M is DNA size marker (Krimi Bencheqroun *et al*., 2015b).

of pathotypes. Therefore, there is an eventual occurrence of sexual reproduction of the pathogen and the primary inoculum might come from ascospores that can cause high disease epidemics. Also, with sexual reproduction, the pathogen might have a high ability to evolve both against resistance genes and against fungicides (Krimi Bencheqroun *et al*., 2015b).

II.2.2. FUSARIUM OXYSPORUM F.SP. CICERI

A study of pathogenic variability among isolates of *F. oxysporum* f.sp. ciceri (Foc) from different chickpea growing area of Morocco was investigated using a standard differential set. Results revealed that Race 1 of Foc was the predominant in five surveyed areas (El-Hadi *et al*., 1994). Another study has revealed the presence of Race 0 of *F. oxysporum in* Morocco using 10 differential lines (El Aoufir, 2001).

III. DISEASE MANAGEMENT OF FOOD LEGUMES

III.1. HOST PLANT RESISTANCE TO MAJOR DISEASES

The main emphasis in research to control food legume diseases is on host resistance. Selecting and planting resistant cultivars is the most economical and one of the most important means in managing many diseases.

A special attention in the INRA plant pathology program was given to the identification of durable and stable sources of resistance to Ascochyta blight for the use in the breeding program and in integrated disease management. Therefore, a regular screening was initiated in national program in Morocco since 1975 with the FAO support (Pieters and Tahiri, 1986). More than 1160 national and international chickpea lines have been screened for Ascochyta blight, in controlled infestation conditions in field and greenhouse (Beniwall and Lamnouni, 1994; Chettou and Sakr, 1999; Lamnouni, 2004; Krimi Bencheqroun, 2013). No high level of resistance with consistent reaction to Ascochyta blight had been found. However, 38 stable sources of resistance have been identified through a multi-location and multiyear evaluation of chickpea lines, and these lines have been exploited in the breeding program of INRA (Beniwall and Lamnouni, 1994; Krimi Bencheqroun, 2013). Some of breeding materials were screened against virulent isolates of *A. rabiei* belonging to the most aggressive pathotype (PIII) in the greenhouse and so far, low levels of resistance have been observed (Krimi Bencheqroun *et al*., 2016b). Developing chickpea varieties with high levels of resistance to Ascochyta blight is a challenging proposition because of a highly variable pathogen population (Sharma and Ghosh, 2016).

Furthermore, several lines have been screened against Fusarium wilt of chickpea in Merchouch and Sidi El Aidi sick plots. Around 126 genotypes were resistant in severe disease infection during several consecutive years (El Hadi, 2003; El Hadi, 2004). These genotypes had been introduced in the breeding program and tested for other traits (El Hadi, 2004).

III.2. INTEGRATED DISEASE MANAGEMENT TO BRIDGE YIELD GAP

Successful disease management requires the integration of several different strategies. It consists in combining host plant resistant with cultural practices and if necessary rational use of fungicides.

On chickpea, several studies worldwide showed that a typical integrated disease management recommendation against Ascochyta blight includes use of pathogen-free seeds, seed treatment with fungicides, crop rotation, deep plowing of chickpea fields to bury infested debris, use of disease resistant cultivars and the strategic application of fungicides (Pande *et al*., 2005; Chen *et al*., 2004). In Morocco no fungicide had yet been registered against chickpea diseases. However, some researches have shown that the treatment of seeds with fungicides (Mancozeb, captane, carboxine, carbendazim, maneb) and the use of crop rotation, tolerant chickpea cultivars and the foliar fungicide (dithiocarbanate) can be effective against Ascochyta blight (Benali, 1994; Hidan, 1985).

The use of two or three applications of Chlorothalonil on moderately resistant cultivars had significantly reduced incidence and severity of Ascochyta blight and enhanced grain yield (Chettou, 2003). In another experiment, the use of different systemic fungicides (Azoxystrobine, Flutriafol + Carbendazime and Chlorothalonil + Carbendazime) as foliar treatment had effectively controlled the disease on moderately resistant cultivar better than a contact fungicide (Mancozeb). They contribute in enhancing grain yield by 43-47% (Table 46). Whereas on a susceptible cultivar, no fungicide can control the disease during epidemic conditions (Krimi Bencheqroun, 2016).

On faba bean, the integrated disease management strategy for controlling foliar diseases includes the use of disease-free seed, the practice of 3-4-year crop rotation, select the tolerant variety to the main disease risk in particular region and rational use of

Table 46. Effects of chemical control on grain yield of two chickpea cultivars during 2015-16 cropping season (krimi Bencheqroun, 2016)

Foliar treatment	Garbanzo (S) (ql/ha)	Rizki (MR) (ql/ha)
T0 (Control)	0	18.72
T1 (Mancozeb 80%)	0.08	15.12
T2 (Flutriafol + Carbendazime (117,5 + 250) g/l)	0.06	26.48 (+43%)
T3(Chlorothalonil + Carbendazime (500+100) g/l)	0.32	26.44 (+43%)
T4 (Azoxystrobine (250 g/l))	0.07	27.24 (+47%)
LSD (0.05)	4.55	

LSD = Least significant Difference at p=0,05; S: Susceptible cultivar, MR: Moderately resistant cultivar

foliar fungicides. The decision and timing of fungicide application is based on the disease level observed, the time since the previous application, and the likelihood of rainfall and other conditions conducive to infection and spread of diseases. Rust had been effectively controlled using resistant cultivars and 2 or 3 applications of Mancozeb at the beginning of infection (Meskine *et al*., 2007). Chocolate spot can be managed using Mancozeb or vinchlozoline in combination with tolerant cultivars. The optimal time of application must be at the beginning of visible symptoms and during high humidity pressure (Mabsoute and Saadaoui, 1991, Meskine *et al*., 2007).

The integrated disease management can be extended to an integrated pest management (IPM) by combing other pests like insects and weeds to enable the farmer to achieve maximum economic return. The dissemination and adoption of improved technologies by farmers through participatory knowledge had been investigated in several collaborative projects in different regions in Morocco. With the framework of the EU-IFAD project, several IPM-platforms were established in rainfed area in Zemmour–Zear region to promote technologies for wheat-legume rotation systems. Results showed that the application of IPM technologies has considerably increased the control of different pests and the yield compared to the farmer conventional package. In chickpea and faba bean IPM- platforms, the yield has been increased by 120% and 325% respectively, compared to regional average farmer yield. Therefore, the adoption of improved IPM technological package had increased the farmer's net benefits by more than 200% (EU-IFAD, 2015).

IV. CONCLUSION AND FUTURE PROSPECT

Host plant resistance is a highly effective management option in food legumes, but cultivated germplasm has only moderate resistance levels to some key diseases. Therefore, increasing resistance levels is required to minimize disease losses. Development of cultivars with enhanced resistance will strengthen the control of food legumes diseases.

Future integrated disease strategies have to account effect of climate change on pathogen dynamics that is contributing to emergence of new pathogen pathotypes/races, requiring the appropriate refinement for disease control, especially in host plant resistance breeding and in fungicide resistance.

The development of alternative strategies to fungicides like natural plant products, biofungicides, botanicals and agronomic practices is also required to be involved in integrated disease management of food legumes. Therefore, persistent need exists for refinement, validation, transfer and adoption of integrated disease management modules.

There's also a need on using information technology for disease modeling, developing decision support systems, and utilization of remote sensing to refine up-scale and disseminate integrated disease management technologies.

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WEED MANAGEMENT IN SMALL GRAIN CEREALS IN MOROCCO, A REVIEW

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SYNOPSIS

This is a review of 375 references published until January 2018 about weed identification, weed seeds, weed competition, weed allelopathy, and weed management in small grain cereals (bread wheat, durum wheat, barley, and triticale) in Morocco. A total of 374 weed species have been identified in cereal fields. Major annual grass weeds were sterile oat (Avena sterilis), rigid ryegrass (Lolium rigidum), canarygrass (Phalaris brachystachys, P. minor, P. paradoxa), and rigid brome (Bromus rigidus). Among annual broadleaf weeds, there were common poppy (Papaver rhoeas), crown daisy (Chrysanthemum coronarium), spiny emex (Emex spinosa), milk thistle (Silybum marianum), and mallow (Malva parviflora). Competition from weeds reduced grain yield of small grain cereals up to 80%. Pre-plant, preemergence, and postemergence herbicides were effective on major weeds. In arid conditions, weeds were often manually removed and collected to feed livestock. Collected weeds had a good forage quality particularly before flowering. Since 2000, the efficacy of herbicides has declined and there was development of cross resistance of rigid ryegrass (Lolium rigidum), common poppy (Papaver rhoeas), and crown daisy (Chrysanthemum coronarium). Integrated weed management combining cultural, mechanical, manual, and herbicides was effective for sustainable cereal production. Some suggestions and recommendations that sustain weed management and aimed at increasing crop productivity and minimizing weed effects are discussed.

I. INTRODUCTION

Farmers often cite weeds as the most significant cereal production problem they encounter (Nassif and Tanji, 2001), and total crop losses from weeds can occur with uncontrolled heavy weed infestation (Zimdahl and El Brahli, 1992). Rigid brome (*Bromus rigidus*), rigid ryegrass (*Lolium rigidum*), sterile oat (Avena sterilis), spiny emex (*Emex spinosa*), crown daisy (*Chrysanthemum coronarium*), common poppy (*Papaver rhoeas*), and others were among the most abundant of the 347 weed species recorded in small grain cereals (Taleb *et al*., 1998; 2000). Perennial weeds such as silverleaf nightshade (*Solanum elaeagnifolium*) and others were also abundant in cereal fields (Tahri *et al*., 2005).

Weeds have many attributes undesirable to cereal producers, not the least being the ability to reduce crop yields through competition for resources such as sunlight, water, nutrients, and space. They also may harbor insects and provide a host for certain viruses and plant pathogens. Some weed species, such as rigid brome (*Bromus rigidus*), can reduce the quality of the harvested crop (Hamal, 1993). Weeds also make the harvesting operation difficult (Boutahar, 2000a; 2000b), and weed seeds can diminish the quality of cereal grain (Tanji and Nasssif, 1997; 1999).

For realizing full genetic yield potential of the crop, the proper weed control is one of the essential ingredients (Shroyer *et al*., 1990). Eliminating or reducing the deleterious effects of weeds on cereal crops is the ultimate goal of integrated weed management. Therefore, for sustaining food grain production to feed ever-increasing population and ensuring food security, effective weed management is very essential.

II. WEED FLORA

Since 1941, botanists and weed scientists have been interested in the weed flora of Morocco (Courtine, 1941; Sauvage and Veilex, 1970). Several researchers have surveyed theweed flora of various cereals and regions. They have documented the numerical a b u n d a n c e and geographical distribution of weed species associated with cereals. Major cereal producing regions that were covered until 2017 by weed surveys were Abda, Chaouia, Doukkala, Gharb, Haouz, Loukkos, Moulouya, Rabat, Sais, Sous-Massa, and Tadla. Regions that were not covered included the irrigated perimeters of Tafilalet and Ouarzazate, all mountains (Rif, Middle Atlas, High Atlas, and Low Atlas) as well as Tangier-Tetouan-Al Hoceima, Khouribga-Oued Zem, Khénifra, and Essaouira.

Other studies covered larger geographical areas (Tanji, 1982; El Antri, 1983a; 1983b; Taleb, 1983; Hoesle, 1984b; Link and Mouch, 1984 ; Taleb, 1996; Tanji *et al*., 1988; Tahri, 1997; Tanji 1997a; Tanji and Taleb, 1997; Taleb *et al*., 1998; Taleb *et al*., 2000; Farsaoui, 2001; Taleb *et al*., 2001; Khaya, 2003; Tahri *et al*., 2005; Taleb and Bouhache, 2005a, 2005b; Tanji, 2005; Taleb, 2007, 2008 and 2009; Zidane *et al*., 2010). There were also syntheses or weed surveys that covered cereal fields in the whole country (Courtine, 1941; Sauvage and Veilex, 1970; El Antri, 1981; Boulet *et al*., 1989; Taleb *et al*., 1989; Tanji, 2005; Tanji, 2015).

In their synthesis, Taleb *et al*., (1998; 2000) listed 374 weed species infesting small grain cereals In Morocco. Weeds were from 48 botanical families, but 6 families (*Asteraceae*, *Fabaceae*, *Poaceae*, *Apiaceae*, *Brassicaceae*, and *Caryophyllaceae*) accounted for 58% of the species. The biological aspect showed the prevalence of the annuals with 77%. However, Tahri (1997) reported that 230 perennial weeds from 53 families were found in various crops, but major ones that could be found in small grain cereals were *Arisarum vulgare*, *Cardaria draba*, *Convolvulus althaeoides*, *Convolvulus arvensis*, *Cynodon dactylon*, *Gladiolus italicus*, *Silene vulgaris*, *Solanum elaeagnifolium*, *Sorghum halepense*, and *Ziziphus lotus*.

According to Tanji (2005), research should focus on 200 major weed species. Annual grass weeds include *Avena srilis*, *Bromus rigidus*, *Hordeum murinum*, *Lolium multiflorum*, *Lolium rigidum*, *Phalaris brachystachys*, *Phalaris minor*, and *Phalaris poaradoxa*. Major annual broadleaf weeds include *Ammi majus*, *Ammi visnaga*, *Anacyclus radiatus*, *Astragalus boeticus*, *Bifora testiculata*, *Calendula arvensis*, *Calendula stellata*, *Centaurea diluta*, *Chrysanthemum coronarium*, *Chrysanthemum segetum*, *Chrysanthemum viscidehirtum*, *Cichorium intybus*, *Diplotaxis assurgens*, *Diplotaxis catholica*, *Diplotaxis tenuisiliqua*, *Emex spinosa*, *Galium tricornutum*, *Geropogon hybridus*, *Glaucium corniculatum*, *Malva parviflora*, *Melilotus sulcata*, *Notobasis syriaca*, *Papaver rhoeas*, *Picris echioides*, *Raphanus raphanistrum*, *Reseda alba*, *Reseda lutea*, *Rhagadiolus stellatus*, *Ridolfia segetum*, *Scolymus hispanicus*, *Scolymus maculatus*, *Silybum marianum*, *Sinapis alba*, *Sinapis arvensis*, *Sonchus oleraceus*, *Thesium humile*, *Vaccaria hispanica*, *Verbesina encelioides*, *Vicia sativa*, etc. Major perennial weeds include *Asphodelus ramosus*, *Bunium fontanesii*, *Cardaria draba*, *Convolvulus althaeoides*, *Convolvulus arvensis*, *Cynodon dactylon*, *Cyperus rotundus*, *Gladiolus italicus*, *Muscari comosum*, *Narcissus tazetta*, *Ornithogalum narbonense*, *Oxalis pes-caprae*, *Silene vulgaris*, *Solanum elaeagnifolium*, *Sorghum halepense*, *Ziziphus lotus*, etc.

Small weeds infesting cereals are not usually harmful, but would be part of the floristic biodiversity: *Alyssum parviflorum*, *Anagallis arvensis*, *Arisarum vulgare*, *Biarum bovei*, *Capsella bursa-pastoris*, *Filago spathulata*, *Herniaria cinerea*, *Lobularia libyca*, *Medicago polymorpha*, *Notoceras bicorne*, *Poa annua*, *Polycarpon tetraphyllum*, *Spergula arvensis*, *Spergularia purpurea*, *Veronica polita*, etc.

Up to 2018, weed surveys covered 11 cereal producing regions. Brief and relevant results are presented below according to the explored region.

II.1. ABDA

In 102 barley and wheat fields, Wahbi (1985) found a total of 270 weed species in the Abda region. Eleven percent (11%) were monocotyledonous species. The 10 most common weeds were *Anagallis arvensis*, *Convolvulus althaeoides*, *Convolvulus arvensis*, *Melilotus sulcatus*, *Papaver rhoeas*, *Plantago afra*, *Retama monosperma*, *Scorpiurus sulcatus*, *Silene vulgaris*, and *Thesium humile*. All these weeds were identified by Bouchti (1985). However, El Hamri (1988) revealed that *Thesium humile*, an obligate root hemiparasitic angiosperm, can live in an autotrophic-like way during several weeks before attachment to the cultivated barley. Densities exceeding 300 plants/m^2 were monitored in barley fields. This weed thrives in shallow and poor soils in arid areas. It emerges in November or December after autumn rain and produces seed in May. It is toxic to livestock.

II.2. CHAOUIA

Several weed surveys were conducted in the Chaouia (Chettou and Taleb, 1981; Deil *et al*., 1988; Tanji and Regehr, 1988; Taleb, 1989; Taleb *et al*., 1989; Taleb and Maillet, 1994a; 1994b; Tanji and Taleb, 1994; Rhazi *et al*., 2006), and a total of 315 weed species were found (Taleb and Maillet 1994a; 1994b). Common weeds included *Bromus rigidus*, *Calendula stellata*, *Chrysanthemum coronarium*, *Cichorium intybus*, *Diplotaxis tenuisiliqua*, *Emex spinosa*, *Papaver rhoeas*, *Ridolfia segetum*, *Silybum marianum*, and *Vicia sativa*. In 40 wheat fields, Tanji and Regehr (1988) found that *Papaver rhoeas* (common poppy) was the most abundant annual broadleaf weed.

In a field study at the Sidi El Aidi experiment station, densities of 657 and 1031 weed seedlings/m^2 were monitored in bread wheat plots in 2000-01 and 2001-02, respectively (Zouhouredine, 2002). Eighty percent (80%) and 93% of weed seedlings emerged in bread wheat before February 1, respectively.

In Chaouia, rigid brome (*Bromus rigidus*) is a serious annual weed problem in barley and wheat (Taleb, 1998a; 1998b; Rsaisi, 1994). It reduces wheat shoot dry weight and grain yield by 26 to 98% depending on weed density and environmental conditions (Tanji, 2000; Tanji and Lhaloui, 2009). It is host to a range of pathogenic fungi, viruses, and nematodes (Tanji *et al*., 1995; Taleb *et al*., 1999). In wheat fields, Tanji (1999b) found that rigid brome produced 10 to 1534 seeds/plant. Its seeds are not only contaminants of grain (Tanji and Nassif, 1997; 1999), but also reduce animal productivity by the awns penetrating the soft tissues of the eyes, mouths, feet, and intestines. Seeds are also a plant contaminant in sheep wool.

Friar's cowl (Arisarum vulgare) is a common perennial weed in the Araceae family with only one sagittate-ovate leaf, rarely two, per plant. It propagates only from tubers. It is common in Chaouia and other regions (Tahri, 1997). Tubers of Friar's cowl are associated with famine periods and harsh times during the early 1940s. They were washed, dried, and milled for bread making. Moroccan tubers contain 38% starch, 1% sugar, and 0.76% nitrogen (Tanji and Nassif, 1995).

Native to South Africa, *Bermuda buttercup* (*Oxalis pes-caprae*) has been found in Chaouia and other regions of Morocco (Tahri, 1997). This perennial usually sprouts with the first autumn rains (september to December), blooms in fall and winter (December to February), and tends to die back in spring and summer (March to May). It doesn't produce viable seed but one plant produces several bulbs in a single growing season. It readily increases in cultivated fields and undisturbed road sides. The plant is difficult to eradicate because it spreads via bulbs (Rsaissi, 1994; Rsaissi and bouhache, 1994; Tanji 1994b). In infested fields, this weed is successfully excluding native plant species and making infested spots unfavorable to re-vegetation with native plant species. Gammarte (1999) confirmed that shoot and root of this weed were allelopathic; wheat germination was reduced with increasing extract concentrations. Besides, shoot and root caused 62, 58 and 42% inhibition of the dry biomass production of wheat, confirming the remarkable allelopathic activity of this weed.

Wild jujube (*Ziziphus lotus*) is a deciduous, thorny shrub of the Rhamnaceae family, occurring throughout the Chaouia where it occupies most soil types (Regehr and El Brahli, 1995; Tahri, 1997; Rsaissi and Bouhache, 2002). Wild jujube plants are erect, and if left uncut, eventually reach heights of 8 to 10 m. The wood is valued by craftsmen and for use as fuel. In arid, uncropped areas, plants typically are allowed to grow to heights of 2 to 3 m. Because of the protection offered by its thorns, wild jujube may serve as biological refuges for a variety of plant species. Wild jujube plants are dormant from October through March. Mature plants flower in June and July, and produce 1-cm diam fruits with a thin, sweet pulp. Fruits may be gathered, dried, and sold for human consumption Nassif and Tanji, 2013). Fruits are sold on sidewalks in late summer and fall, and also found in stores throughout the year (Tanji and Nassif, 1995). According to Regehr and El Brahli (1995), wild jujube fruit was important in antiquity for making bread, wine, and conserves. The fruit also was used for making cough drops and tonics. Commerce in wild jujube fruit is believed to have contributed to spread of the species. The percent and speed of germination increased after seeds passed through goats. The species also spreads by fragmentation of roots and other plant parts.

On Morocco's semi-arid Chaouia plateau, wild jujube occupies deep, fertile agricultural soils, where the primary agronomic crops are wheat and barley. Plants grow in thickets, ranging in size up to 15-m diam. Groups of discrete and irregular-shaped thickets, scattered randomly or sometimes in serpentine patterns, may infest areas of 1 ha or larger. To help prepare infested fields for winter crop production, wild jujube plants are cut at ground level in late summer or fall, and the thorny brush is used to construct enclosures for animals and barriers around fields, and for fuel (Regehr and El Brahli, 1995). This shrub causes complete wheat and barley loss by preventing harvest operations. Changes in total non-structural carbohydrates in its roots were influenced by the plant phenology (Rsaissi *et al*., 2012). These authors found that the largest carbohydrate level was found in August which corresponds to the maturity of fruits. The lowest carbohydrates level was at the vegetative stage in February.

There are 3 mallows (*Malva multiflora = Lavatera cretica*, *Malva nicaeensis*, *Malva parviflora*) infesting barley and wheat fields in Chaouia (Taleb, 1995). They emerge immediately after the first fall rains in October or November. They are competitive with cereal crops and tolerant to several broadleaf herbicides. Mallow plants are often collected before blooming from untreated cereal fields or from field edges and used for food. Only young stems and leaves are cut, steamed, and prepared with green olives, garlic, olive oil, and spices (Tanji, and Nassif, 1995; Nassif and Tanji, 2013).

Milkvetch (*Astragalus baeticus*) is common in Chaouia (Taleb, 1995). It is a member of the Fabaceae family, grows up to 1 m, and flowers from February to April. Flowers and pods are clustered in 2 to 15 in the upper parts of racemes. Pods are 2 to 5 cm by 0.5 cm; they are usually collected from untreated cereal fields and consumed. Milkvetch pods are assembled in bundles and generally sold along roads and near schools (Tanji and Nassif, 1995). Children, particularly shepherds, enjoy collecting and eating milkvetch fruits raw between February and April (Nassif and Tanji, 2013). Tender pods are totally consumed while mature pods are chewed, sucked, and the rest is discarded. Mature milkvetch seeds contain 4.14% nitrogen, 0.37% phosphorus, 0.84% potassium, 0.16% calcium, and 0.20% sodium (Tanji and El Gharous, 1998).

Tassel grapehyacinth (*Muscari comosum*) is a common perennial weed in Chaouia (Taleb, 1995) and other regions (Tahri, 1997). It grows in cultivated fields and fallow parcels. The most frequently used name is 'besseila' which is a diminutive variant of the Moroccan name for onions 'bassla'. The plant is not grazed by animals, but the bulbs are collected to be exported to be used as food and in pharmaceutical industry (Nassif and Tanji, 2017). Its seeds are dormant and require sulfuric acid for germination (El Jamali, 2002). Bulbs are collected and wild-harvested for sales in local rural markets. Immediately after the appearance of the first leaves, children and adults as well start scavenging fields for the collection of bulbs. The wild-harvest of bulbs of *Muscari comosum* for export is an old widespread commercial activity in Chaouia and other regions. Annually, tons of bulbs of the plant are exported, particularly to Europe. One of the consequences of annual harvesting of bulbs, exacerbated by episodic droughts, is the decrease in the plant availability (Nassif and Tanji, 2017).

II.3. DOUKKALA

A preliminary vegetation survey was done by Ionesco (1956), but a more exhaustive survey was completed by Boudhar (1995) and Boudhar and Taleb (1995). These authors reported a total of 188 weed species (156 dicotyledons + 32 monocotyledons) in 105 wheat fields. They found 8 to 30 weed species per field, with an average of 19. Eighty seven percent (87%) of the weeds were annuals. Some common weeds included *Avena sterilis*, *Chenopodium murale*, *Medicago hispida*, *Sinapis arvensis*, *Papaver rhoeas*, *Lolium multiflorium*, *Lolium rigidum*, *Melilotus sulcatus*, *Phalaris minor*, and *Vicia saliva*. Species abundant in the sandy soils were *Anacyclus radiatus*, *Carlina racemosa*, *Chrysanthemum viscidehirtum*, *Leontodon hispidulus*, *Linaria gharbensis*, *Reseda alba*, and *Spergula arvensis*. Species abundant in clay soils included *Anchusa italica*, *Convolvulus tricolor*, *Euphorbia exigua*, *Lavatera trimestris*, and *Ridolfia segetum*.

II.4. GHARB

Weed surveys in barley and wheat fields were done by Lastic and Neuschafer (1988), Taleb (1995; 2000), and Cherragi (2002). The last author found 91 weed species in 60 wheat fields; 90% were dicotyledons and species richness varied from 6 to 21 species per field, with an average of 14. However, Taleb (1995; 2000) cited 534 weed species in 91 barley and wheat fields. Major weeds included *Avena sterilis*, *Centaurea diluta*, *Chrysanthemum coronarium*, *Cichorium intybus*, *Lolium rigidum*, *Phalaris brachystachys*, *Ridolfia segetum*, *Rumex pulcher*, *Sinapis arvensis*, and *Vicia sativa*.

In 100 barley and wheat fields in the Kelaa des Sraghna area, Rahani (1988) cited 205 weed species. Some common weeds included A*nagallis arvensis*, *Avena sterilis*, *cichorium intybus*, *convolvulus arvensis*, *Scorpiurus muricatus*, *medicago polymorpha*, *Sinapis arvensis*, *Sonchus oleraceus*, and *Vicia sativa*.

In 82 wheat fields, Ouatmane (1992) identified 264 weed species; 86% were dicotyledons. Some common weeds included *Avena sterilis*, *Calendula arvensis*, *Chrysanthemum coronarium*, *Cynodon dactylon*, *Launaea nudicaulis*, *Malva parviflora*, *Melilotus sulcata*, *and Sinapis arvensis*, *Torilis nodosa*, and *Vicia sativa*. All these species were found by Tahri *et al*., (1994).

II.5. LOUKKOS

A weed survey in 60 barley and wheat fields revealed the presence of 255 weed species; 83% were annuals and 84% were dicotyledons (Chougrani, 1984; Bouhache *et al*., 1994). The 10 most abundant weed species were *Anagallis arvensis*, *Arisarum vulgare*, *Lathyrus articulatus*, *Medicago polymorpha*, *Misopates orontium*, *Teucrium resupinatum*, *Ridolfia segetum*, *Scorpiurus muricatus*, *Sinapis arvensis*, and *Vicia sativa*.

II.6. MOULOUYA AND EASTERN MOROCCO

A survey in 100 barley and wheat fields in the Moulouya perimeter revealed 268 weed species that belong to 45 botanical families (Chafik *et al*., 2012). The *Asteraceae*, *Poaceae*, *Fabaceae*, *Brassicaceae*, and *Apiaceae* were the most dominant families with 51% of species. Eighty two percent (82%) were broadleaves and 72% were annuals. Some common weeds included *Avena sterilis*, *Chrysanthemum coronarium*, *Cynodon dactylon*, *Emex spinosa*, *Lolium rigidum*, *Malva parviflora*, *Papaver rhoeas*, *Sinapis arvensis*, and *Sisymbrium irio*. All these weeds were found in cereals and other crops planted in autumn or winter (Chafik *et al*., 2013b).

Chafik *et al.*, (2013c) considered *Cardaria draba* (Hoary cress) a noxious weed in cereals in Eastern part of Morocco. This plant is a member of the mustard family and can grow up to 60 cm in height with creeping rhizomatous roots that can extend 60 cm down. Hoary cress is difficult to control because it can reproduce through its roots as well as through its seeds. Its control requires the combination of herbicides and tillage.

Silverleaf nightshade (*Solanum elaeagnifolium*) has been introduced into Moulouya (Chafik *et al.*, 2013a). It is an important weed of croplands and pastures in cultivated land and undisturbed areas. The invasiveness is aggravated by high seed production and an extensive root system that promotes vegetative multiplication and renders conventional control methods very difficult. Other negative effects include hindering commercial cropping activities, being toxic to livestock, and reducing land values.

II.7. RABAT-ZEMMOUR-ZAIR

In 100 barley and wheat fields, El Houjjaji (1982) found 270 weed species; 85% were dicotyledons. Common weeds were *Anagallis arvensis*, *Avena sterilis*, *Cichorium intybus*, *Lolium multiflorum*, *Misopates orontium*, *Papaver hybridum*, *Papaver rhoeas*, *Silene gallica*, *Raphanus raphanistrum*, and *Vicia sativa*. Weeds found in clay soils included *Bupleurum lancifolium*, *Cichorium intybus*, *Picris echioides*, and *Vaccaria hispanica*.

II.8. SAÏS

Several weed surveys were conducted in the Sais region (Chama, 1971; Loudyi, 1978; Ndzoumba, 1981; Loudyi, 1982; Yoba, 1982; Loudyi, 1985; 1986; Laghmouchi and Zahri, 1987; Fatah, 1989; Loudyi, 1995). The compilation of all these research activities provided a total of 314 weed species in barley and wheat fields (Loudyi, 1995). The 10 most common weeds were *Avena sterilis*, *Bifora testiculata*, *Convolvulus arvensis*, *Fumaria parviflora*, *Galium tricornutum*, *Medicago polymorpha*, *Papaver rhoeas*, *Polygonum aviculare*, *Sinapis arvensis*, and *Vaccaria hispanica*.

Although, both grass and broadleaf weeds infest cereal crops, rigid brome (*Bromus rigidus*) has been a serious annual weed problem in small grain cereals in the Saïs area (Fatah, 1989; Hamal *et al.*, 1998a; Taleb, 1998; Hamal *et al*., 2000a; 2001a; 2005).

This well adapted weed has proliferated due to monocropping cereal/cereal and inappropriate use of effective herbicides for its control in cereals. It reduced wheat grain yield by 26 to 98% depending on weed density and environmental conditions (Saffour, 1992; Hamal, 1993; Hamal *et al*., 1994; Hamal *et al*., 1996b; Rzozi *et al*., 1998; Hamal *et al*., 2001b). It is host to barley yellow dwarf virus (Tanji *et al*., 1995; Taleb *et al*., 1999). Its seeds are not only contaminants of grain (Zemrag and El Abdaoui, 1979; Akaaboune, 1981; Tanji and Nassif, 1997; 1999; Tourkmani *et al*., 2000), but also reduce animal productivity by the awns penetrating the soft tissues of the eyes, mouths, feet, and intestines. Seeds are also a plant contaminant in sheep wool.

The influence of depth and duration of burial on the deterioration, germination, and viability of rigid brome seed was studied in the field. Hamal *et al*., (2001c) reported that tillage affected the density and vertical distribution of rigid brome seeds in the soil. No-tilled plots had the highest seedbank (876 rigid brome plants/m²) compared to tilled plots. Hfidi (1989) found that 72% of soil seedbank of rigid brome was located in the upper 20 cm. Seeds of rigid brome can survive in the soil more than three years (Hamal *et al*., 2001c), but germination of seeds buried in the soil at 0-5 and 5-15 cm were 84 and 77%, respectively (Hamal *et al*., 2007). In a greenhouse study, Tanji (2000b) found that shoot biomass of several wheat cultivars responded similarly to the competitiveness of rigid brome.

II.9. SOUS-MASSA

Tanji and Ait Lhaj (2010) conducted a weed survey in 47 barley fields and 27 bread wheat fields in Souss (Agadir-Taroudant), Massa (Agadir-Tiznit), and South of the High Atlas. A total of 224 weed species were found in the 74 surveyed fields: 87% were broadleaf species and 81% were annuals. There were differences in weed species composition between locations and between crops. In clay silt soils of the Souss, the 5 predominant weeds were *Chenopodium murale*, *Cynodon dactylon*, *Diplotaxis tenuisiliqua*, *Emex spinosa*, and *Launaea nudicaulis*. In sandy soils of the Massa region, the 5 predominant weeds were *Bromus rigidus*, *Cynodon dactylon*, *Diplotaxis catholica*, *Echinops spinosus*, and *Reichardia tingitana*. In the South of the high Atlas, the 5 predominant species were *Cladanthus arabicus*, *Coronilla scorpioides*, *Lotus arenarius*, *Medicago polymorpha*, and *Plantago lagopus*. All these weeds were found in various crops of the Sous-Massa region (Wahbi, 1989; Boulet *et al*., 1991).

Crownbeard (*Verbesina encelioides*) is an annual *Asteraceae* recently introduced into the Sous-Massa region (El Mfadli, 2001; Taleb *et al*., 2002). It is native to the southwestern U.S. and the Mexican plateau, but it can now be found in a number of other countries of the world. It has also been reported growing in several regions of Morocco. The weed grows and produces flowers and seeds throughout the year. It prefers to grow on deep sandy soils in undisturbed sites. It is resilient to drought stress conditions and once established can survive without rain or irrigation. It possesses allelopathic properties. The weed is not edible by animals, and it has been shown to exhibit toxic effects to livestock.

II.10. TADLA

Weed surveys revealed the presence of more than 300 weed species in the Tadla perimeter (Tanji and Boulet, 1986; Gmira *et al*., 1997; Zidane *et al*., 2000; Tanji, 2001a; Tanji and El Mejahed, 2004). The most noxious weed in this perimeter is silverleaf nightshade (Solanum elaeagnifolium) (Tanji *et al*., 1984; 1985). Some common weeds in wheat and barley fields include *Avena sterilis*, *Convolvulus arvensis*, *Convolvulus althaeoides*, *Diptotaxis assurgens*, *Lolium rigidum*, *Medicago polymorpha*, *Papaver rhoeas*, *Sinapis arvensis*, *Silybum marianum*, and *Solanum eleagnifolium*.

The most noxious weed in Tadla is *silverleaf nightshade* (*Solanum elaeagnifolium*). It is believed that it has been infesting the Tadla perimeter since 1949 (Taleb *et al*., 2007). It now infests several regions of Morocco (Ben Ghabrit *et al*., 2016). It is a perennial with four different growth forms: from seeds (as a therophyte) germinating from spring through summer; from buds above soil level giving new shoots in spring (chamaephyte); from buds at the soil surface (hemicryptophyte); from buds buried in the soil, which regenerate from its roots (horizontal or vertical), from which new shoots arise (geophyte). It mainly reproduces vegetatively, from buds on underground fragments. Fragments as small as 0.5 cm long and as deep as 20 cm deep can regenerate (Tahri, 1987).

Seedlings are able to regenerate (Tahri, 1987). Spread is possible by livestock and manure, irrigation water, agricultural machinery, rooted nursery plants, contaminated straw or seeds. Vehicles and tools used in agriculture, bulldozers and other earth-moving equipment can also spread the weed by transporting both seeds and sections of root. Soil, sand and ornamental plants can be contaminated by fragments of roots or seeds of *S. elaeagnifolium* (Taleb *et al*., 2007). Agricultural land infested with *S. elaeagnifolium* loses considerable rental and resale value. In Morocco, the value of infested fields decreased by 25% (Gmira *et al*., 1998). Almost 70% of infested sites are located in major agricultural regions of the country and the majority of the other 30% are in the Rabat-Casablanca axis (Ben Ghabrit *et al*., 2016). The invasion is promoted by low altitude (≤ 350 m) and it tolerates high summer temperatures (up to 40.5°C). This aggressive vegetative growth from deep rootstocks makes silverleaf nightshade very difficult to control, both mechanically and chemically.

III. WHY ARE WHEAT FIELDS INFESTED WITH WEEDS?

There are several reasons for having cereal fields infested with weeds by the end of the crop cycle (Grillot, 1951; Cherragi, 2002; Hajjaj, 2010). In a survey of 215 farmers in the province of Meknes, Hamal (1984) reported that drought was the main reason that prevented farmers to apply herbicides in 1983-84 on durum wheat and bread wheat. In this study, most farmers who used herbicides did not respect the time of application.

Of 195 farmers surveyed in the Safi province, only 17 used herbicides in 1987-88 in wheat and barley fields (El Hamri, 1988). This survey revealed that 15 out of 17 farmers obtained very low weed control due to non-respect of the dose and the time of application of herbicides.

In a field survey with 107 farmers in the Tadla irrigated perimeter in April 1997, Nassif and Tanji (2001) enumerated reasons that prevented wheat producers from having wheat fields with no weeds or low weed densities were: (i) inefficacy of herbicides and weeds continue to grow even after herbicide use, (ii) underestimation of weed infestation at the time of appropriate weed control, (iii) expensive herbicides, (iv) inability to spray at the right stage (v) inability to identify grass seedlings to apply suitable herbicides on time, and (vi) shortage in money to buy herbicides.

IV. WEED SEEDS

IV.1. SEED PRODUCTION OF WEEDS

In a field survey in the Settat, El Jadida, and Safi provinces, Tanji (1999) investigated seed production of 55 weed species collected from 93 small grain cereal fields. Weed plants were harvested in May 1991 at maturity of bread wheat, durum wheat and barley, and the number of seeds per plant was determined. Six weeds produced an average between 1000 and 2000 seeds/plant, 12 weeds had between 500 and 1000 seeds/plant, 26 weeds had between 100 and 500 seeds/plant, and 17 had less than 100 seeds/plant. The six high seed producing weeds in at least one cereal crop were *Ammi majus* (1177 seeds/plant), *Astragalus hamosus* (1248), *Glaucium corniculatum* (1685), *Rumex pulcher* (1284), *Sinapis alba* (1189), and *Sinapis arvensis* (1372). Ten Fabaceae had between 21 and 82 seeds/plant (*Coronilla scorpioides*, *Lathyrus aphaca*, *Lathyrus articulatus*, *Lathyrus cicera*, *Lathyrus ochrus*, *Lupinus micranthus*, *Scorpiurus muricatus*, *Vicia lutea*, *Vicia monantha*, and *Vicia sativa*) (Table 47).

IV.2. WEED SEED ASSOCIATED WITH GRAINS IN THE SEED MARKET

At cereal harvest, weed seed increase the moisture of crop seed and reduce their quality. In addition, combine harvesters play an important role in the weed seed dispersal (Zemrag and El Abdaoui, 1979; Akaaboune, 1981; Boutaher, 1994; Aitounejjar and Tanji, 1997). Tanji and Nassif (1997) examined 165 seed samples of barley, bread wheat, and durum wheat that were collected from a weekly market at Ben Guerir and from a daily grain market in Casablanca. All cereal samples were contaminated with weed seeds. Sixty-nine (69) weed species were recorded; 55 were dicotyledons. Seeds of Lolium rigidum and Melilotus sulcatus were the most frequent and abundant (Table 48).

VI.3. WEED SEED ASSOCIATED WITH GRAINS PLANTED BY FARMERS

Planting certified or pure cereal seeds is essential for a good quality cereal production. The analysis of 4667 durum and bread wheat seed samples from of the certified seed production showed 59 weed seed species; Vicia sp., Astragalus boeticus, Vaccaria hispanica and Avena sterilis were found in 39, 28, 26, and 10% of cereal samples, respectively (Zemrag and El Abdaoui, 1979). In another survey, Akaaboune (1981) found an average of 480 weed seed per kg of non-certified durum wheat seed and 620 per kg of barley seed.

Table 47. Seed production of some major weeds from cereal fields in Morocco (Tanji, 1999b).

Monocotyledons weeds	Number of plants processed	Number of seeds/plants		
		Min.	Max.	Mean + SE
Avena sterilis	190	4	1292	189 + 14
Bromus rigidus	120	10	1534	170 + 22
Lolium rigidum	55	68	8976	651 + 175
Phalaris brachystachys	75	13	1284	294 + 30
Phalaris minor	30	9	3248	842 + 191
Phalaris paradoxa	5	160	366	236 + 35
Broadleaf weeds				
Ammi majus	5	740	1785	1177 + 206
Anchusa italica	20	2	460	126 + 27
Astragalus boeticus	120	9	684	157 + 11
Astragalus hamosus	10	328	2400	1005 + 210
Buglossoides arvensis	10	136	494	295 + 39
Bupleurum lancifolium	10	62	264	163 + 21
Calendula arvensis	130	15	1955	235 + 24
Carduus pycnocephalus	20	22	463	134 + 23
Centaurea diluta	10	46	406	172 + 40
Centaurea eriophora	60	0	202	55 + 5
Coronilla scorpioides	5	45	73	57 + 5
Echinops spinosus	10	28	1087	379 + 130
Emex spinosa	100	25	1328	324 + 30
Gallium tricornutum	5	25	132	63 + 20
Glaucium corniculatum	15	570	3823	1434 +233
Hedypnois cretica	5	222	2026	961 + 314
Hippocrepis multisiliquosa	10	192	1328	631 + 101

Monocotyledons weeds	Number of plants processed	Number of seeds/plants		
		Min.	Max.	Mean + SE
Lathyrus aphaca	10	29	140	73 + 11
Lathyrus articulatus	10	2	104	30 + 10
Malva parviflora	20	275	1608	683 + 80
Medicago polymorpha	10	132	827	337 + 72
Melilotus indicus	15	116	2086	968 + 137
Melilotus sulcatus	245	7	2706	479 + 27
Notobasis syriaca	115	0	316	55 + 5
Plantago afra	35	119	1385	492 + 57
Raphanus raphanistrum	20	48	1505	367 + 91
Rhagadiolus stellatus	35	51	578	194 + 21
Rumex bucephalophorus	30	98	3982	772 + 185
Rumex pulcher	10	52	2122	574 + 223
Scorpiurus muricatus	10	25	175	80 + 18
Silybum marianum	55	0	612	148 + 20
Sinapis alba	5	543	2184	1189 + 300
Sinapis arvensis	40	84	14538	1093 + 389
Torilis arvensis	10	52	302	156 + 27
Torilis nodosa	15	29	372	150 + 28
Tragopon hybridus	25	28	884	189 + 41
Vaccaria hispanica	75	14	2286	321 + 40
Vicia benghalensis	40	6	274	69 + 9
Vicia lutea	50	8	220	51 + 6
Vicia monantha	20	6	41	19 + 3
Vicia sativa	185	3	518	89 + 6

Table 48. Weed seeds associated with cereal seeds in the grain market in Casablanca in 1995 (Tanji and Nassif, 1997).

Weed species	*Number of weed seeds/kg of cereal seeds*		
	Barley (30 samples)	Durum wheat (47 samples)	Bread wheat (18 samples)
Annual grass weeds			
Avena sterilis	6	4	4
Bromus rigidus	11	8	10
Lolium rigidum	169	243	223
Phalaris brachystachys	1	61	255
Annual broadleaf weeds			
Anagallis arvensis	1	1	2
Astragalus boeticus	10	3	1
Beta macrocarpa	2	4	4
Bupleurum lancifolium	3	8	5
Chrysanthemum coronarium	80	31	13
Coronilla scorpioides	2	1	1
Emex spinosa	13	18	20
Galium triicornutum	6	9	6
Galium verrucosum	2	2	1

Weed species	*Number of weed seeds/kg of cereal seeds*		
	Barley (30 samples)	Durum wheat (47 samples)	Bread wheat (18 samples)
Geropogon hybridus	1	3	2
Glaucium corniculatum	2	29	3
Malva parviflora	12	19	29
Medicago polymorpha	2	2	4
Melilotus indicus	3	4	18
Melilotus sulcatus	100	43	49
Misopates orontium	2	4	1
Papaver rhoeas	3	4	8
Polygonum aviculare	2	15	16
Raphanus raphanistrum	6	1	1
Scorpiurus muricatus	3	2	2
Silybum marianum	1	1	1
Sinapis arvensis	51	55	27
Torilis nodosa	4	8	1
Vaccaria hispanica	24	94	61

IV.3. WEED SEED ASSOCIATED WITH GRAINS PLANTED BY FARMERS

Planting certified or pure cereal seeds is essential for a good quality cereal production. The analysis of 4667 durum and bread wheat seed samples from of the certified seed production showed 59 weed seed species; *Vicia sp.*, *Astragalus boeticus*, *Vaccaria hispanica* and *Avena sterilis* were found in 39, 28, 26, and 10% of cereal samples, respectively (Zemrag and El Abdaoui, 1979). In another survey, Akaaboune (1981) found an average of 480 weed seed per kg of non certified durum wheat seed and 620 per kg of barley seed.

Tanji and Nassif (1999) examined 100 samples of seeds of durum wheat, bread wheat, and barley that were collected from farmers in the Settat province in December 1995 and analyzed for the 4 major contaminants: weed seed, crop seeds, straw, and soil debris. Purchased seeds of barley, bread wheat, and durum wheat had an average of 7305, 621 and 440 weed seeds per kg, respectively, while self-produced seeds of the same crops had 1009, 860 and 796 seeds per kg, respectively. Forteen (14) monocotyledons and 83 dicotyledons weed species were identified. Some major weeds are indicated in Table 49.

Field inspection from 1997-98 to 2001-02 revealed that 20 to 321 hectares of G4 and 28 to 124 hectares of R1 cereal crops were annually refused for certification due to high weed infestations before harvest (Table 50 from Annual Reports, Seed Control Service, ONSSA). This situation demonstrated that weeds infesting cereal fields before harvest were essentially due to (i) inefficacy of used herbicides, (ii) inadequate herbicide treatments, (iii) inappropriate herbicide choice, and (iv) expensive grass herbicide (Nassif and Tanji, 2001).

After assessment of 28941 cereal seed samples from 1994-95 to 1998-99, Tourkmani *et al.* (2000) found 27 weed seed species infesting grain cereals before processing for certification. Eight weed species were dominant: *Astragalus boeticus*, *Bromus rigidus*, *Convolvulus arvensis*, *Emex spinosa*, *Galium tricornutum*, *Malva parviflora*, *Silybum marianum*, and *Vaccaria hispanica* (Table 51).

Table 49. Some weed seeds contaminating cereal seeds planted by Chaouia farmers in December 1995 (Tanji and Nassif, 1999).

	Number of weed seeds/kg of cereal seeds		
	Barley *(24 samples)*	Durum wheat *(44 samples)*	Bread wheat *(32 samples)*
Annual grass weeds			
Avena sterilis	20	4	20
Bromus rigidus	55	14	47
Lolium rigidum	70	39	37
Phalaris brachystachys	15	25	47
Annual broadleaf weeds			
Astragalus boeticus	50	32	33
Beta macrocarpa	25	7	13
Bupleurum lancifolium	20	43	13
Chrysanthemum coronarium	70	32	13
Convolvulus althaeoides	10	11	7
Emex spinosa	85	46	47
Galium tricornutum	35	21	40
Galium verrucosum	20	14	27
Malva parviflora	50	21	20
Melilotus sulcatus	90	46	40
Polygonum aviculare	40	54	47
Raphanus raphanistrum	5	4	40
Rhagadiolus stellatus	15	4	20
Scorpiurus muricatus	5	21	20
Torilis nodosa	50	11	20
Vaccaria hispanica	90	86	47

Table 50. Area and quantity of 5 cereals (durum wheat, bread wheat, barley, secale, and triticale) not accepted for certification due to weeds or weed seeds (Annual reports, "Service de contrôle des semences", ONSSA).

Growing season	Area of small grain cereals refused due to high weed infestations (ha)		Quantity of small grain cereal seeds refused due to excess of weed seeds (ql)	
	R1	R2	R1	R2
1997-98	20	124	2202	846
1998-99	39	65	956	2891
1999-00	119	28	981	803
2000-01	270	109	4552	3077
2001-02	321	35	5693	252

Table 51. Frequency of weed seeds in small grain cereal seeds before processing certified seeds (durum wheat, bread wheat, barley, secale, and triticale) (Tourkmani *et al.*, 2000).

	1994-95	1995-96	1996-97	1997-98	1998-99
Number of cereal samples examined	6496	5609	5321	5304	6211
Weed species *Frequency (%)*					
Astragalus boeticus	8	18	4	6	3
Bromus rigidus	10	5	6	5	7
Convolvulus arvensis	16	8	12	7	20
Emex spinosa	13	10	11	8	7
Galium tricornutum	9	15	9	7	9
Malva parviflora	6	4	5	2	5
Silybum marianum	3	10	7	10	7
Vaccaria hispanica	5	4	11	4	6

V. WEED SEED BANK

In a field study in the Oued Zem area, Tanji *et al.* (2017a) found that the initial seedbank in 6 fields was 2354 seeds m^{-2}. When herbicide-free barley + pea forage mixture (cut for hay) was followed by bread wheat, seedbank reductions were 35% after two years. When bread wheat was followed by herbicide-free barley+pea forage mixture, seedbank reductions were only 5% in two years.

In Chaouia, Tanji *et al.* (2017b) found that initial germinable weed seedbank density estimated in September 2012, before no-till planting was 1890 seeds m^{-2}. After two growing seasons, seedbank reductions were 23% in continuous durum wheat, 68% in canola/durum wheat/durum wheat, and 72% in barley+pea/durum wheat/durum wheat. This study demonstrated the combined merits of pre-plant glyphosate, herbicide use in wheat, herbicide-free barley + pea haying, and durum wheat rotation with either canola or barley + pea to manage weeds in no-till systems in semi-arid Morocco.

VI. COMPETITON BETWEEN WEEDS AND CEREALS

Weeds compete with crop plants for moisture, nutrients, light and space, thereby depriving the crop of vital inputs. Therefore, weed competition is one of the most important constraints in crop production. Weed-crop competition begins when crop plants and weeds grow in close proximity and their root or shoot system overlaps. The competition becomes severe due to more smothering effect, when weeds emerge earlier than the crop.

Numerous experiments have investigated crop–weed competition from a variety of aspects. The results of these studies can be helpful to those making decisions about weed management, as guidelines can be prepared that indicate in general the relative competitive ability of various weeds at various densities in the major crops. These experiments also provide guidance for the duration of weed-free conditions needed after crop emergence and for when weeds should be removed with herbicides. Other concerns may be as important as yield loss indications from crop–weed competition studies in determining the types of weed management systems implemented.

Weed-crop competition is a complex field of study. The extent of competition is governed by a number of factors including crop species, crop cultivar, crop density, weed species, weed density, the relative time of emergence of the crop and weed, the duration of the weed presence, the efficiency of weed control, and soil and environmental factors.

VI.1. EFFECT OF WEED DENSITY ON CEREALS

The actual weed density at which wheat yield losses occur is weed species and environmentally dependent. Generally, the greater the weed density, the greater the yield losses. Pedzoldt and Salah-Bennani (1978) found that densities of 10 to 20 plants m^{-2} of *Avena sterilis* (sterile oat) did not significantly reduce wheat yields; whereas, Derbal and Zidane (1980) reported that densities of 20 to 30 panicles m^{-2} decreased wheat yield by 30%, and more than 100 panicles m^{-2} reduced it by 80%. Losses were estimated at 83% when Avena sterilis densities were 173 panicles m^{-2} (Sidibe, 1982), A simple regression mode (Y=2.95–0.46D) was found between the wheat yield loss and panicle density of Avena sterilis. The same author reported that signifieant wheat yield losses were noted from 10 plants of Avena sterilisand Sinapis arvensis (wild mustard), from 20 plants m^{-2} of *Lolium multiforum* (Italian ryegrass) and from 40 plants m^{-2} of *Galium tricornutum* (corn cleavers).

In greenhouse and field experiments, Tanji *et al.*, (1997) found that bread wheat was the dominant competitor with rigid ryegrass (*Lolium rigidum*) or cowcockle (*Vaccaria hispanica*). One wheat plant was as competitive as 11 or 19 rigid ryegrass plants in greenhouse and field experiments, respectively. One wheat plant was as competitive as three to 24 cowcockle plants, depending on environmental conditions. They noticed that growth analyses of individual plants showed that wheat had a greater leaf area, shoot and root dry weight, and absolute growth rate than rigid ryegrass or cowcockle, panicularly early in the season.

In extreme cases, the losses caused by weeds can be up to complete crop failure. The cases of complete crop failure were quite common due to heavy population of *Bromus rigidus* or *Lolium rigidum* after the evolution of resistance (Tanji, 2011a; 2014). Under both situations, some of the farmers were forced to harvest their immature wheat crops as fodder.

VI.2. WEED COMPETITION FOR WATER

Weeds compete with cultivated plants for water that is available and create an early water deficit. Studies conducted in arid and semi-arid areas of Morocco show that although weedy wheat extracted more water than weed-free wheat, crop yields and water use efficiency (WUE) were improved only when weeds were controlled early in the season (Tanji *et al*., 1987; Tanji and Karrou, 1992; Aboudrare, 1999; Aboudrare *et al*., 2000). During a dry year (203 mm of rain), weed control increased grain yield by 8.4%. However, during a relatively wet season (469 mm) the increase was 69.2%. WUE increased by controlling weeds from 55 to 68 and from 27 to 96 in dry and wet years, respectively (Tanji and Karrou, 1992) (Table 52).

Table 52. Effect of weeds on water use and water use efficiency of bread wheat at the Sidi El Aidi experiment station, Morocco (Tanji and Karrou, 1992).

	1986-87 (203 mm of rain)			*1987-88 (469 mm of rain)*		
	WUE (Mm/kg)	WU (mm)	Grain yield (Kg/ha)	WUE (Mm/kg)	WU (mm)	Grain yield (Kg/ha)
Weed-free wheat	6.80	161	1285	9.58	316	3021
Weedy wheat	5.51	182	994	2.66	366	931

VI.3. WEED COMPETITION FOR NUTRIENTS

Nitrogen is one of the most important nutrients applied to improve crop yield. The timing of application and amount of N fertilizer can impact competition between weed and crop species. Competition increased with higher N levels. Studies showed that weedy wheat extracted more nitrogen than weed-free wheat (Chaouki, 1994) (Table 53). However, the rate of N accumulation in wheat grain and straw was determined by the N availability and weed competition (Diab, 1996) (Table 54).

Tanji and El Gharous (1998) studied the mineral composition of weed seeds of mature weeds collected from cereal fields. They found that 39 weeds had similar or higher N content than wheat grain. Species with high P concentrations included *Diplotaxis tenuisiliqua* (0.79%). The highest Ca and Na concentrations were found in *Beta macrocarpa* (2.37% and 0.55%, respectively). The highest Fe and Zn contents were observed in *Chenopodium murale* (0.059% and 0.034%, respectively). From a nutritional point of view, there is no need to discard weed seeds from cereal grains. Poisonous seeds such as those of *Lathyrus sp.* and *Lupinus sp.* have to be discarded before milling.

Table 53. Effect of weed control on nitrogen accumulation in weed plants in a durum wheat crop in Doukkala in 1993-94 (Chaouki, 1994).

(Kg/ha)	Site 1	Site 2	Site 3
Weedy wheat	77	80	138
Late weed control	67	36	91
Early weed control	15	9	4

Table 54. Effect of weed control on nitrogen concentration in wheat grain and straw in Tadla in 1994-95 (Diab, 1996).

	% Nitrogen	
	Wheat grain	Wheat straw
Durum wheat		
Weedy wheat	2.07	0.54
Weed-free wheat	2.26	0.72
Bread wheat		
Weedy wheat	1.60	0.33
Weed-free wheat	2.18	0.46

VI.4. DURATION OF COMPETITION

Experiments have attempted to define the critical duration of weed competition and to determine the optimal time to implement weed management practices. One type of experiment is designed to determine the early-season weed-free interval needed before weeds can effectively compete with crops with no resultant deleterious effects on quantity and quality of crop yield. Another type of experiment is designed to determine how long weeds can remain in the crop with no resultant deleterious effects on quantity and quality of crop yield.

Studies carried out in the Saïs area in 1991-92 and 1992-93 showed that for a durum wheat yield loss of 15, 10, and 5% due to rigid brome (Bromus rigidus) competition, the critical period should range from 75-77 to 105-106 days after sowing (DAS), 44- 60 to 126-127 DAS and 30-34 to 150-151 DAS, depending on the year. These periods corresponded to the intervals between jointing and early heading, from early tillering to heading and from early tillering to full bloom, respectively (Saffour, 1992; Hamal, 1993; Rzozi *et al*., 1998).

VI.5. ALLELOPATHY

Allelopathy is the reduction or stimulation of plant growth due to release of natural plant-derived substances. It is thought to be relatively minor and is very difficult to demonstrate. However, in dense infestations of weeds, allelopathy could be a contributing factor to yield loss in addition to competition.

Laboratory and greenhouse pot experiments showed the effects of the extracts from living roots of Bermuda buttercup plants on wheat and barley germinations. Wheat and barley seeds were significantly inhibited by allelopathic activity of Bermuda buttercup. Seed germinations were reduced up to 54, 48, and 56%, with increasing extract concentrations, in durum wheat, bread wheat, and barley, respectively. Root exudates of Bermuda buttercup caused reduction of the dry biomass production of wheat and barley, confirming the remarkable allelopathic activity of this weed (Gammarte, 1999) (Table 55).

Table 55. Allelopathic effects of Oxalis pes-caprae on wheat and barley (Bouhache et Gammarte, 2002).

Concentration of weed juice (%)	*% germination*		
	Durum wheat	Bread wheat	Barley
0	94	98	96
30	90	87	93
60	64	77	74
100	46	52	44

VI.6. YIELD LOSS DUE TO WEED INTERFERENCE

Heavy weed infestations at cereal maturity can hamper harvest and cause grain yield loss (Table 56). Boutahar (2000) found that bread wheat yield losses before harvest were 5 and 11% in weed-free plots and weedy plots, respectively. Losses due to the combine were 3 and 7% in weed-free plots and weedy plots, respectively. The author concluded that total loss was 8% in weed-free bread wheat and 18% in weedy wheat but losses varied with the cereal species and the cultivar.

In Chaouia, Zimdahl and El Brahli (1992) estimated an average annual loss of 30% of cereal yield due to weeds. It is suggested that cereal yield losses due to weeds are too high and that cereal grain yield could be increased dramatically with proper use of available technology.

Tanji (2002) collected data from 123 weed control trials in bread wheat conducted in 10 provinces and 4 irrigated perimeters from 1948-49 to 2000-01: 100 trials in rainfed conditions and 23 trials irrigated. Weed densities estimated at wheat heading in weedy plots varied from 7 to 488 plants/m^2 and dry weights varied from 51 to 6486 kg/ha. Wheat grain yield losses due to weeds varied from 0 to 80% in rainfed and irrigated trials.

In a synthesis of 117 weed control trials in durum wheat conducted in 8 provinces and 4 irrigated perimeters from 1970-71 to 2000-01, Tanji (2002) found that weed densities estimated at wheat heading in weedy plots varied from 6 to 741 plants/m^2, and dry weights varied from 50 to 7990 kg/ha. In this study, wheat grain yield losses due to weeds varied from 0 to 100% in rainfed trials and from 0 to 80% in irrigated trials.

Tanji (2000) examined 25 weed control tials in rainfed barley conducted from 1975 to 2000: 19 trials in the Settat province, 5 in the Kelaa des Sraghna province and one in the Safi province. Yield losses due to weeds varied from 0 to 70%.

Table 56. Yield loss due to weed competition

Location	Crop	Grain yield loss due to weeds (%)	Source
Chaouia	Durum wheat	40	Zimdahl, El Brahli (1992)
	Bread wheat	13-36	
	Barley	28-49	
Gharb	Triticale	16	Traibi (1997)
	Durum wheat	10-57	Sebbani (1996)
	Durum wheat	27	Ait hmida (1993)
	Bread wheat	34	Touri (1984)
Saïs	Durum wheat	67	Saffour (1992), Hamal (1993)
	Bread wheat	41	Boukhadda (1982)
Tadla	Bread wheat	42	Benahnia (1985)
	Bread wheat	31	Rafrafi (1988)

VI.7. WEEDS HOSTS OF VIRUSES AND PATHOGENS

A bibliographical review indicated that 85 weed species and 19 genera were considered hosts to various pathogens (virus, mycoplasms, nematodes, and fungus) (Taleb *et al.*, 1999; Tanji *et al.*, 1995). Barley yellow dwarf virus and barley yellow striate mosaic virus were detected in 5 and 2 Poaceae, respectively. Brown rust was detected on Anchusa italica (Ezzahiri *et al.*, 1992). Investigation and identification of other pathogens and insects should continue to complete these studies which will lead to a better control of alternative hosts and to identification of weeds and wild plants that possess genes for resistance to various pathogens and pests (Ezzahiri *et al.*, 1992; Taleb *et al.*, 1999; Tanji *et al.*, 1995), (Table 57) .

Table 57. Weeds hosts of viruses and pathogens attacking small grain cereals (Zeddouk, 1986; Ezzahiri *et al.*, 1992; Taleb *et al.*, 1999; Tanji *et al.*, 1995).

Weed species	Virus or pathogen
Avena sterilis	Barley yellow dwarf virus
Bromus rigidus	
Cynodon dactylon	
Phalaris paradoxa	
Sorghum halepense	
Phalaris brachystachys	Tan spot due to *Pyrenophora trichostoma*
Hordeum murinum	
Phalaris paradoxa	Barley yellow striate virus
Cynodon dactylon	
Anchusa italica	Brown rust (*Puccinia recondita f. sp. tritici*)

VII. WEED MANAGEMENT PRACTICES

Different weed control methods (agronomical, mechanical, chemical and manual) are used to control weeds in small grain cereals under various cropping patterns (cereal/fallow, small grain cereal/corn, cereal/food legume, cereal/forage for silage or hay).

VII.1. AGRONOMICAL OR CULTURAL CONTROL OF WEEDS

VII.1.1. CROP ROTATION

Crop rotation provides the foundation for long-term weed management. Planting a wide variety of crops with varied characteristics reduces the likelihood that specific weed species will become adapted to the system and become problematic. The success of rotation systems for weed suppression appears to be based on the use of crop sequences that employ varying weed management options that prevent the proliferation of weed species. Some of the crop characteristics to consider when planning a diverse rotation include: (i) grassy *Vs*. broadleaved; (ii) annual, biennial, or perennial, (iii) cool-season *Vs*. warm- season, (iv) seeding date (fall, early spring, late spring); (v) growth habit; (vi) competitive ability; and (vii) fertility requirements, etc.

Crop rotation has been found to be a very effective cultural practice in breaking the association of problematic weeds like Bromus rigidus in wheat (Tanji *et al*., 2017b). Rotating wheat with other crops like canola, chickpea, or barley + pea helps in reducing weed populations. Also, inclusion of berseem or oats for fodder once in three year reduces the weed infestation. Besides lower weed population, cropping sequence provides higher system productivity leading to greater profit.

In Doukkala irrigated perimeter, crop rotation can also slow the development of herbicide resistant weeds. An on-farm study in Doukkala showed that herbicide resistant rigid ryegrass (*Lolium rigidum*) was more likely to be found in fields that did not have forage crops such as Egyptian (*Trifolium alexandrinum*) and alfalfa (*Medicago sativa*) in the rotation (Tanji, 2016).

In general, crops that developed a full canopy and/or competed with weeds for resources caused a certain amount of weed suppression. Oat, barley or triticale in mixture with pea or vetch resulted in lower weed pressure (Tanji *et al*., 2017a). Including forages in the crop rotation is a relatively simple way to add an element to the cropping system which provides many benefits, including long-term weed management (Table 58).

VII.1.2. COMPETITIVE CROPS AND CULTIVARS

Cereals vary widely in their ability to compete with weeds. Even within one species, different cultivars may have very different competitive abilities. In general, the competitive ability of a crop is related to its ability to access resources including light, water, and nutrients. It may be discussed as the ability of a crop to tolerate weed pressure and maintain yield, or the ability of a crop to suppress weed growth and seed production.

Tanji *et al*. (1993) found that barley, bread wheat, triticale, and durum wheat reduced weed biomass 94, 91, 72, and 69%, respectively. All cultivars had the ability to compete with weeds, but barley were the most competitive of the cereals. This was likely due to greater light interception by barley cultivars.

Using additive series and growth analysis in greenhouse and field experiments, Tanji *et al.* (1997) found that bread wheat was the dominant competitor with rigid ryegrass (*Lolium rigidum*) or cowcockle (*Vaccaria hispanica*). In this study, one wheat plant was as competitive as 11 or 19 rigid ryegrass plants in greenhouse and field experiments, respectively. One wheat plant was as competitive as 3 to 24 cowcockle plants, depending on environmental conditions. Growth analyses of individual plants showed that wheat had a greater leaf area, shoot and root dry weight, and absolute growth rate than rigid ryegrass or cowcockle, panicularly early in the season.

Using additive series in greenhouse experiments, Tanji (2000) found that 8 bread wheat cultivars did not differ in their relative competitive ability with rigid brome (*Bromus rigidus*). He found that 1 rigid brome was as competitive as 1 wheat plant of any cultivar. A range of 120 to 360 wheat plants m-2 reduced leaf blade, stem, and panicle dry weight per plant of rigid brome.

Table 58. Effect of crop rotation on weed density in 3 rotations in Chaouia, from 2012- 13 to 2014-15 (Tanji *et al*., 2017b).

	16 Nov. 2012	17 Jan. 2013	16 Apr. 2013	24 Dec. 2013	9 Feb. 2014	8 Mar. 2014	24 Nov. 2014	15 Jan. 2015	1 Apr. 2015
Rotation 1: Continuous no- till durum wheat	273	115	57	46	25	18	59	36	49
Rotation 2: Barley + pea/durum wheat/durum wheat	489	87	59	128	101	59	42	15	10
Rotation 3: Canola/durum wheat/durum wheat	58	82	49	20	27	12	25	22	6

VII.1.3. FALSE SEEDBED WITH DELAYING SOWING TIME

Delayed seeding is often used to allow for control of early-emerging weeds with herbicides or tillage. This practice is known as "stale or false seedbed". Weed emergence requires good soil moisture and soil temperature conditions. However, tillage or herbicide use to kill emerged weeds and volunteer crops requires low soil moisture and sunny conditions. Judicious use of certain tillage operations in the cropping system can reduce the need for chemical weed control.

Allowing rigid ryegrass (*Lolium rigidum*) resistant to herbicides to grow to the two-leaf stage and then destroying it with tillage, prior to late seeding irrigated bread wheat cultivars, resulted in total weed control without sacrificing crop yield (Tanji and Boutfirass, unpublished) (Table 59).

VII.1.4. CROP DENSITY AND SEED RATE

The competitive ability of cereal plants with weeds can be achieved by increasing plant population or reducing the space for weeds. In general, a denser plant stand allows the crop to compete better with weeds. In certain cases, however, a high seeding rate may allow farmers to eliminate in-crop herbicide or reduce herbicide rates. The higher density smothers weeds, due to better early canopy coverage. Maata (1994) found higher rainfed bread wheat density (400 plants/m²) was effective in reducing weed biomass compared to low crop density (200 plants/m²) (Table 60).

VII.1.5. MECHANICAL WEED CONTROL

Tillage is one of the most important weed control tools in crop production systems. Tillage operations that aim to kill weeds work best in drier conditions. At planting, tillage operations serve the dual purpose of preparing the seedbed and controlling weeds (in case weeds and volunteer crops have already emerged). Complete control of weeds present at the time of planting is required for a successful integrated crop management.

Table 60. Effect of rainfed bread wheat density on weed biomass in Chaouia, in 1995- 96 (Maata, 1994).

	Weed biomass (g/m²)	
Bread wheat density (plants/m²)	**200**	**400**
Rigid brome	125	26
Broadleaf weeds	57	29

VII.1.6. MANUAL WEED CONTROL OR HAND PULLING WEEDS

Many farmers in rainfed areas of Morocco practice a fallow/cereal/food legume rotation. Thus, animal feed comes from weedy fallow, barley grain, cereal and food legume straw, and weeds collected from cultivated fields. Farmers collect weeds from cultivated fields, roadsides, and field edges to feed their animals, and weed control strategy is essentially based on hand pulling weeds. Hand pulling weeds from wheat and barley fields is done over an extended period of time (January to April) in order to provide daily green fodder for livestock. Prevalent collected weeds are mentioned in Table 61.

Studuying the forage quality of 26 common weeds collected from wheat fields in Chaouia, Tanji (1993) found that: (i) forage quality of weeds varied between species and plant stages, (ii) most weeds have good forage quality at the vegetative stage compared with the flowering or fruiting stage, and (iii) weeds can play an important role in feeding livestock in arid and semi-arid areas of Morocco (Table 62).

94 cropping season. Hand pulling weeds was ranked first with 60 hours which represented 9% of the total time spent on crop production. Hand pulling weeds was primarily performed by unpaid family male labor (78%); farmers' wives contributed with 22%. Hand pulling weeds was performed by sons alone in 33% of the cases. Farmers' wives and their children participated in 26%. Total hand weeding time was estimated at about 1300 hours with an average of 42 hours per hectare. In some cases, neighbors interested in weeds may ask for permission before entering cereal fields to collect for free large weeds to feed livestock.

Table 59. Effect of false seedbed, delay in seeding, and pre-emergence herbicides on rigid ryegrass shoot biomass at harvest in an on-farm experiment in 2016-17 at Souk Sebt, Tadla irrigated perimeter (Tanji and Boutfirass, unpublished).

	November 22 planting, rigid ryegrass shoots dry weight (g/m²)						December 26 planting, rigid ryegrass shoots dry weight (g/m²)					
	Amal	Faiza	Najia	Rajae	Wafia	LSD (0.05)	Amal	Faiza	Najia	Rajae	Wafia	LSD (0.05)
AUBAINE (4 L/ha) Chlortoluron (2000 g/ha) + Isoxaben (74.8 g/ha)	7	30	35	61	47	NS	0	0	0	0	0	NS
BOXER (5 L/ha) Prosulfocarb (4000 g/ha)	13	13	17	40	55	NS	0	0	0	0	0	NS
BOXER GOLD (2.5 L/ha) Prosulfocarb (2000 g/ha) + s-metolachlore (300 g/ha)	0	0	40	23	27	NS	0	0	0	0	0	NS
PROWL (4 L/ha) Pendimethaline (1320 g/ha)	73	57	0	63	67	NS	0	0	0	0	0	NS
Untreated Check	583	930	150	715	1017	280	0	0	0	0	0	NS
LSD (0.05)	212	70	73	168	67		NS	NS	NS	NS	NS	

From the farmers' point of view, hand pulling weeds is used more to provide gradual feed for livestock than to increase crop production. Livestock production plays a strategic role in sustaining rainfed farming systems. Livestock production represents relatively less risk than crop production and it contributes the largest share to farmers' income.

From the weed scientits' point of view, hand pulling weeds is not an adequate method to control weeds in small grain cereals. Tanji and Regehr (1988) found in 39 on-farm trials in the Settat province that 1 kg of dry weight of hand pulled weeds equaled 0.4 kg of bread wheat grain yield loss. Hand pulling did not increase grain yield over the nonweeded plots because of (i) trampling of the crop by individuals; (ii) damaging wheat plants by nearby weeds being pulled; and (iii) late timing of the removal of weeds. However, pulling weeds at the booting stage of wheat reduced the density and dry weight of weeds by 38 and 69% respectively, compared with unweeded control plots. Generally, manual weeding is less effective under heavy soil, while most efficient in light soils. Hand weeding is ineffective particularly with grassy weeds and perennials. Herbicides have now replaced the manual weeding at most of the fields due to increased labour cost and non-availability of labour during peak periods of weeding.

Table 62. Persons who contribute to manual weeding in Chaouia, semi-arid Morocco.

Household members	Distribution of farm households *(%)*
Farmer and wife	19
Farmers and adult sons	10
Farmer, male and female children	10
Framer alone	6
Wife alone	13
Wife and adult sons	7
Wife and adult daughters	3
Adult sons alone	19
Adult sons, daughters and stepdaughters	10
Male and female children	3

Table 61. Forage quality of some weeds collected from wheat fields in Chaouia, semi- arid Morocco (Tanji, 1993).

	% digestibility		*% crude protein*	
Weed species	Veg. stage	Flow. stage	Veg. stage	Flow. stage
Anagallis arvensis	67	63	21	13
Anchusa azurea	55	56	20	16
Astragalus boeticus	71	72	23	16
Bupleurum lancifolium	74	68	12	12
Calendula arvensis	68	67	22	16
Chenopodium murale	75	71	21	18
Chrysanthemum coronarium	70	63	25	11
Cichorium intybus	66	64	21	14
Convolvulus althaeoides	69	62	22	14
Convolvulus arvensis	71	66	24	20
Cynodon dactylon	59	55	15	10
Ecballium elaterium	76	73	25	23
Emex spinosa	68	57	23	14
Galium tricornutum	7	13	18	13
Glaucium corniculatum	66	55	25	15
Medicago polymorpha	79	66	20	14
Melilotus sulcatus	76	70	24	18
Misopates orontium	74	69	19	12
Papaver rhoeas	72	67	24	17
Ridolfia segetum	78	65	19	12
Scorpiurus muricatus	67	69	17	15
Silene vulgaris	74	68	20	14
Sinapis arvensis	71	68	27	19
Vaccaria hispanica	75	74	19	10
Ziziphus lotus	52	x	18	x
Cultivated forage crops				
Vicia villosa + Avena sativa	x	73	x	16

VII.1.7. GRAZING

Not all weeds growing in one-year-fallow or fields before planting small grain cereals need to be controlled with tillage or herbicides. Usually, fallow land is grazed during several months (generally from December to April) by various animals (cattle, sheep, goats, donkeys, and horses) or hayed in April, baled, and stored for sale or for feed. This is done because many farmers grow small grain cereals in rotation with weedy fallow. They claim that they practice cereal/weedy fallow rotation because they need the weeds as forage for their livestock. Most of weeds found in weedy fallow have good forage quality, particularly at the vegetative stage (Tanji, 1993).

VII.1.8. CHEMICAL WEED CONTROL

Herbicides are often the primary tools of choice for weed management. Many different herbicides and herbicide formulations are commercially available, including soil-applied and foliar-applied products, selective and nonselective products, products with long soil persistence, and products with no soil residual activity. The selection of which herbicide to use should be based on multiple factors, including soils, cropping rotations; tillage practices, and weed species. Sole dependence on herbicides may not necessarily provide the most economical or sustainable weed management. Integrating multiple practices reduces the likelihood of poor weed control due to unfavorable environmental conditions and reduces the intensity of selection for herbicide-resistant weeds.

PRE-PLANT HERBICIDES: With conventional planting or direct drilling (no-till), the control of weeds and volunteer crops can be accomplished before planting with burndown herbicides such as glufosinate, glyphosate or paraquat. Adjuvants may be tank-mixed with these herbicides to help improve control of certain weed species. The required application rate varies, depending on plant species and size. Glufosinate and paraquat are both contact herbicides and provide faster kill. Glyphosate is preferred if perennial weeds are present. If no weeds and no volunteer crops are present, a burndown herbicide is not needed (Tanji *et al*., 2017a; 2017b).

PRE-EMERGENCE HERBICIDES: Preemergence herbicides require appropriate soil moisture (from rain or irrigation) after planting cereals. Many weed species, in particular small-seeded ones, germinate from shallow depths in the soil. The top 2 à 5 cm of soil is the primary zone of weed seed germination and should thus be the target area for herbicide placement. Shallow incorporation can be achieved by precipitation or irrigation. Generally, 10 to 20 mm of rain or irrigation within 7 to 10 days are sufficient. Herbicides remaining on the soil surface, or those placed too deeply in the soil, may not be intercepted by the emerging weed seedlings. Herbicides that remain on a dry soil surface after application may not provide much effective weed control and are subjects to various dissipation processes that reduce their availability. Volatility (the change from a liquid to gaseous state) and photolysis (degradation due to absorption of sunlight) are two common processes that can reduce the availability of pre-emergence herbicides remaining on the soil surface.

In Morocco, chlorotoluron (2000 g/ha) + isoxaben (74.8 g/ha), prosulfocarb (4000 g/ha), and prosulfocarb (2000 g/ha) + s-metolachlore (300 g/ha) can be used in wheat or barley to control rigid ryegrass that is resistant to herbicides. Tanji and Boutfirass (2018) found that these 3 preemergence herbicide treatments reduced rigid ryegrass shoot biomass by >90% 1 to 3 months after treatments (MAT). Pendimethalin (1320 g ha^{-1}) achieved 83-99% rigid ryegrass control 1 to 3 MAT. The authors confirmed that preemergence herbicide treatments may reduce wheat density if heavy rain occurs after herbicide treatments and before crop emergence. They concluded that preemergence herbicides can be used by wheat growers as part of an integrated weed management program.

POST-EMERGENCE HERBICIDES: Table 63 cites herbicides registered for weed control in small grain cereals. It should be noted that high relative humidity, adequate soil moisture, and moderate to warm air temperatures all favor enhanced herbicide absorption. Conditions that enhance herbicide absorption into weeds also enhance absorption into the crop, which may result in crop injury. Postemergence herbicides vary in their mobility within the plant. Some demonstrate very limited movement following absorption and are commonly referred to as “contact” herbicides (example diflufenican which is a broadleaf herbicide for use in wheat and barley). Others can move extensively within the vascular elements of the plant and are referred to as “translocated” herbicides (examples 2,4-D, MCPA, amidosulfuron, dicamba, florasulam, iodosulfuron, mesosulfuron, metosulam, metsulfuron, pyroxsulam, triasulfuron, tribenuron, etc.). Contact herbicides do show some movement following absorption, but they do not move nearly as extensively as translocated herbicides. Thorough spray coverage of the plant foliage is very important with contact herbicides but some-what less important with translocated herbicides.

VII.2. EFFECTS OF WEED MANAGEMENT ON BREAD WHEAT

Research on weed control in bread wheat started with 2,4-D herbicide in 1948-49 (Lobstein and Giannesini, 1950; Grillot, 1951). Tanji (2002a) reviewed 123 weed control trials in bread wheat conducted in 10 provinces and 4 perimeters from 1948- 49 to 2000-2001: 100 trials in rainfed conditions and 23 trials irrigated. A total of 39 herbicides with one, two or three active ingredients were tested in rainfed trials and 21 herbicides evaluated in irrigated trials. Increases in grain yield compared to untreated checks exceeded l00% in 10 rainfed and 8 irrigated trials. They exceed 1000 kg/ha in 16 rainfed (16%) and 19 irrigated (83%) trials. Increases in straw yield exceeded 1000 kg/ha in 4 rainfed and 4 irrigated trials. The excellent effectiveness of herbicides on weeds and increases in bread wheat yields have been reported in several weed control trials (Tanji and El Mejahed, 2004; Hajjaj *et al*., 2016, Tanji *et al*., 2017; Tanji and Boutfirass, 2018).

Table 63. Crop tolerance and weed response to herbicides in small grains

Herbicide (rate ha^{-1})		Site of action (HRAC)	Crop tolerance			Annual grass weeds				Annual broadleaf weeds						
			Wheat and triticale	Barley	-	Canarygrass (*Phalaris*)	-	Oat (*Avena*)	Brome (*Bromus*)	Poppy (*Papaver rhoeas*)	Crown daisy	Marigold (Calendula)	Milk thistle (Silybum	Wild mustard (*Sinapis arvensis*)	Mallow (*Malva parviflora*)	Spiny emex (*Emex*
Metsulfuron (6 g)	STARKEM (10 g) and others	B	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Tribénuron methyl (9.375 g)	GRANSTAR (12.5 g) and others	B	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Amidosulfuron (15 g) + iodosulfuron (3.75 g)	SEKATOR (150 ml)	B	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Aminopyralide (9.9 g) + florasulame (4.95 g)	LANCELOT (33 g)	O+B	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Dicamba (120 g) + 2,4-D (344 g)	DIALEN SUPER (1 L)	0	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Flumetsulam (5 g) + florasulam (3.75 g)	DERBY (50 ml)	B	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Florasulam (3.75 g) + 2,4-D (180 g)	MUSTANG (600 ml) and others	B+O	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Triasulfuron (6.15 g) + dicamba (98.85 g)	LINTUR (150 g) and others	B+O	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Tribénuron methyl (5 g) + thifensulfuro n (10 g)	HARMONY (20 g) and others	B	T	T	T	T	T	T	T	S	S	S	S	S	S	S
2,4-D		O	T	T	T	T	T	T	T	S	S	S	S	S	S	S
2,4-D + MCPA		O	T	T	T	T	T	T	T	S	S	S	S	S	S	S
Clodinafop (60 g)	TOPIK (750 ml)	A	T	T	S	T	S	S	S	T	T	T	T	T	T	T
Flucarbazone (61.4 g)	EVEREST (43 g)	B	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Fenoxaprop (64 g)	PUMA (1 L)	A	T	S	S	S	S	S	S	T	T	T	T	T	T	T
Pinoxaden (45 g)	AXIAL (1 L)	A	T	S	S	S	S	S	S	T	T	T	T	T	T	T
Pyroxsulam (225 g)	PALLAS (500 g)	B	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Pinoxaden (22.5 g) + clodinafop (22,5 g)	TRAXOS (1 L)	A	T	S	S	S	S	S	S	T	T	T	T	T	T	T
Tralkoxydime (250 g)	MAJOR (1 L)	A	T	S	S	S	S	S	S	T	T	T	T	T	T	T
Sulfosulfuron (75%)	APYROS (26.6 g)	B	T	S	S	S	M	S	S	S	S	S	S	S	S	S
Iodosulfuron (8 g) + fenoxaprop (64 g)	HUSSAR (1 L)	A+B	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Mesosulfuron (15 g) + iodosulfuron (3 g)	ATLANTIS (500 ml)	B	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Mesosulfuron (7.5 g) + iodosulfuron (7.5 g)	COSSACK (1 L)	B	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Meso (7.2 g) + iodo (6 g) + diflufen (96 g)	KALENKOA (1 L)	B+F1	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Meso (7.5 g) + iodo (2.5 g) + diflufen (50 g)	OTHELLO (800 ml)	B+F1	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Pinoxaden (45 g) + florasulam (5 g)	NAVIGATOR (1 L)	A+B	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Pinox (30 g) + clodin (30 g) + floras (7.5 g)	SWIPE (1 L)	A+B	T	S	S	S	S	S	S	S	S	S	S	S	S	S
Pyroxsulam (22.656 g) + florasulam (4.260 g)	FLORAMIX (320 g)	B	T	S	S	S	S	S	S	S	S	S	S	S	S	S

Crop tolerance: S: susceptile (crop injury: 70-100%); M: moderately susceptible (crop injury: 40-70%); T: tolerant (crop injury: 0-40%). Weed response: S: susceptile (efficacy 70-100%); M: moderately susceptinble (efficacy: 40-70%); T: tolerant (efficacy: 0-40%). Meso: mesosulfuron, iodo: iodosulfuron, diflufen: diflufenican, pinox: pinoxaden, clodin: clodinafop, floras: florasulam. HRAC: Herbicide Resistance Action Committee. A: inhibitors of acetyl coenzyme A carboxylase (ACCase). B: inhibitors of acetolactate synthase (ALS). F1: inhibitors of carotenoid biosynthesis at the phytoene desaturase step (PDS). O: action like indol acetic acid (synthetic auxins).

Several research documents were about rigid brome (*Bromus rigidus*) which is a major weed in the Sais and Chaouia regions. They focused on brome seedbank (Fatah, 1989; Hfidi, 1989; Hamal *et al*., 2001c; Hamal *et al*., 2007; Tanji *et al*., 2017b), competition (Saffour 1992; Hamal, 1993; Hamal *et al*., 1994; Hamal *et al*., 1996b; Hamal *et al*., 1998; Rzozi *et al*., 1998; Hamal *et al*., 2000a; Tanji, 2000b; Hamal *et al*., 2001a ; Hamal *et al*., 2001b; Hamal *et al*., 2005; Tanji and Lhaloui, 2009), and control (Hassnaoui, 1994; Rsaissi, 1994; Boukhsim, 1995; Hamal *et al*., 1995; Hamal *et al*., 1996a; Jawad, 1996; Saffour and Bouhache 1996; Bouhache and El Antri, 1997; Bouhache *et al*., 1997; Hamal, 1997; Hamal *et al*., 1997; Bouhache and El Antri, 1998;Tanji 1998a; Tanji, 1999a; Abdennadher, 2000; Hamal *et al*., 2000b; Hamal *et al*., 2000c; Bouhache *et al*., 2001; Tanji, 2001b; Ait Bouhouch, 2002; Hamal *et al*., 2010; Joine, 2010).

Herbicides that were tested on rigid brome included metribuzin (Hassnaoui, 1994; Rsaissi, 1994; Boukhsim, 1995; Hamal *et al*., 1995; Hamal *et al*., 1996a; Saffour and Bouhache 1996; Bouhache and El Antri, 1997; Bouhache *et al*.; Hamal, 1997; Hamal *et al*., 1997; Bouhache and El Antri, 1998;Tanji 1998a; Hamal *et al*., 2000c), triallate (Jawad, 1996; Bouhache *et al*., 2001), and sulfosulfuron (Tanji, 1999a; Abdennadher, 2000; Hamal *et al*., 2000c; Tanji, 2001b; Hamal *et al*., 2000b; Ait Bouhouch, 2002; Hamal *et al*., 2010; Joine 2010).

Sulfosulfuron at 20 g/ha (+ adjuvant) controlled rigid brome and some broadleaf weed species such as wild mustard (*Sinapis arvensis*) and bedstraw (*Galium tricornutum*) without affecting bread wheat. However, it persisted in treated soils and affected the emergence of the crops planted several months after treatment (Abdennadher and Tanji, 2000; El Ghasi, 2003). Combining herbicides and other cultural practices reduced rigid brome density (Maata 1994; Hamal *et al*., 1998b; Hamdaouy, 1998; Grimmeh, 2000; Ferrak, 2001; Hamal, 2005). Sulfosulfuron (20 g/ha) applied postemergence at 2-3 leaf stage of rigid brome provided excellent control compared to than when applied at the tillering stage, while late applications suppressed rigid brome, but brome plants were partially controlled and produced seed (Tanji, 1999b). However, effective control of rigid brome can be obtained in the food legume or dicotyledon phase of crop rotations with the use of acetyl-Coenzyme A carboxylase (ACCase)-inhibiting herbicides (graminicides). Because of greater risk of food legume crop failure due to drought and higher input costs as compared to small grain cereals, growers are reluctant to cultivate legumes in low rainfall regions such as Chaouia and Sais. Dryland cropping systems in Morocco are therefore dominated by wheat and barley crops (monocropping) where it is difficult to achieve excellent, selective, and sustainable control of rigid brome. Wheat rotation with canola or barley+pea reduced rigid brome seedbank and density compared to monocropping wheat (Tanji *et al*., 2017b).

Annual ryegrass (*Lolium multiflorum*) and rigid ryegrass (*Lolium rigidum*) are both major weeds in small grain cereals (Tanji, 2005). However, rigid ryegrass has now evolved resistance to many herbicides with different modes of action (Tanji, 2009a; Tanji, 2014; Tanji and Boutfirass, 2018). Tanji (1999b) found that rigid ryegrass produced 68 to 8976 seeds/plant in wheat fields. Most of these seeds do not have long dormancy, and can easily germinate under field and greenhouse conditions. In a competition study, Tanji (1994d) and Tanji *et al*., (1997) reported that one bread wheat plant was as competitive as 11 or 19 rigid ryegrass plants in greenhouse and field experiments, respectively. They found that growth analyses of individual plants showed that wheat had a greater leaf area, shoot and root dry weight, and absolute growth rate than rigid ryegrass, particularly early in the season.

Sterile oat is an annual grassy weed that infests cereal crops (Tanji, 2005). The potential reproductive output of sterile oat is substantial, with as much as 1292 seeds per plant produced in wheat fields (Tanji, 1999b). The negative outcome of sterile oat competition on wheat yield and profitability is extensive (Petzoldt and Salah Bennani, 1978; Soriba, 1982; Laita and Lasly, 1983; El Atmani and Oudou, 1984; Schuler 1984a; 1984b; Schuler and koch, 1984; Moutawakil, 1988). Several pre-emergence and post-emergence herbicides were evaluated for its control (Traoré, 1983; El Antri, 1995; El Antri, 1998; Bencheikh, 1995; El Antri *et al*., 1995a, 1995b, 1996; El Antri and Nalewaja, 1997). Despite large efforts to control the weed through herbicide use and various technological advancements, sterile oat populations continue to persist, and it remains one of the most abundant and competitive weeds (Zidane, 2004; Tanji, 2005).

There are 3 annual canarygrass weed species found in cereal fields (*Phalaris brachystachys*, *P. minor*, *P. paradoxa*) (Tanji, 2005). Studies have indicated that competition between canarygrass weeds and wheat is affected by weed species, weed density, crop density as well as environmental factors (Hoesle, 1984a). The most likely reasons for their prevalence in cereal crops are their similar growth period with that of small grain cereals, the earlier dispersal of seeds before cereal harvest, the ability of seeds to remain dormant in the soil for several years, the cereal grown in monoculture, and the low use of effective herbicides for their control in cereals.

Mouse barley (*Hordeum murinum*) is a vigorous winter annual. It is considered a weed in small grain cereals and other crops (Bouhache and Taleb, 2013). After flowering in the spring, the grass matures rapidly to produce a large number of viable seeds. These seeds easily disperse when the long awn attaches to stock and wildlife, and then to the soil. The majority of seeds remain dormant during the heat of the summer, not germinating until the autumn. The weed has demonstrated a superior capacity to set seed in difficult seasons, such as during droughts. Seeds shatter before cereal harvest, so that they rarely contaminated crop seeds. Sulfosulfuron at 20 g/ha provided excellent control of mouse barley (Tanji, 1999a).

Wild mustard (*Sinapis arvensis*) is considered a serious weed of small grain cereals (Tanji, 2005). Its prolific seed production and persistent seedbank ensure that even a small number of plants surviving weed control measures can produce seeds that contaminate crop production (Tanji and Nassif, 1997 and 1999). In wheat fields, wild mustard produced 84 to 14538 seeds/plant with an average of 1093 seeds/plant (Tanji, 1999b). Wild mustard is a host to insect, nematode, fungal, and viral pests that cause damage to various cultivated crops (Tanji *et al*., 1995; Taleb *et al*., 1999) and it produces glucosinolates, which can be toxic to animals in large doses. The species germinates during fall and winter months (October to February). Competition studies showed that wild mustard reduced wheat yields (Rahali, 1982; Soriba, 1982). Wild mustard can be controlled by all wheat herbicides (Tanji *et al*., 2017).

Cowcockle (*Vaccaria hispanica*) is a prevalent annual broadleaf weed (Tanji, 2005). In wheat fields, Tanji (1999b) found that one cowcockle plant produced 14 to 2286 seeds/plant, with an average of 321 seeds/plant. The law prohibits the sale of small grain cereals contaminated with cowcockle seed (Tourkmani *et al*., 2000). Cowcockle competes with wheat and reduce crop biomass and yield (Rahali, 1982; Soriba, 1982). In greenhouse and field experiments, Tanji (1994) and Tanji *et al*., (1997) found that one wheat plant was as competitive as 3 to 24 cowcockle plants, depending on environmental conditions. They reported that wheat had a greater leaf area, shoot and root dry weight, and absolute growth rate than rigid ryegrass or cowcockle, particularly early in the season.

In wheat and barley, chemicals applied early post-emergence that provide acceptable crop safety and control bedstraw, include bromoxynil + MCPA ester + dicamba, flumetsulam, bromoxynil + diflufenican, fluroxypyr and amidosulfuron. Metsulfuron- methyl, metsulfuron-methyl + bromoxynil + MCPA ester, bromoxynil + MCPA ester and chlorsulfuron did not consistently control bedstraw in cereals. Bedstraw can be effectively controlled at later cereal growth stages with 2,4-D amine or fluroxypyr. Yield responses to chemical control of bedstraw were greater with herbicide applied earlier than later in the growing season.

Corn cleavers or threehorn bedstraw (*Galium tricornutum*) is an important dicotyledonous weed of small grain cereals (Tanji, 2005). It is considered a competitive weed, where an infestation of 100 plants m^{-2} can reduce wheat yield (Soriba, 1982). It is also known to contaminate cereal grain during harvesting (Tanji and Nassif, 1997; 1999). It produced 25 to 132 seeds/plant with an average of 63 (Tanji, 1999b). The law prohibits the sale of small grain cereals contaminated with corn cleavers seed (Tourkmani *et al.*, 2000).

Crownbeard (*Verbesina encelioides*) is an annual Asteraceae that was inadvertently introduced into Morocco probably in 2000 (El Mfadli, 2001; Taleb *et al*., 2002). It is a weed that flowers and produces seed all year round. Pure stands of this weed appear in a variety of habitats in different regions in the North and South of the country. It is abundant along roadsides and railway roads, and on the wastelands, occurring mostly in sandy soils. It propagates by seeds which are produced in abundance. Its seeds exhibit remarkable endurance to climatic extremes and survive under extremely high summer temperatures (30 to 40 °C) and soil droughts during which they lie dormant in soils. Due to its bad odour, the plant is not edible by livestock.

Native to South Africa, Bermuda buttercup (*Oxalis pes-caprae*) infests Chaouia and other regions of Morocco. It blooms in fall and winter (October to January). The plant is difficult to eradicate because it spreads via bulbs (Rsaissi, 1994; Rsaissi and bouhache, 1994; Tanji 1994b). Tribenuron 9.37 g/ha followed by metribuzine 350 g/ha applied at early and late tillering reduced density 96% and biomass 99% (Rsaissi and Bouhache, 1994). Tribenuron 11.25 g/ha applied at early tillering reduced density 60% and biomass 93% (Rsaissi and Bouhache, 1994).

Since 1980, numerous studies have been accomplished on the biology of silverleaf nightshade (*Solanum elaeagnifolium*) (Tanji *et al*., 1984; 1985; Bouhache and Tanji, 1985 ; Tahri, 1987; Tahri *et al*., 1989a, 1989b; 1992; Taleb, 1996; 1998c; Ameur, 1993; Taleb, 1996; Gmira *et al*., 1997; Zaki, 1997; Taleb 1998c; Ameur *et al*., 2000; Chafik *et al*., 2013a) and its control (Tahri, 1987; Tahri *et al*., 1989a; 1989b; Tahri *et al*., 1992; Ameur, 1993; Taleb, 1996; Gmira *et al*., 1997; Zaki, 1997; Taleb 1998c; Ameur *et al*., 2000; Chafik *et al*., 2013a). The weed infests cereals in spring (heading to maturity or February to June) when it is not possible to spray broadleaf herbicides in cereal crops. However, results showed that glyphosate efficacy on silverleaf nightshade was influenced by growth stage, herbicide rate, adjuvant, environmental conditions, and spray solution pH. *Solanum elaeagnifolium* Wild jujube (*Ziziphus lotus*) is considered a deciduous and thorny shrub that can cause complete crop loss by preventing harvest operations. Field studies conducted by Regehr and El Brahli (1995) showed that 1 year after treatment, over 97% reduction of wild jujube regrowth was achieved with initial treatments of 7.2 and 10.7 g ae/L of the isopropylamine salt of glyphosate, 2.4 and 3.6 g ae/L of the potassium salt of picloram, and mixtures of glyphosate plus picloram at half those concentrations, followed 2 to 3 mo later with a repeat herbicide treatment or sweep tillage. About 60% reduction in wild jujube regrowth was achieved with two sweep tillage operations 25 cm deep. Mixtures of half rates of glyphosate plus picloram were less costly than full rates of glyphosate alone and had less carryover to wheat than full rates of picloram alone. Other field trials revealed that high rates of glyphosate provided excellent control of wild jujube (Rsaissi and Bouhache, 1994).

Hoary cress or whitetop (*Cardaria draba*) is a perennial herbaceous weed that is considered a major weed in small grain cereal (Tanji, 2005). Most increases in ramet density are due to vegetative reproduction and seed germination. The weed forms dense patches in cultivated and natural areas in several areas particularly in the East of Morocco (Chafik *et al.*, (2013c).

VII.3. WEED MANAGEMENT IN DURUM WHEAT

The oldest report on weed control in durum wheat was that of Anechoum (1975). The author did a survey in 44 durum wheat fields in Larache area and found that 52% of fields were sprayed with 2,4-D and 37% were weeded manually in 1974-75. In a synthesis of 117 chemical weed control trials conducted in 7 provinces and 4 irrigated perimeters from 1970-71 to 2000-01, Tanji (2002) found that 45 herbicides with one, two or three active ingredients were tested in rainfed trials and 15 herbicides were evaluated in irrigated trials. Wheat grain yield losses due to weeds varied from 0 to 100% in rainfed trials and from 0 to 80% in irrigated trials. Increases in grain yield, compared to untreated checks, exceeded 100% in 8 rainfed and non irrigated trials. They were higher than 100 kg/ha in 100% of irrigated trials and in 70% of rainfed trials. They exceeded 1000 kg/ha in 24 irrigated trials (77%) and 15 rainfed triats (17%). Increases in staw yield exceeded I000 kg/ha in 10 irrigated trials and 6 rainfed trials. Increases in grain and straw yields were higher when weed control was associated with other efficient agricultural techniques.

Rigid brome (*Bromus rigidus*) infests durum wheat fields. In 2 field trials, Bouhache *et al.* (2001) found that metribuzin effectively controlled rigid brome 92-100% when applied at 700 g/ha at full tillering stage or when spliting rate (350 g/ha at full tillering and early jointing). A slight crop injury was noted on both varieties (Tassaout and Karim) when metribuzin was applied at early stages of growth. A moderate efficacy was obtained by diclofop-methyl incorporated in pre-sowing or by terbutryn in pre-emergence of durum wheat crop. A high negative correlation (R^2=0.87) was obtained between wheat yield and biomass of rigid brome.

VII.4. WEED MANAGEMENT IN RAINFED BARLEY

Tanji (2000) compiled 25 weed control tials in rainfed barley conducted from 1975 to 2000: 19 trials in the Settat province, 5 in the Kelaa des Sraghna province, and one in the Safi province. Yield losses due to weeds varted from 0 to 70%. More than 100% grain yield increase was obtained in 3 trials. Increase in grain yield was higher than 100 kg/ha in 76% of the trials. In a field study in Tadla, Tanji and El Mejahed (2004) showed that the application at early crop tillering of either triasuffitron + terbutryn (15 + 150 g/ha) or tribenuron methyl (9.375 g/ha) reduced weed dry weight 91 to 100%. Triasulfuron + terburtyne (15 + 150 g/ha) increctsed grain and straw yields of barley compared with 2,4-D + MCPA (33O + 341 g/ha) applied at crop jointing.

VII.5. WEED MANAGEMENT IN RAINFED TRITICALE

Tanji *et al*., (1993) found that triticale (*X. triticosecale*) was more competitive with weeds compared to barley, durum wheat, and bread wheat. However, 28% grain yield loss and 14% straw yield loss were found by Sebbani (1996). Therefore, weed control with herbicides is required if weed infestation is consistant. Tanji (1994) found that all post-emergence herbicides reduced weed density and biomass, and all herbicides, except dinoterb (600 g/ha) + mecoprop (100 g/ha), increased grain yield over the unweeded check. Most herbicides increased straw yields over the unweeded check. In a field study in Tadla, Tanji and El Mejahed (2004) showed that the application of triasulfuron + terbutryn (15 + 150 g/ha) at early crop tillering provided 95% control of broadleaf weeds and increased grain yield.

VIII. HERBICIDE APPLICATION TECHNOLOGY

To spray herbicides, most farmers use backpack sprayers, tractor or Jeep-mounted sprayers. Not all farmers calibrate their sprayers, and mistakes are often committed: nozzles, product rate, water volume, speed, pressure, etc. Weather conditions are often not respected when spraying. This may damage the crop, affect the environment, and/or increase the selection pressure for resistance to herbicides. Therefore, there is great need to educate farmers on proper spray technology. Care should also be taken to have good soil moisture for better performance of preemergence herbicides. Multiple-nozzles-boom should be developed and promoted for herbicide application. It will save application time and will improve weed control due to better coverage.

VIII.1. ROLE OF SURFACTANT AND ADJUVANT

Some of the herbicides (such as glyphosate before planting and postemergence sulfosulfuron or tralkoxydim, etc.) require surfactants for better efficacy. Surfactants help in better penetration and spread over leaf surface by reducing the surface tension thereby increasing the contact area. The efficacy of herbicide and herbicide mixtures can be improved with the use of surfactant and can reduce the dose of herbicides with increased spectrum of weed control. Many workers have reported improvement in the efficacy of sulfonylurea herbicides with surfactant. Many adjuvants also alter the cuticular waxes on the leaf surface which may enable herbicide to penetrate the cuticle. Some times foliar crop injury may occur with the use of surfactants. So, enough care should be taken while selecting surfactants. Fertilizers like ammonium sulfate increase herbicide absorption into plants because it overcomes the decreased herbicide activity due to antagonism caused by the presence of metal cations (Ca, Na, K and Mg) in water used as spray solution.

VIII.2. EFFECT OF HERBICIDES IN THE ENVIRONMENT

While herbicides are very important to agriculture, under certain circumstances they may act as pollutants that can deteriorate soils, ground waters, and surface waters. While most herbicides are not intentionally applied onto soil, they can enter the soil environment from (i) direct interception of spray by the soil surface during early season or post-harvest applications; (ii) runoff of the herbicide from vegetation; and (iii) leaching.

VIII.3. RESIDUAL EFFECT OF HERBICIDES ON SUCCEEDING CROPS

The time of an herbicide remains active in soil is called "soil persistence," or "soil residual life". For some herbicides, there may be a fine line between controlling weeds for the entire growing season and then planting a sensitive rotation crop. Anything that affects the disappearance or breakdown of herbicides affects persistance. Herbicides vary in their potential to persist in soil. Cereal herbicides that have persistence are aminopyralid, mesosulfuron, sulfosulfuron, triasulfuron, etc.

The persistence of herbicides in soils is a real problem for the environment (injury to succeding crops, toxicity to soil microflora, and ground water contamination) (Sayah, 1982, Machhouri, 1983; Amrani 1992, Zimdahl and El Brahli 1992, Mosseddaq *et al*., 1997; Dahchour and El Amrani 1999, El Ghazi 2003; Hassoun *et al*., 2017). Herbicides that are characterized by a short persistence period (usually a few days) are: cyhalofop (Maghfour *et al*., 2006) and 2,4-D phenoxycarboxylic or MCPA (El Hadiri *et al*., 1992, El Hadiri, 1994, Bahhar 2000, Belmouden *et al*., 2000, Fdil *et al*., 2003, Abounouass *et al*., 2006, Legrouri *et al*., 2006). Herbicides with medium or long persistence duration (usually a few months) included sulfosulfuron (Abdennadher and Tanji, 2000, Ait Bouhouch, 2002; El Ghazi, 2003), triasulfuron (Hormatallah, 1998), tribenuron (Dahchour *et al*., 2006), triflusulfuron (Chafik *et al*., 2001, Satrallah *et al*., 1996 and 1998), imazapyr (El Azzouzi *et al*., 1998, Baye 2000, Kaichouh *et al*., (2004), imazethapyr (El Azzouzi *et al*., 2002), triazines (Amrani 1992, Mountacer *et al*., 1996, Yassir, 1999, El Ghazi 2003), linuron (Dahchour *et al*., 2005, Haouari *et al*., 2005; 2006, El Imache *et al*., 2009; Rissouli *et al*., 2016a; 2016b), diuron (Haouari *et al*., 2006), ethofumesate (Satrallah *et al*., 2002), and isoproturon (El Khattabi *et al*., 2004).

In Morocco, damage due to herbicide residues has been observed in several regions on sugar beet, faba bean, and other sensitive crops. Using bioassays, Tanji (2009b) studied persistance of herbicides on germination and growth of sugar beet, bread wheat, oat, barley, lentil, and turnip. This study showed that herbicide residue damage observed on the seedlings of different indicator plants suggested 4 groups of herbicides: (i) group of herbicides without persistence or having a very short persistence (a few hours to a few days) such as phenoxycarboxylic; aryloxyphenoxypropionates and cyclohexanediones, (ii) group of herbicides having a persistence period ranging from 1 to 3 months such as acetochlor, alachlor, flucarbazone, linuron, metamitron, oxyfluorfen, pyroxsulam, and triflusulfuron, (iii) group of herbicides with a persistence of 4 to 6 months such as pendimethalin, tribenuron, and s-metolachlor, and (iv) a group of herbicides generally of 6 to 12 months persistence such as iodosulfuron, mesosulfuron, rimsulfuron, sulfosulfuron, triasulfuron, florasulam, flumetsulam, mesotrione and metribuzin. The author concluded that deep plowing, after harvesting crops treated with persistent herbicides, may help overcome the adverse effects of herbicide persistence.

VIII.4. PREHARVEST INTERVAL

Almost every postemergence herbicide has a preharvest interval specified on the label. A preharvest interval indicates the amount of time that must elapse between herbicide application and crop harvest. Such intervals are established to allow sufficient time for the herbicide to be broken down or metabolized in the plant. Additionally, the preharvest interval reduces the likelihood of herbicide residue remaining on the harvested portion of the crop. Failure to observe the preharvest interval may result in herbicide residue in the crop in excess of established limits. In addition to preharvest intervals, there are restrictions on many postemergence herbicides labels about whether the treated crop may be used for livestock feed or whether treated fields may be grazed as forage.

IX. WEED RESISTANCE TO HERBICIDES

In Morocco, rigid ryegrass has infested Tadla irrigated perimeter since 2010 (Baye, 2014) and Doukkala since 2000 (Tanji, 2009; 2011; Tanji *et al*., 2012; Tanji, 2013; El Aimani and Tanji, 2016). Rigid ryegrass is now resisting 13 herbicides (7 wheat herbicides: clodinafop, diclofop, fenoxaprop, mesosulfuron, pinoxaden, pyroxsulam, and tralkoxydim, and 6 sugar beet (and other broadleaf crops) herbicides: cycloxydim, fluazifop, haloxyfop, propaquizafop, quizalofop, and tepraloxydim). All these herbicides that are no longer effective on rigid ryegrass have two modes of action: inhibition of acetyl coenzyme A carboxylase (ACCase) (group A) such as clodinafop, cycloxydim, diclofop, fenoxaprop, fluazifop, haloxyfop, pinoxaden, propaquizafop, quizalofop, tepraloxydim, and tralkoxydim, and inhibition of acetolactate synthase (ALS) (group B) such as mesosulfuron and pyroxsulam. Temporarily, clethodim has the ability to control rigid ryegrass populations having resistance to other ACCase-inhibiting herbicides (Tanji, 2013).

Common poppy (*Papaver rhoeas*) populations resistant to herbicides have evolved in the Sefrou area since (2000) and later in Tadla irrigated perimeter since 2010 (Tanji, 2009; 2011, Tanji *et al*., 2012, Tanji, 2013). In 2017, the weed showed resistance to all broadleaf herbicides registered for weed control in small grain cereals, except aminopyralid. Herbicides that are no longer effective on common poppy are inhibitors of acetolactate synthase inhibitors (ALS) such as iodosulfuron, metsulfuron, pyroxsulam, thifensulfuron, triasulfuson, tribenuron and auxin inhibitors such as dicamba, 2,4-D, MCPA.

X. CEREAL INJURY DUE TO HERBICIDES

When a crop is growing under favorable conditions, it rapidly metabolizes the herbicide and no injury occurs. If, however, the wheat plant is under stress (which could be caused by a variety of factors), its ability to metabolize the herbicide may be slowed enough that injury symptoms develop. The environment has a large influence on the severity of crop injury symptoms from both soil-applied and postemergence herbicides. In most cases, herbicide selectivity arises from the crop's ability to metabolize the herbicide to a nonphytotoxic form before it causes injury.

In a greenhouse study, Lachgar (1996) noticed that 5 bread wheat cultivars and 5 durum wheat cultivars were tolerant to clodinafop when sprayed at 2-3 leaf stage or at the tillering stage at 60 or 120 g a.i./ha. Diclofop at 900 or 1800 g a.i./ha and fenoxaprop at 69 or 138 g a.i./ha injured "Karim" and "Cocorit". Tanji *et al.*, (2017) found that recommended rates of pyroxsulam and mesosulfuron + iodosulfuron caused severe injury to irrigated "Amal" bread wheat in Tadla and Doukkala, but grain yield was not affected. There were several cases of herbicide injury on bread wheat plants after application of preemergence herbicides such as prosulfocarb, prosulfocarb + s-metolachlore, chlorotoluron + isoxaben, or pendimethaline (Tanji *et al.*, 2018).

XI. EFFECT OF WEED CONTROL AND IRRIGATION

Irrigation and weed control with herbicides enhance crop growth. Field studies demonstrated that irrigation increased grain yield of bread wheat in Moulouya (Hamid, 1995), (Table 64).

XII. EFFECT OF WEED CONTROL AND FERTILIZER USE

Fertilizer use at planting as well as top dressing nitrogen after weed control with herbicides enhances crop growth. Field studies demonstrated that adequate fertilizers increased nitrogen content in grain and straw of bread wheat in Tadla (Diab, 1996), (Table 65).

XIII. EFFECT OF WEED CONTROL AND FOLIAR FUNGICIDES

Weed and disease control are two different management considerations in wheat production. For weed management, growers often use postemergence herbicides at the tillering stage of small grain cereals. For disease management, growers often use one or two foliar applications of fungicides. The first fungicide application is usually at the booting stage and the second at the heading stage. After an excellent weed control, one or two fungicide applications on weed-free wheat increased grain yield of irrigated bread wheat (Tables 66 and 67).

Table 64. Effect of weed control with herbicides and appropriate fertilizers on "Marchouch" bread wheat yield in 1994-95 in the Moulouya perimeter (Hamid, 1995).

	Grain yield of weedy wheat (kg/ha)	Grain yield of weed-free wheat (kg/ha)
Early seeding *(15 december 1994)*		
Irrigation	2605	3419
Rainfed	1300	1767
Late seeding *(16 january 1995)*		
Irrigation	3247	4093
Rainfed	1448	2025

Table 65. Effect of weed control on nitrogen concentration in wheat grain and straw in Tadla in 1994-95 (Diab, 1996).

	% nitrogen	
	Wheat grain at maturity	Wheat straw at maturity
Durum wheat		
Weedy wheat	2.07	0.54
Weed-free wheat	2.26	0.72
Bread wheat		
Weedy wheat	1.60	0.33
Weed-free wheat	2.18	0.46

Table 66. Effect of weed control and fungicides on grain yield in irrigated bread wheat in the Gharb (Zbair *et al.*, 2000).

	Grain yield (Kg/ha)		
	No foliar fungicide	1 foliar fungicide	2 foliar fungicides
Weedy wheat	2680	3760	x
Grass herbicides	3280	4100	x
Broadleaf herbicides	4120	6540	x
Grass and broadleaf herbicides	5290	7660	7860

Table 67. Effet du désherbage chimique et des fongicides foliaires sur le rendement du blé aux Doukkala en 1995-96 (Haichem, 1996).

	Grain yield in qx/ha				
Situation	Site 1	Site 2	Site 3	Site 5	Site 6
Weedy wheat	34	31	38	31	34
Désherbage chimique sans traitement avec les fongicides foliaires	54	52	59	51	55
Désherbage chimique avec traitement fongicide foliaire	63	62	60	61	60

XIV. HERBICIDE LEACHING

Leaching is one mechanism responsible for herbicide dissipation. The solubility of a herbicide in water helps determine its leaching potential. Leaching occurs when a herbicide is dissolved in water and moves down through the soil profile. Herbicides that readily leach may be carried away from crop and weed germination zones.

In general, those herbicides which are completely water-soluble are most easily leached. Salts of 2,4-D are water-soluble and leach readily through porous, sandy soils whereas esters of 2,4-D are low in solubility and do not leach easily. Herbicides have been known to move upward in the soil. If water evaporates from the soil surface, water may move slowly upward. The water may carry with it soluble herbicides. As the water evaporates, the herbicide is deposited on the soil surface.

XV. INFLUENCE OF THE HERBICIDES ON SOIL MICROBIAL COMMUNITY

Changes in microbial numbers and activities in a soil in response to bentazon applied at 10 and 100 ppm were studied after 4 and 30 weeks of incubation in laboratory conditions. As regards the eight general and functional microbial groups studied (aerobic and anaerobic bacteria, fungi, aerobic and anaerobic N2-fixing bacteria, nitrifiers, aerobic and anaerobic cellulolytic microorganisms), only the number of anaerobic N2-fixing bacteria significantly decreased, in the presence of the highest herbicide concentration for 30 weeks. At both the incubation times, only the higher dose of bentazon markedly inhibited soil nitrification and CO_2 emission. Methanogenesis was inhibited by 1000 ppm bentazon added to anaerobic liquid cultures containing 5% soil for at least 2 weeks. There was an incomplete recovery of the herbicide at the two incubation times: <5% of 10 ppm after 4 weeks and about 30% of 100 ppm after 30 weeks. No biodegradation of the compound was observed in liquid cultures under aerobic or anaerobic conditions. It is concluded that a bentazon concentration no higher than the field rate distributed within a 2-cm layer of soil does not considerably affect the microflora even in the absence of microbial degradation.

XVI. CONCLUSIONS AND PROSPECTS

Weeds are a major biotic constraint to cereal production all over the world, and Morocco is no exception. Herbicide use is increasing in different cereal crops and this trend is expected to continue. Increased use of herbicides has been associated with shifts in weed population, increased costs of chemical control measures, and concerns over the environment. In addition, there is evidence of weeds developing multiple resistance to herbicides of different modes of action, risking the sustainability of herbicides. Prevention of weeds developing resistance in farmers' field is emerging as a major challenge, as new herbicides are being introduced into Morocco. pendimethalin, tribenuron, and s-metolachlor, and (iv) a group of herbicides generally of 6 to 12 months persistence such as iodosulfuron, mesosulfuron, rimsulfuron, sulfosulfuron, triasulfuron, florasulam, flumetsulam, mesotrione and metribuzin. The author concluded that deep plowing, after harvesting crops treated with persistent herbicides, may help overcome the adverse effects of herbicide persistence.

VIII.4. PREHARVEST INTERVAL

Almost every postemergence herbicide has a preharvest interval specified on the label. A preharvest interval indicates the amount of time that must elapse between herbicide application and crop harvest. Such intervals are established to allow sufficient time for the herbicide to be broken down or metabolized in the plant. Additionally, the preharvest interval reduces the likelihood of herbicide residue remaining on the harvested portion of the crop. Failure to observe the preharvest interval may result in herbicide residue in the crop in excess of established limits. In addition to preharvest intervals, there are restrictions on many postemergence herbicides labels about whether the treated crop may be used for livestock feed or whether treated fields may be grazed as forage.

IX. WEED RESISTANCE TO HERBICIDES

In Morocco, rigid ryegrass has infested Tadla irrigated perimeter since 2010 (Baye, 2014) and Doukkala since 2000 (Tanji, 2009; 2011; Tanji *et al.*, 2012; Tanji, 2013; El Aimani and Tanji, 2016). Rigid ryegrass is now resisting 13 herbicides (7 wheat herbicides: clodinafop, diclofop, fenoxaprop, mesosulfuron, pinoxaden, pyroxsulam, and tralkoxydim, and 6 sugar beet (and other broadleaf crops) herbicides: cycloxydim, fluazifop, haloxyfop, propaquizafop, quizalofop, and tepraloxydim). All these herbicides that are no longer effective on rigid ryegrass have two modes of action: inhibition of acetyl coenzyme A carboxylase (ACCase) (group A) such as clodinafop, cycloxydim, diclofop, fenoxaprop, fluazifop, haloxyfop, pinoxaden, propaquizafop, quizalofop, tepraloxydim, and tralkoxydim, and inhibition of acetolactate synthase (ALS) (group B) such as mesosulfuron and pyroxsulam. Temporarily, clethodim has the ability to control rigid ryegrass populations having resistance to other ACCase-inhibiting herbicides (Tanji, 2013).

Common poppy (*Papaver rhoeas*) populations resistant to herbicides have evolved in the Sefrou area since (2000) and later in Tadla irrigated perimeter since 2010 (Tanji, 2009; 2011, Tanji *et al.*, 2012, Tanji, 2013). In 2017, the weed showed resistance to all broadleaf herbicides registered for weed control in small grain cereals, except aminopyralid. Herbicides that are no longer effective on common poppy are inhibitors of acetolactate synthase inhibitors (ALS) such as iodosulfuron, metsulfuron, pyroxsulam, thifensulfuron, triasulfuson, tribenuron and auxin inhibitors such as dicamba, 2,4-D, MCPA.

The major future challenges Moroccan weed scientists currently face include developing innovative, effective, economical, resilient, and environmentally safe weed management technologies to successfully manage weeds, particularly at a time when the effects of climate change are being felt. In this regard, greater emphasis needs to be given to the following:

• Yield loss due to weeds: this should be pursued on farmers' fields in different

agro-ecological regions to quantify crop losses caused by weeds.

• Weed biology and ecology: more studies are needed on weed ecology and biology, especially in understanding the seed bank dynamics in different locations and cropping systems. Better understanding of weed seed germination is needed to manage weeds effectively in conventional and conservation agriculture systems. Farmers need to identify the weed problems before implementing integrated weed management. Help with the identification of weeds can be obtained on the web, or from local advisors. Importantly, the types and amounts of weedy species do not stay static. Instead, they fluctuate based on environmental factors and previous management practices. As such, weed scientists (and also farmers) need to be aware of the changes and keep up to date with the current weed problems in production fields.

• Weed resistance: research must involve herbicide resistance, weed eco- physiology, molecular biology and genetics, assessment of pre- and post-control shifts in weed community.

• Integrated weed management: Future research needs to focus on evaluation of the effect of agronomic approaches (i.e. cultural weed control methods, such as crop rotations, high seeding rates, narrow rows, weed-competitive cultivars, false seedbed, late planting, etc...) on weed management, especially where herbicide use is limited or less effective. In addition to developing weed competitive cultivars, allelopathic crop cultivars may be identified and evaluated. Integrated weed management practices are required for effective management of weeds in small grain cereals. Such practices also include prevention, crop rotation, herbicide rotation and mixture, mechanical weeding, cultural control, and manual weeding. It is very clear that herbicide alone will not be the solution for weed problem.

• Climate change: there is a need to increase research on how weeds and weed management practices may respond to the climate changes. Climate change is becoming a reality, and increase in temperature, atmospheric greenhouse gases, and water shortage have multiple impacts on weeds. It may increase the adoption of conservation agriculture systems, in which glyphosate and other herbicides could be used. Increased C02 concentrations may also stimulate below-ground plant growth, suggesting that the problem of perennial weeds may increase with climate change. Better understanding of weed response to climate change will help improving weed management in the future.

• Extension activity on proper herbicide use: There is a need to set up linkage between research and extension to educate farmers on the judicious use of herbicides and other weed management methods. The recent advances in communication and information technology may effectively be used for transferring weed management technologies to farmers.

• On-farm assessment of available IWM options: the IWM options identified by researchers must be tested in the farmers' fields to assess their effectiveness and economic viability. Closer linkage between research and extension is needed to scale out effective and economical IWM options.

• Knowledge-based decision making tools: There is a need to (i) develop a larger database of weed ecology and biology characteristics; (ii) develop, improve, and refine integrated weed management system simulation models; and (iii) determine the utility of these models to be used by farmers and extension personnel in IWM and to predict areas of future research.

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INTEGRATED PEST MANAGEMENT IN CEREAL AND FOOD LEGUMES CROPPING SYSTEM IN MOROCCO BASED ON FARMER PARTICIPATORY APPROACHES

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SYNOPSIS

Cereals and food legumes are the major food and feed crops in Morocco. They occupy more than 70% of the arable land of the country. However, their yield potential is far from being reached because of the negative effects of several biotic and abiotic factors. Indeed, insect pests, diseases and weeds cause heavy yield loss yearly both in quantity and quality. Even though pest control options are continuously being developed by researchers and made available for use by farmers, they are very slow to reach these end users. In this study, a farmer participatory based approach was adopted to convey an integrated pest management (IPM) strategy to farmers. This approach consisted of adopting IPM Pilot sites as a backbone, around which farmer field schools, training and learning sessions were organized. Thus, pilot sites were established at farmer's fields, and school sessions of training and learning were continuously held. Results showed that yield gains, 4 to 5 times those of the check, were possible for bread wheat, chickpea and faba bean when IPM packages were applied. Farmer field schools, training and learning sessions were very educative of farmers. The latters were able to notice the varietal differences in host plant resistance to insects, to learn about all pest problems that occur during the cropping season, their natural enemies, and their means of control based on their own knowledge of pest protection methods acquired during the learning sessions. At the end of this study, farmers became knowledge handlers instead of mere recipients of information, and the top-down procedure of technology dissemination was revised. Furthermore, farmers were convinced that IPM of cereal and food legume pests allows crop protection and contributes positively to yield increase, enhancing the productivity, the national production of these basic food crops, and the livelihood of the farmers and their families

I. INTRODUCTION

The program on Integrated Pest Management of cereals and food legumes was initiated in Morocco in the 2000-2001 cropping season, with funding from the System Wide Program on Integrated Pest Management (SP-IPM), a CGIAR initiative. The first phase of the project generated very satisfactory results and several pest control options were transferred to participating farmers. The starting of the Morocco Collaborative Grant Program came to enhance action in the same SP-IPM regions and extended it to other communities in new regions of the country.

The study had three major objectives: (i) develop pest control methods through back up research; (ii) put various control options into an integrated pest management package that combines resistant varieties, cultural practices, adequate chemical control, seed treatment, rotation, fertilizers, etc. to reduce crop losses caused by major pests without causing adverse effects on the environment; and (iii) strengthen human capacities through training of technicians and young scientists on IPM principles, and farmers via farmer participatory research and learning approaches that involves farmers, researchers and extension specialists.

The farmer participatory approach was adopted as a tool for conducting this work. This approach was based on the fallowing principles: (i) The management of pests within the system and not their complete elimination; (ii) A multidisciplinary and multi-institutional teamwork; (iii) Establishment of IPM pilot sites by farmers and in farmer's fields; (iv) The participatory identification of control options and the total implication of farmers in the process of evaluation and selection of the best options; (v) Conducting participatory learning and training sessions in the field; (vi) Dissemination of the acquired IPM knowledge to neighbouring farmers of the same community and other communities.

II. RELEVANCE OF THE STUDY TO MOROCCO

The economy of Morocco is mainly based on agriculture. Cereals are the major food crops cultivated in the country; they are grown over more than 5 million hectares, occupying more than 70% of the arable land yearly. Wheat is a strategic crop in the country, covering more than 2.5 million ha yearly. Food legumes are important crops, grown in rotation with cereals. Both crops contribute by more than 55% to the national Agricultural production. The per capita wheat consumption is around 250 kg, making the annual needs of the country near 80 million qls (MAPM, 2010). Lately, the demand for these commodities has increased even further because of population growth and better lifestyles.

Unfortunately, these crops regularly suffer from the negative effects of adverse environmental conditions, mainly drought and extreme temperatures that limit their production potential. In seasons like these, the country will be obliged to import more than 50% of its needs. On the other hand, most available cultivars used by farmers are susceptible to several insect pests and diseases, and crops frequently suffer from attacks of several insect pests, diseases and weeds that depreciate their yield quality and quantity. Resulting yield losses vary according to climatic conditions, pest's intensity and severity. Average losses can amount to 30% of the grain yields annually and will get higher in seasons of high pest incidence.

As an example, the Hessian fly, *Mayetiola destructor* (Say) is the most damaging insect pest of wheat. Heavy infestations are regularly detected in Morocco where severe infestations and consequent damage are yearly registered in the major cereal growing regions of the country. Yield losses due to this pest alone average more than 30% yearly, and the pest can wipe out the total crop production in cases of heavy infestations that usually happen in dry and mild seasons.

Economically, yield losses due to Hessian fly damage on wheat in the arid and semi- arid areas of Morocco were estimated at more than $ 20US million a year. An economic study revealed that investing in research to develop wheat varieties resistant to this pest, generates an internal rate of return of 39%. This figure is considered by financial experts as a high rate of return (Azzam *et al*., 1996).

The best control method to limit this damage caused by pests is Integrated Pest management (IPM). This strategy is a combination of all control methods to reduce crop losses caused by major agents of biological stress by keeping pest populations under the ultimate degree of damage while being sustainable and economical. It is based on management rather than elimination of pests, which reduces selection pressure thus the chances of new biotypes to erupt. However, it requires a long-term approach involving both strategic, applied, and adaptive research, and extensive evaluation and feedback through on-farm testing with researchers and farmers.

In Morocco, various pest management techniques have been developed by researchers and made available for use by farmers. These include resistant cultivars, seed treatment, adequate pesticide application's dates and rates, and agronomic practices. These techniques have been assembled in improved crop production packages and recommended to farmers. These crop improvement packages based on integrated pest management, contribute to overall natural resource management in any crop and not only pest management.

However, the process for technology transfer in Morocco is slow in reaching the end users. Consequently, INRA tried a new way that resides into farmer training and learning of IPM principals and involving farmers in the transfer of pest management technologies. The objective of this initiative was to ensure wheat and food legume production sustainability and improve farmer's livelihood. In fact, using farmer participatory approaches and involving them in testing and selecting the best bet pest management techniques makes them part of the process and not only mere recipients of technology produced by researchers. In addition, the process insures that produced technology remains relevant to crop development and responds to farmer's needs.

III. GOAL OF THE STUDY

The goal of this study was to enhance the productivity of cereal and food legumes farming system in Morocco by developing and promoting sustainable and ecologically sound integrated pest management systems that reduce crop losses caused by major pests, diseases, and weeds.

IV. PURPOSE OF THE STUDY

The purpose was to enhance pest management technology transfer in the cereal/food legumes cropping system through farmer participatory approaches. The objective is to initiate and orient farmers towards integrated pest management in the cereal and food legumes cropping system through their full involvement and participation in the process, and conduct farmers training on major pests of the system and best options for their control.

V. DEFINING THE BIOTIC PROBLEMS LIMITING THE YIELD PRODUCTION

Like for other crops, cereals and food legumes are yearly affected by a large number of insect pests, diseases and weeds that depreciate not only the quantity but also the quality of yields of these crops.

V.1. INSECT PESTS

Several insect species are associated with cereals in Morocco. The Hessian fly, *Mayetiola destructor* (Say) is the most destructive insect pest of wheat. Losses dues to this pest are around 30 % in average and can amount to 100% when severe infestations occur on young seedlings (Lhaloui *et al.* (1992), Amri *et al.* (1992). Grain yield losses dues to attacks by this pest were estimated at 20 million $US per year (Azzam *et al.*, 1996).

The most efficient method of control of this pest is host plant resistance, through cultivar resistance. Three bread wheat varieties were developed as resistant to Hessian fly and registered in the national official catalogue for use by farmers. These varieties are Saada, Aguilal, and Arrihane, carrying the resistance genes H5, H22, and H5/L222 respectively. A fourth variety was registered as tolerant. Five durum wheat resistant varieties were also registered in 2005 (Lhaloui *et al.*, 2005) (Table 68) and new more improved resistant varieties have been registered since then. However, getting these varieties to farmers is very slow, and there is a real need to look for a process that provides a faster way of bringing these varieties to farmers, and making them available for use.

The second most efficient control method of H. fly is the planting date. This cultural practice will limit the incidence and damage inflicted by the pest. Early planting significantly reduces pest incidence and subsequent losses caused by the first generation of the pest (Lhaloui, 1986). Late seeding of susceptible varieties will make the seedling stage of plants coincide with the heavy H. fly populations of the second generation, inducing sever damage.

Table 68. Bread and durum wheat varieties carrying resistance to Hessian fly in Morocco (Lhaloui *et al.*, 2005)

Saada	Bread wheat, Semi-arid, Resistant to Hessian fly
Arrihane	Bread wheat, Semi-arid, Resistant to Hessian fly
Aguilal	Bread wheat, Semi-arid, Resistant to Hessian fly
Massira	Bread wheat, Semi-arid, Tolerant to Hessian fly
Marwane	Durum wheat, Semi-arid, Resistant to Hessian fly
Amria	Durum wheat, Semi-arid, Resistant to Hessian fly
Nassira	Durum wheat, Semi-arid, Resistant to Hessian fly
Chaoui	Durum wheat, Semi-arid, Resistant to Hessian fly
Irden	Durum wheat, Semi-arid, Resistant to Hessian fly

Other insect pests such as the wheat stem sawfly, the cereal leaf beetle, and aphids could also cause significant damage in years of heavy infestations, however, no control methods have been developed outside of chemical insecticides. (Lhaloui *et al.*, 2005).

As to food legume's insect pests, several have been reported as economically damaging of these crops. On chickpea, the leaf miner (*Liriomyza cicerina Rondani*) is the most important parasite. The winter chickpea stands a better opportunity to escape heavy damage as compared to spring chickpea. The former has the chance to put on enough vegetative growth before arrival of adult flies that emerge on the onset of spring (Lhaloui, 2010). Other potential insect pests are mainly Lepidopteron. In years favorable for their development, species such as *Helicoverpa armigera* Hurnest, and *Spodoptera littoralis* F., can cause economic damage. As an indicator, chickpea grain yield loss reached 50% in the 2003/2004 cropping season that was favorable for the pest development (Lhaloui, 2004).

On faba bean, it's mainly aphids that present a real threat to this crop. Both Aphis fabae and Aphis craccvora have been reported during our surveys. Sitona weevils are also important parasites, mainly the larval stage that feeds on the root's nodules. The lixus weevil's infestations are usually light in the semi-arid region, but are heavy in all parts of the country north of Rabat, where the pest is omnipresent (Lhaloui *et al.*, 2014)

V.2. DISEASES OF CEREALS AND FOOD LEGUMES IN MOROCCO

A large number of diseases threaten the cereal and food legume production in Morocco. Most varieties grown in Morocco are susceptible to one or more diseases. Seed transmitted diseases such as root rots, are very much problematic in traditional cropping systems that do not use selected seed. Other leaf and stem diseases are also very common.

V.2.1. CEREAL DISEASES

The most important diseases are Septoria (*Mycosphaerella graminicola*), yellow rust (*Puccinia striiformis f.sp. tritici*), leaf rust (*Puccinia recondita*), and root rots. In years where environmental conditions are favorable to heavy infections, such as during the 2008-2009 cropping season, yield losses due to diseases incidence neared 25 to 30% (Ramdani, 2009).

V.2.2. FOOD LEGUMES

The chocolate spot caused by *Botrytis fabae* and *B. cinerea* is the most important disease on faba bean in Morocco (Mabsoute *et al.*, 1996). Under humid conditions, yield losses due to this disease can be disastrous. Chemical control is available through application of specific fungicides.

As to chickpea, Ascochyta blight, caused by *Ascochyta rabiei*, and fusarium caused by *Fusarium oxysporum* f.s. ciceris are the most important diseases. In cases of high infection and severity levels, these two diseases can result in disastrous yield losses that can reach a complete destruction of the crop (Krimi Bencheqroun, 2009).

VI. WEEDS

In general, cereals and food legumes are associated with the same weed flora, because of the fallowing arguments: (i) The Cereal/Food legumes cropping system predominates in the arid and semi- arid regions, where the cereal/ food legumes rotation is widespread; (ii) Cereals and most food legumes are seeded in the fall, thus have the same flora that starts and grows in the fall; and (iii) The use of herbicides is limited on cereals and even more on food legumes, the selection pressure is weak and no flora specific to either cereals or food legumes was able to get established.

Weeds are considered very problematic in cereals. Several studies indicated the presence of more than 800 taxons with more than 134 weed species. In general, weed infestation in cereals is dominated by dicotyledonous (EL Brahli, 1984; Tanji, 1985, Tanji *et al.*, 1988). But several monocotyledonous species such as *Avena sterilis*, *Loium multiflorum*, *Bromusrigidus*, and *Phalaris spp* have gained more space lately.

Average yield losses dues to weeds on cereals were estimated at 29.5, 39.6 and 38.7% for bread wheat, durum wheat and barley, respectively (Zimdahl et El Brahli, 1992).

Food legumes are also infested by a diversified flora, made by predominantly dicotyledonous species (88%) as compared to monocotyledonous species (12%). Infestations by monocotyledonous are particularly important in areas with high precipitations located in the northern part of the country (Taleb *et al.*, 1998, Saffour *et al.*, 2008). Research studies showed that average yield losses resulting from weed competition were estimated at 36 and 60% of grain yield and biomass respectively (Zemrag, 1996).

However, the most noxious weed species in food legumes remain Orobanche (*O. crenata*) that limits food legume production in most regions of the country. Damage on faba bean is very often spectacular and can easily fully wipe out crops. *O. crenata* is largely spread in Morocco and infests about 69% of the cropped land. Herbicide application remains the best and most efficient way of control. However, efforts are needed to make the technology easily practicable by farmers (Saffour *et al.*, 2008).

VII. INTEGRATED MANAGEMENT OF CROPPING SYSTEM PEST'S BASED ON FARMER PARTICIPATORY APPROACHES

VII.1. INTRODUCTION TO INTEGRATED MANAGEMENT OF CROP PESTS

Integrated pest management (IPM) is a combination of all available control methods (cultivar resistance, cultural practices, chemical control, biological control, etc.) in order to control most important enemies in a given cropping system, while keeping yield losses below an economic threshold and not causing any adverse effect to the environment. The approach is based on management rather than complete elimination of pests. The approach reduces selection pressure thus the probabilities of the pests developing new more virulent biotypes/races which extends the durability of resistance of host cultivars or efficiency of pesticides. Consequently, an IPM strategy will provide a durable system of pest management in the cereal food legume cropping system.

IPM is justified when the values of gains in yield are higher than the cost of control measures utilized, as long as these measures are practical, easy to apply by farmers and environment friendly.

Lots of progress has been achieved in Morocco on methods of pest control in the cereal and food legume cropping system. These include the development of resistant cultivars, seed treatment, adequate use of pesticides at convenient precise dates and rates, and cultural practices such as planting dates, rotations and adequate fertilization.

However, cultivar resistance is the most reliable and environmentally friendly way of pest control. Hence, in the cereal food legume cropping system, cultivar resistance could be the pivot around which other methods of pest control may be assembled in a pest management strategy that could be transferred to end users.

If adoption of this strategy occurs, it would enhance cereal and food legume productivity, in a durable production system that is ecologically sound and environmentally friendly, and still economic and profitable for farmers. This will largely contribute to ensuring the Moroccan self-sufficiency in cereal and food legume grains, and the nation's food security.

VII.2. FARMER PARTICIPATORY APPROACHES AS USED IN THE CEREAL FOOD LEGUME CROPPING SYSTEM PEST MANAGEMENT

For an integrated pest management strategy to reach a large number of farmers, it will need an easy and efficient way to be conveyed. The traditional top-down method (from researchers to extension to farmers) has worked over a period of time and help accomplish the technology transfer mission. At present, a more farmer participatory approach, implemented by farmers learning sessions, or farmer's field schools, would be a better conveyer. This multidisciplinary and inter-institutional approach will provide close coaching of farmers on use of IPM strategy under the supervision of researchers and development specialists. The active participation of farmers is essential to the conception and execution of an IPM program that is appropriate to each cropping system and specific to each region, consequently, will be more efficient and sustainable.

The prevailing conventional way of technology transfer needs to be substituted with participatory methods where farmers are key partners in technology development and not only mere recipients of IPM messages formulated by researchers. IPM projects executed in several countries of west Asia clearly showed that farmer's participation is a major key for a durable pest management and environment protection (Yudelman *et al.*, 1998).

Participatory approaches help rise farmers awareness of pests and associated losses they may inflict on crops, encourage them to adopt IPM options, and contribute to their dissemination among other farmers. Field demonstrations of IPM techniques and other training activities will contribute to enhancing farmers capabilities to manage the host-parasite system and take informed pest control decisions based on their own acquired knowledge and not only on recommendations formulated by researchers and extension agents.

Farmer Participatory approaches are widely used in different fields. As an example, they have recently been used in India to develop packages of organic input for soil fertility maintenance that suits farmer's typology and are more likely to be adopted by farmers (Biswas *et al.*, 2016).

VII.3. METHODOLOGY

As a reminder, the goal of this study is to enhance the cereal and food legume productivity through a better pest management strategy that minimizes crop losses and contributes to a more sustainable farming.

As stated earlier in this document, several pest control techniques have been developed by national and international researchers but unfortunately most often, these technologies stay in scientific papers or in researchers' drawers. As an example, two bread wheat varieties carrying resistance to Hessian fly, were unknown by farmers for more than five years after they were registered and made available for use by farmers.

Only a farmer participatory based program of IPM has the power to redress this situation, and fluently convey to farmers technologies as there are developed without major delays. This will bring out the add value and advantages of new technologies in limiting pest damage.

To materialize this study, planning meetings were held with farmer's communities and organizations. During the discussions, major wheat, faba bean, and chickpea pest problems were discussed and prioritized. The most important pest on wheat that surfaced out was Hessian fly. For Faba bean, orobanche was a devastating weed that was whipping out this crop all through the country. Chickpea yields were suppressed by Ascochyta blight attacks that hit the crop mainly in spring.

Other production constraints were fertilizer application rates, early cereal weed control, and cereal disease control.

This brainstorming led to a participatory selection among available pest control options, with farmers and development agents. Lead farmers for IPM pilot sites were also identified.

VIII. BASIS AND RATIONAL OF FARMER PARTICIPATORY BASED APPROACHES

The approach is based on: (i) Management of pests within a cropping system and not their complete elimination; (ii) Multidisciplinary and multi-institutional teams; (iii) Establishment of IPM Pilot sites in farmer's fields; (iv) Participatory identification of best bet pest control options and farmers' full involvement in the process, their evaluation and selection of most performing ones; (v) Conducting farmer participatory training and learning sessions; and (vi) Dissemination of the process to neighboring farmers within the community and those of other communities.

VIII.1. ESTABLISHING INTEGRATED PEST MANAGEMENT (IPM) PILOT SITES

At the start of the study, a farmer's community where the cereal/food legume cropping system predominates was selected close to the INRA-Settat research center and Sidi El Aidi experimental domain. Discussions with community members led to identification of representatives called IPM pilot sites lead famers that are receptive of new technologies and respected by other farmers. This group of lead farmers was joined by researchers, development agents, and NGOs, members to form the executive committee of the pilot site. This committee was responsible for identifying the plant protection problems within the community. These problems were afterwards presented and discussed in farmer field days, training and learning activities. The major plant protection constraints of wheat, faba bean and chickpea were identified and prioritized and the best bet pest control options were identified.

The pilot sites were established, and different control options tested. At the beginning, the study started with 3 Pilot sites in the Chaouia region. The study was progressively extended to several other cereal/food legume-cropping areas (Doukkala, Abda, B. Mellal, Gharb, Meknès, and Zaer). At planting time of each year, IPM pilot sites were established in the lead farmer's fields. These sites included several pest managements options: (i) During the first season, farmers selected control options that are most fit for their fields. In this choice, they were assisted by researchers, development agents, and lead farmers; and (ii) During the second season, the best control options selected were tested by a larger number of farmers of the same community. The number of farmers that adopted a specific technology represents. The higher is the number farmers that adopt a technology, the larger this technology is disseminated. This number is an indicator of technology adoption rate and its usefulness for farmers.

VIII.2. IDENTIFICATION OF CROP PROTECTION CONSTRAINTS AND IPM SOLUTIONS

VIII.2.1. IDENTIFICATION OF CEREALS CONSTRAINTS

During the brainstorming to identify crops to be tackled in this study, bread wheat came out as the most problematic and needing of technologies, thus it was the cereal included in the study to represent the cereals. Several reasons were behind this choice, but mainly because: (i) It is widely grown over the country, more than 2 million ha, but still the country imports more than half of its annual needs; (ii) In the arid and semi-arid regions, and even regions with moderate rainfall, bread wheat suffers from severe Hessian fly attacks and subsequent damage could amount to total crop loss in cases of drought and late seeding that induce high infestation levels, thus productivity was low; (iii) Technologies to control this pest are available: resistant cultivars with high yield potential and resistance to some diseases, and cultural practices residing in adequate planting dates to escape high infestation levels and rotations with food legumes; (iv) Research results demonstrated that the combination of these technologies into an IPM package boosted yields 3 to 4 folds as compared to conventional practices; and (v) The gap: these technologies are not known to farmers, thus need to be disseminated. This package of selected IPM options for bread wheat was set up as a pillar around which other control options will be added in this management strategy.

Cereal leaf diseases were also indicated as problematic by farmers, although as secondary to Hessian fly. Fungicide treatments were programmed based on follow ups of field infection levels and were programmed in the control calendar as needed.

As to weed control, it was recommended to apply an early herbicide control, at the 2 to 3 leaf stage, and avoid the farmer practice of late controlling weeds, when they start being problematic in the field.

Fertilization is often applied randomly, with no soil analysis. The committee advised the use of fertilizers based on soils analysis results and recommendations. Most farmers seeded by hand broadcasting and, the use of the drill was really rare. The use of the drill was included as a component of the package.

The identified bread wheat protection constraints, technologies applied by farmers and control options identified by the pilot site committee are all presented in table 69.

Table 69. Bread wheat protection constraints, technologies applied by farmers and IPM options selected for testing at the Pilot sites.

Constraints identified and prioritized	Control measures used by farmers	IPM options suggested for testing
Hessian fly	None	Resistant Varieties
Planting date	After the rainfall, No specific date	Two weeks after the significant rain in the fall, starting early November but not to exceed mid-December.
Leaf Diseases	Rarely apply a spray after the disease is widespread	Apply fungicides when a threshold is present
Weed control	Late chemical control, hand weeding	Early control
Fertilization	Random application	Based on recommendations fallowing soil analysis
Seeding	Hand broadcast, rarely use the drill	All seeding must be done by a drill

VIII.2.2. IDENTIFICATION OF FOOD LEGUMES CONSTRAINTS

The discussions around food legume's plant protection problems revealed that orobanche was a major constraint, mainly on faba bean. Few farmers were familiar with chemical control using glyphosate, but none have ever applied it. The second major problem identified was ascochyta blight on chickpea. The faba bean disease Botrytis well known among farmers, but they estimated that it was less important than the first 2 diseases. As to insect pests, black aphids surfaced as the most noxious pests mainly attacking faba bean. The chickpea leaf miner (*Liriomyza cericina*) was not known by farmers. Damage inflicted by this pest was confused with leaf senescence. However, it was included in the program. The pod borer (*Helicoverpa armigera*) was reported by some farmers as they sometimes notice empty pods associated with green larvae, mainly in season of luxurious vegetation around the end of the season.

The farmers were introduced to the winter chickpea, as an alternative to the spring cultivated one. This type of chickpea is seeded early, and is in full growth when the ascochyta blight hits the crop. It allows avoidance of high infection and damage. It also allows escape of spring drought and terminal heat, as the crop reaches grain filling stages and sometimes nears maturity by this time. Similarly, to the case of wheat, it was suggested to use the drill to seed chickpea, as well as other food legumes such as faba bean minor, lentil, and peas. The identified food legumes protection constraints, technologies applied by farmers and control options identified by the pilot site committee are all presented in table 70.

Table 70. Food legumes protection constraints, technologies applied by farmers and IPM options selected for testing at the Pilot sites.

Constraints identified and prioritized	Control measures used by farmers	IPM options suggested for testing at the pilot sites
Orobanche	None	Apply glyphosate
Botrytis	None	applying preventive chemical control under inductive weather
Ascochyta blight	None	Cropping winter chickpea, applying preventive chemical control under inductive weather conditions
Leaf Diseases	Rarely apply a spray after the disease is widespread	Apply fungicides when a threshold is present
Weed control	Hand weeding, harrowing	Early control of monocots, harrowing
Fertilization	None	Apply phosphorus based on recommendations fallowing soil analysis, and some nitrogen as a starter
Seeding	Hand seeding in mechanically opened farrows	Use the drill

IX. ESTABLISHING THE IPM PILOT SITES

IX.1. IPM OPTIONS SELECTED & TESTED IN THE PILOT SITES

The pilot sites were established in farmer's fields and the following options were tested: (i) Applying fertilization as recommended after soil analysis; (ii) Cropping of two Hessian fly resistant bread wheat varieties, and a susceptible check; (iii) Testing two seeding dates (early and late) of the H. fly susceptible and resistant cultivars; (iv) Applying early weed control in wheat, and disease control when appropriate; (v) Respecting a rotation of wheat with faba bean or winter chickpea; (vi) Controlling orobanche and botrytis on faba bean; (vii) Using the seed drill; (viii) Conducting farmer's field schools, visits, cross visits, training and learning on sites.

IX.2. FARMER PARTICIPATORY LEARNING TRAINING AND FIELD SCHOOLS

This activity was based on 6 pillars: (i) Motivation of the farmer's community to go through farmer training sessions in the field on Integrated Pest Management; (ii) Planning all participative research, training and learning activities; (iii) Diagnosis of plant protection problems and identification of those that need to go through training sessions in the field; (iv) Conducting farmer's training and learning sessions at each community; (v) Conduct all planned activities; (vi) Evaluate activities conducted at the beginning of each new training session.

This training is based on learning the basics of the biology, ecology, and epidemiology of insect pests, diseases and weeds, their levels of infestation/ infection, and associated losses. Farmers were also presented with the various control methods available for each parasite, and their compared efficiency and harmony with the environment. In addition, basic knowledge on agro-ecosystem analysis was discussed.

IX.3. ESTIMATES OF YIELDS OF PLOTS UNDER VARIOUS CONTROL OPTIONS

As harvest time got closer, farmers were trained on how to estimate yields and appreciate yield differences depending on various pest control options. Samples of 1 m^2 each, repeated 4 times were taken from each plot, of all pilot sites. All plant material was cut at the soil level, and dry matter and grain yields were determined. The final grain yield was calculated after harvest of whole pilot sites.

Similar methodologies were adopted to determine yield of food legumes, except that in this case, samples of 2 linear meters were used as basic yield estimates units instead of m^2.

The process of Farmer participatory approach based IPM experience in Morocco was pursued on the basis of 3 cropping seasons per cycle and per community:

IX.3.1. FIRST CROPPING SEASON

Test the different IPM options that were selected to resolve specific problems identified during the diagnosis phase. These options are tested in the pilot sites. At the end of the season, the lead farmers, in collaboration with the researchers and the development agents, select the IPM options that were most performing. The neighboring farmers are always present to evaluate the efficiency of the selected options.

IX.3.2. SECOND CROPPING SEASON:

Evaluate the IPM options selected during the first season. The procedure gives the IPM options a second testing chance and a way of confirmation of their performance. However, this time, testing and selection are extended to cover a higher number of farmers of the community. The pilot site lead farmers play an important role in leading and coaching other farmers of their communities. This group is called "cluster farmers". During this process, the whole team is under researchers and development agent's supervision and assistance.

At this stage starts the process of "learning by doing" in the field, the crucial phase of the community participatory research. At the end of the season, the best options are again selected. Different communities may select different IPM options that suit their needs.

IX.3.3. THIRD CROPPING SEASON:

Test the best IPM options selected during the second season. A higher number of farmers of each community participate in this test. At this point, we can talk about adoption of the selected options, since they are used by larger numbers of farmers.

This IPM process, basic knowledge of the biology and epidemiology of major pests, efficiency of different IPM options, and the agro ecosystem analysis are taught to lead farmers, which in turn, and with the help of researchers and development agents, should pass the information down to other farmers of the community.

For new plant protection problems which emerged after the pilot sites were established, or those present, but were not detected during the diagnosis phase, their importance was discussed, and a participatory decision was taken on whether they should be included in the testing program.

First set of IPM pilot sites was established in 3 regions in 2001: Sidi El Aidi, Ain N'zagh and Jemaa Shaim. New sites were established in Meknes, Gharb and Zaer in 2004, and in Beni Mellal and Khemis Zemamra in 2005 (Table 71).

Table 69. Bread wheat protection constraints, technologies applied by farmers and IPM options selected for testing at the Pilot sites.

Seasons	Regions and Community	IPM Options tested
2001-02, 2002-03, 2003-04	Chaouia: 1 Pilot Site (Sidi El Aidi)	1. Control of Hessian fly through resistant varieties and early seeding
		2. Winter chickpea
		3. Early broad leaf weed control in cereals
		4. Graminea control in cereals
		5. Orobanche and Botrytis control in Faba Bean
		6. Adequate fertilization and nitrogen top dressing
2004-05, 2005-06	Chaouia: 3 Sites: *Sidi El Aidi, Ain Nzagh, Ouled Said*	1. Control of Hessian fly through resistant varieties and early seeding
		2. Early broad leaf weed control in cereals
	Abda: 3 sites Doukkala: 2	3. Graminea control in cereals
	Gharb: 3 Zemmour-Zaer: 2	4. Disease control in cereals
	Meknès: 3	5. Winter chickpea
2007-08, 2008-09, 2009-10	Chaouia: 3 sites	6. Orobanche and Botrytis control in Faba Bean
	Abda: 3 sites	7. Adequate fertilization and nitrogen top dressing.
	Beni Mellal: 3 sites	8. Improved lentil cultivars
	Mekness: 3 sites	9. Leaf rust resistance
	Zemmour-Zaer: 2 sites	10. Faba been and pea cultivars
		11. Control of orobanche on peas.

X. RESULTS AND DISCUSSION OF THE STUDY'S ACHIEVEMENTS

Over the several cropping seasons of the study, IPM pilot sites were established in seven regions of Morocco, and various farmer training and learning sessions were held in the field. Participatory research was also conducted. These regions were scattered all over the country, from Jemâa Shaim (South), to Meknès (North West), and Beni Mellal (Center).

Farmers participated and were full partners in all activities that were carried out during the season. Farmers attended all the process from the pilot site establishment to harvest. All activities were jointly conducted with the farmers, the development agents, supervised by disciplinary researchers.

Trainings were conducted in the field on the insect pest biology, the recognition of each pest's type of damage, symptoms of diseases and methods of following up on disease progress of infection as a basic tool before fungicide application, and finally, herbicide dose applications, mainly those of glyphosate against orobanche.

Weather and climatic conditions varied largely from one season to the other, mainly went through extreme drought and cold, to bad rainfall distribution. These conditions prevented varieties from expressing their yield potential, also seasons with very adequate rainfall that allowed varieties to express their yield potential. Despite all, the pilot sites were effective showrooms of the enormous differences that pest control options can print on the crops.

X.1. IMPROVING WHEAT YIELD

Genetic resistance to Hessian fly, expressed in the bread wheat varieties Arrihane and Aguilal, allowed excellent yields as compared with the susceptible variety Marchouch. In addition, early seeding gave an excellent yield as compared to late seeding. This difference was more pronounced for the susceptible varieties. Late seeded susceptible cultivars had very low yields, not exceeding 5qls. The Hessian fly resistant varieties performed very well. Yields were more than double those of the susceptible cultivars in early seeded plots (Figure 46).

When comparing yields, yield losses of different span are noticed. At early seeding, yield losses of 30 % are recorded between Arrihane (resistant) and Marchouch (susceptible). While there was only 16% yield loss between Marchouch and Aguilal (resistant). This is because even though this variety is resistant to Hessian fly, it is susceptible to foliar diseases that depreciate its yield. Arrihane is resistant to several diseases, including rusts. On the other hand, when late seeding is practiced, results showed that yield gap gets really huge. Indeed, the difference in yield between Arrihane and Marchouch seeded late reached more than 80%. Moreover, the difference in yield between Arrihane seeded early and Marchouch seeded late was 10-fold; 52.8 qls for Arrihane as compared to 5.2 for Marchouch, which is enormous (Table 72 & Figure 46). This yield gap between a resistant and a susceptible variety nicely illustrates damage that can be caused by Hessian fly. In this trial, the cultivar Aguilal, susceptible to diseases, was not sprayed in order to demonstrate the cumulative effect of the interaction between different biotic stress agents, in this case Hessian fly and foliar diseases.

This result shows that producing new improved varieties and cropping them at large scale will lead to a high increase of bread wheat production in the country. Their adoption by farmers will also boost the Moroccan wheat production by at least 30%, which will positively affect the national economy. In fact, these Hessian fly resistant wheat varieties will make the Moroccan economy gain the 20 million dirham that are lost due to damage by this pest each year. They will very positively contribute to the increase of the national wheat production, and will make Morocco reach self-sufficiency in wheat, and meet the demand of its fast-growing population. Consequently, annual wheat importations will decrease and eventually stop. This gain will also improve farmer's livelihood.

In the other Pilot sites placed in the various regions of the country, such as Meknès, Marchouch, Beni Mellal and Abda, yields of the Hessian fly susceptible and resistant varieties exhibited similar tendencies, with the variety Arrihane showing very high yield performance. This cultivar was able to get a very large dissemination, even to regions where there were no pilot sites of the project. Such was the case in the region of Souk Al Arbaa. Here a farmer cooperative bought the seed from farmer of the Sidi El Aidi pilot site and cropped it to a large area. They started producing seed for their own need and selling the remaining to other farmers.

Table 72. Grain yields (qls/ha) of resistant and susceptible bread wheat seeded early (D1), and late, (D2), in the IPM Pilot sites of Sidi El Aidi-Chaouia. Morocco.

	Early Seeding (D1)			*Late Seeding (D2)*	
Pilot Sites	Arrihane	Aguilal	Marchouch	**Arrihane**	Marchouch
Site I	52.8	41.4	24.7	33.1	5.2
Site II	42.9	25.8	22.6	24.9	10.4
Site III	42.3	35.1	28.4	41.2	5.0

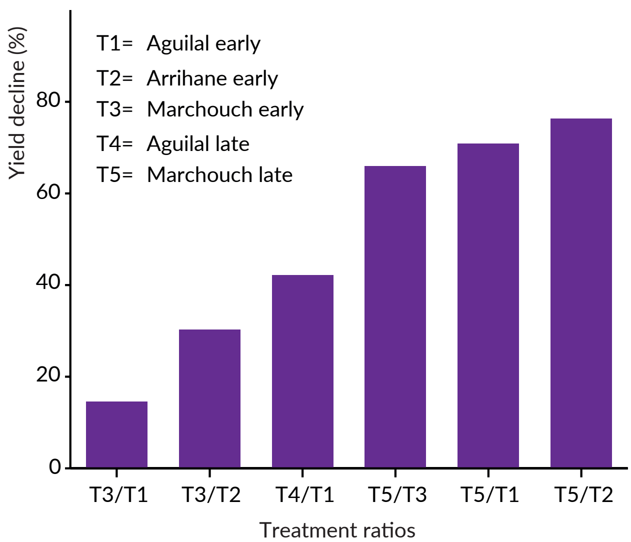

Figure 46. Compared yields losses of Hessian fly resistant and susceptible bread wheat cultivars seeded early and late.

X.2. IMPROVING CHICKPEA YIELD

As stated earlier in this document, improving chickpea yields was targeted using several crop management options that include IPM techniques, cultural practices and moving the crop from spring to winter. These options were realized through: (i) First, moving the chickpea cropping from spring to winter; this action required that winter chickpea was adopted in the pilot sites, and spring chickpea was used as a check. Moving to winter allowed the crop to take advantage of the available moisture. Spring is mostly dry in Morocco, and often, the crops seeded in spring will get very limited rainfall, mainly from storms; (ii) Using the drill to seed the plot with a recommended seeding rate of 80 to 100kg/ha. This technique allowed an even distribution of seed in the field; (iii) Applying fertilizers as a starter. Limited rates of Nitrogen, but good rates of phosphorus, reaching 1 quintal of P_2O_5 per hectare; (iv) Early control of weeds using some pre-emergence herbicides, and a post emergence control of monocotyledonous weeds; (v) Early control of main diseases and pests such as Ascochyta blight and chickpea leaf minor.

The results showed that winter chickpea (WCP) yields were always and in all pilot sites, higher than those of the spring planted one. In most cases, yields of WCP were at least double those of SCP, and in several cases, WCP plots were the only ones that produced a yield, while the SCP did not produce any yield. The grain yield was associated with a high total biomass. WCP takes advantage of moisture available from early precipitations, and also escapes the end of the season drought. On the other hand, WCP cycle allowed it to develop and cumulates enough vegetative growth before the onset of heat and moisture of the spring, that are favorable conditions for disease epidemics (Figures 47 & 48).

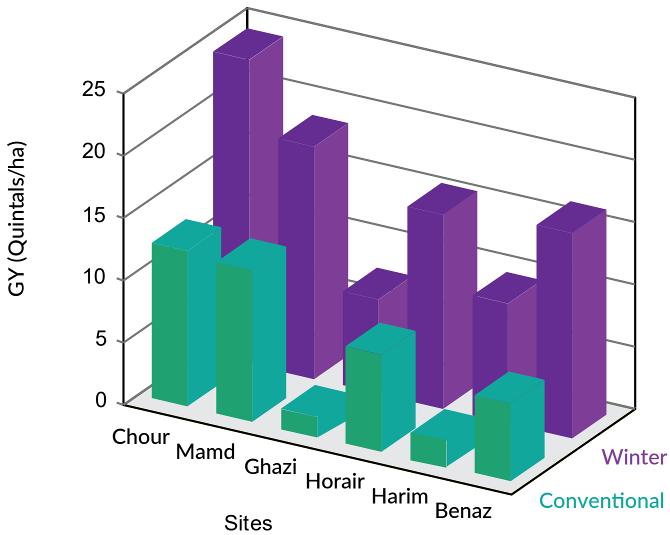

Figure 47. Grain yield (GY) of winter

Figure 48. Spring vs winter chickpea

The pilot site study allowed several achievements in chickpea production: (i) Winter chickpea has a high yield potential, 2-4 folds that of the spring (Figures 47 & 48); (ii) Advancing the crop planting in the season allows the plants to take advantage of early cycle humidity, and escape end of the season drought; (iii) It allows escape or tolerance of Ascochyta blight. The disease hits in the spring when temperatures start rising, but the winter chickpea plants would have already set seed; and (iv) Benefits of the application of pre-emergence herbicides.

X.3. IMPROVING FABA BEAN YIELDS

Orobanche is considered as a yield-suppressing parasitic weed of faba bean in Morocco. Botrytis is another problem that can destroy the crop when environmental conditions are inductive of the disease. Controlling these 2 pests allowed an excellent yield increase that varied from 4 to more than 10-fold (Table 73, Figures 49 & 50)

Table 73. Grain yieldof faba bean at IPM pilot sites

Farmers	Yield (qls/ha)
Beni Mellal (Irriguated)	39.6
Meknès (My Driss Zerhoune)	15.0
Khemisset (Had Ait Mimoun)	21.0
Gharb (Souk Larbaa)	14.0
Check	0 to 3

Figure 49. Orobanche controlled vs check faba bean change field

Figure 50. A farmer very proud of his IPM controlled Faba bean field: notice the abundance of pods

During the crop production constraints diagnosis sessions held with farmers at the beginning of the study, only orobanche came out as problematic to the faba bean crops. However, it was noticed from the first season of testing that botrytis can also be a yield suppressing factor in seasons where weather conditions are inductive of the parasite. Farmers confound all faba bean diseases into one entity, called "Harakia" or leaf burning. Even though it was not planned to spray against this disease, we did apply a fungicide treatment against it to demonstrate the importance of disease control. Therefore, adoption of a package of control options against orobanche and botrytis positively impacted growth and yield of faba bean, as compared to the check.

Grain yields varied according to regions and cropping seasons. Under favorable rainfall, yields varied from 8 to 15 qls/ha at Meknès and 7 to 14 qls/ha at Gharb. At Had Ait Mimoun, the average yield obtained by farmers reached 21 qls/ha. This was a record yield; it was more than two folds the average of the region. In these 3 sites, farmers regained confidence in faba bean cropping which they had almost abandoned because of Orobanche infestations. In Beni Mellal region, specifically at Ighram Laalam, farmers realized almost 40 qls/ha (39.6 qls/ha) under irrigation, which was also a record (Table 73, figures. 49 & 50). These results clearly demonstrated the positive effects of orobanche control in faba bean.

It appeared also that orobanche control not only prevented the weed from growing but also decreased its seed bank. Indeed, a large number of orobanche seed germinates, but even though the seedling attaches to the faba bean roots, it remains very small, and does not set seed.

X.4. FARMER FIELD SCHOOLS, LEARNING AND TRAINING SESSIONS

The pilot sites served as open field schools where the major pests, their development and control methods were taught to farmers. These included:

• Different IPM options are discussed and evaluated on site by farmers, and suggestions of solutions are elaborated in the field. All along the season, field days for farmers training and learning are organized in all the pilot sites. These sessions are animated by pilot sites lead farmers, farmers of the community, researchers, and development agents. Early in the season, farmers were trained on: (i) Choosing the most performing varieties, based on their resistance to the prevailing pests; and (ii) Applying adequate fertilization based on soil analysis, and the most appropriate herbicide and fungicide treatments, using the application date and rate.

• Farmers were present at all the sessions for control of weeds, orobanche and foliar diseases. A Special interest was given to control of orobanche parasitic weed. Farmers were trained on how to recognize the young seedling stage of the weed, and when and how to control the weed. Systematic spraying of faba bean crops starting from 5 to 10% flowering, repeated at least twice, at a two-week time interval, was adopted by farmers. The spraying activities are conducted by farmers themselves. The very important issue was that farmers: (i) learned how to adjust their sprayers; (ii) calculate the rate of glyphosate to use in each sprayer; (iii) Synchronize the walking speed of the applicator/the tracted sprayer; and (iv) Choose the right time of spraying; when almost 10% of the faba bean have flowered.

• Control options were evaluated on site, all emerging problems and suggested solutions are discussed among farmers, researchers and development agents in the field.

• Cross visits to different pilot sites were organized for Farmers to learn of different pilot sites experiences (Figure 51).

Figure 51. A farmer field school and learning day on orobanche control

• While visiting some pilot sites several seasons after the beginning of the program, it was very rewarding to notice that farmers still practice pest control technologies that they learned during the IPM project. Faba bean fields were orobanche and botrytis free. The project made an oil spill at Meknes, where farmers that participated to the orobanche control days were still using the technique to rid their fields of this nasty weed.

• As to Hessian fly, the life cycle of the pest as well as the different development stages were explained to farmers. The resistance vs the susceptibility of bread wheat cultivars was also explained. Other insect pests of less importance such as, the wheat stem sawfly, the cereal leaf beetle were also discussed as they appeared in the field.

• These field schools were very much appreciated by farmers. They express their interest in these learning methods that are based on recognizing and practicing all activities in the field.

X.5. VISITS ORGANIZED TO THE DIFFERENT PILOT SITES

The pilot sites were visited by a large number of farmers, technicians, researchers, development agents, and decision makers. Cross visits were organized to different sites, to allow farmers to learn from each other's experience.

In addition, the pilot sites were visited by several delegations, mainly His Excellency the minister of Agriculture, the USA ambassador to Morocco, people from different organisms that were visiting the INRA-CRRA Settat center, such as the American Ambassador to Morocco and His Excellency the minister of Agriculture (Figure 52).

All visitors showed their positive reaction for the study, its progress, the training and technology dissemination adopted, and the outcomes of the study.

Figure 52. Sidi El Aidi pilot site was visited by USA Ambassador in Morocco (Up) and the Minister of Agriculture (Down).

XI. CONCLUSIONS, SPILL OVER'S, AND RECOMMENDATIONS OF THE STUDY

This study was an open classroom to farmers and gave an opportunity to learn about managing the cereal and food legume pests as a system, and as separate crops. They had the chance to learn about existing science around host plant resistance, pests and pesticides management, and environmental protection. Several conclusions and spill overs could be drawn out of this very instructive study, in particular:

- Farmers became knowledgeable of major insect pests, diseases and weeds of cereals and food legumes, the timing of their appearance in the field, the damaging development stage of insect pests, therefore, they became more knowledgeable and accept the idea of directing the pest control on target damaging stage
- Farmers became aware of wheat and food legumes varieties, the varietal differences dues to genetic or host plant resistance, pests' symptoms and IPM control options available. This enabled them to take their own pest management decisions based on their own knowledge, acquired in the pilot sites
- Yields at the pilot sites IPM managed trials were clearly higher than the checks and those obtained by neighboring farmers. The bread wheat grain yield was substantially increased by adoption of the IPM package. Yields of the Hessian fly resistant varieties were 2 to 4-fold at early seeding, For the late seeding, it was more than five folds those of the susceptible varieties. The Hassian fly resistant variety Arrihane was highly appreciated by farmers, who played an excellent role in its dissemination via farmer-to- farmer communication. Its adoption rate was the highest among all technologies tested in the study. At the third season after the start of the project, the demand of seed of this variety was so high that the seed company was in an obligation to repatriate seed from all regions of Morocco to regions were pilot sites were installed, to meet the farmers demand. In addition, Arrihane seed was also sold by farmers, and moved for long distances, exceeding 300 km as was the case from the Chaouia to Gharb.
- Faba bean yields were very high as compared with non-orobanche and botrytis treated nearby fields. Indeed, orobanche control in particular, in addition to foliar diseases allowed a net increase of yield of faba bean. At Moulay Idriss region, where a pilot site focused on orobanche control as the major plant protection component, area cropped to faba bean clearly increased as compared with previous seasons, mainly because farmers learned and mastered how to control orobanche.
- Yields of chickpea have increased with the advance of the crop from spring to winter, using adapted varieties and an optimum package of technologies. In fact, the application of selected IPM options such as selected high potential varieties, early weed control either by cultivation or pre-emergence herbicides, the orobanche control, control of insect pests such as the chickpea leaf miner and the pod borer when infestation reaches economic damage, and the control of major diseases, particularly Ascochyta blight, has increased yields from an average 3-4 qls/ha to an average 20qls/ha, making yields of winter chick pea 4 folds those of the spring planted one.
- Several training and learning sessions were held in the field on various topics all along the season, and farmers' visits and cross visits to the different pilot sites were conducted. Famers had a broad vision of the IPM package all over the country.
- Farmers truly accepted that Integrated Management of cereal and food legume pests allows crop protection, and positively contributes to the national production of these major food staples.

• A large number of farmers adopted the IPM options offered: Hessian fly resistant varieties, early weed control, adequate fertilization, and use of the drill for wheat, and Orobanche and botrytis control for faba bean. In the beginning, smaller numbers of farmers were convinced, but this number doubled more than 100-fold by the end of the study.

• As this was the very first experience of its kind in the country, a high number of decision makers, researchers, development agents and experts, and media visited the pilot sites.

• The study also contributed to Improved Farmers livelihood: The use of IPM options helped alleviate crop losses and stabilize crop production. The income of resource-poor farmers was improved. Also, it reduced pesticides use, thus preventing pollution and saving farmers budget.

• At last but not least, the project contributed to creating new job ideas. As a matter of fact, one lead farmer who was a young person with a masters in agronomy, started his private company to offer crop protection services to other farmers.

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