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

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Foreword

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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.

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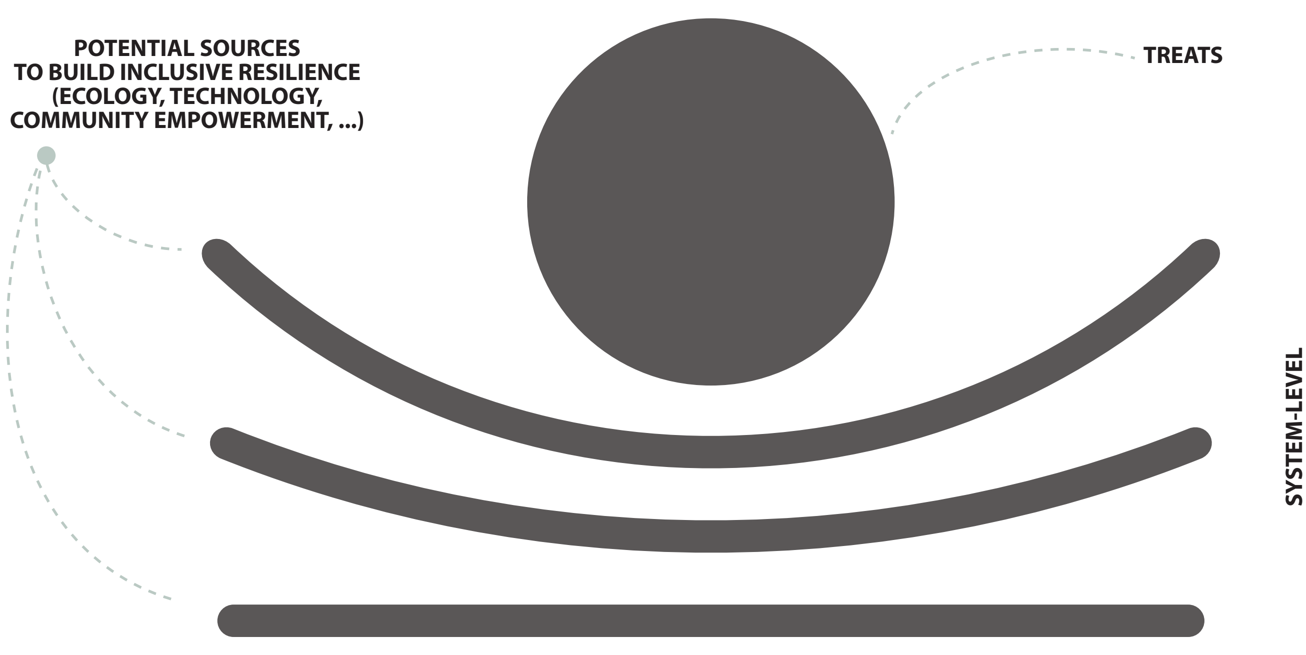
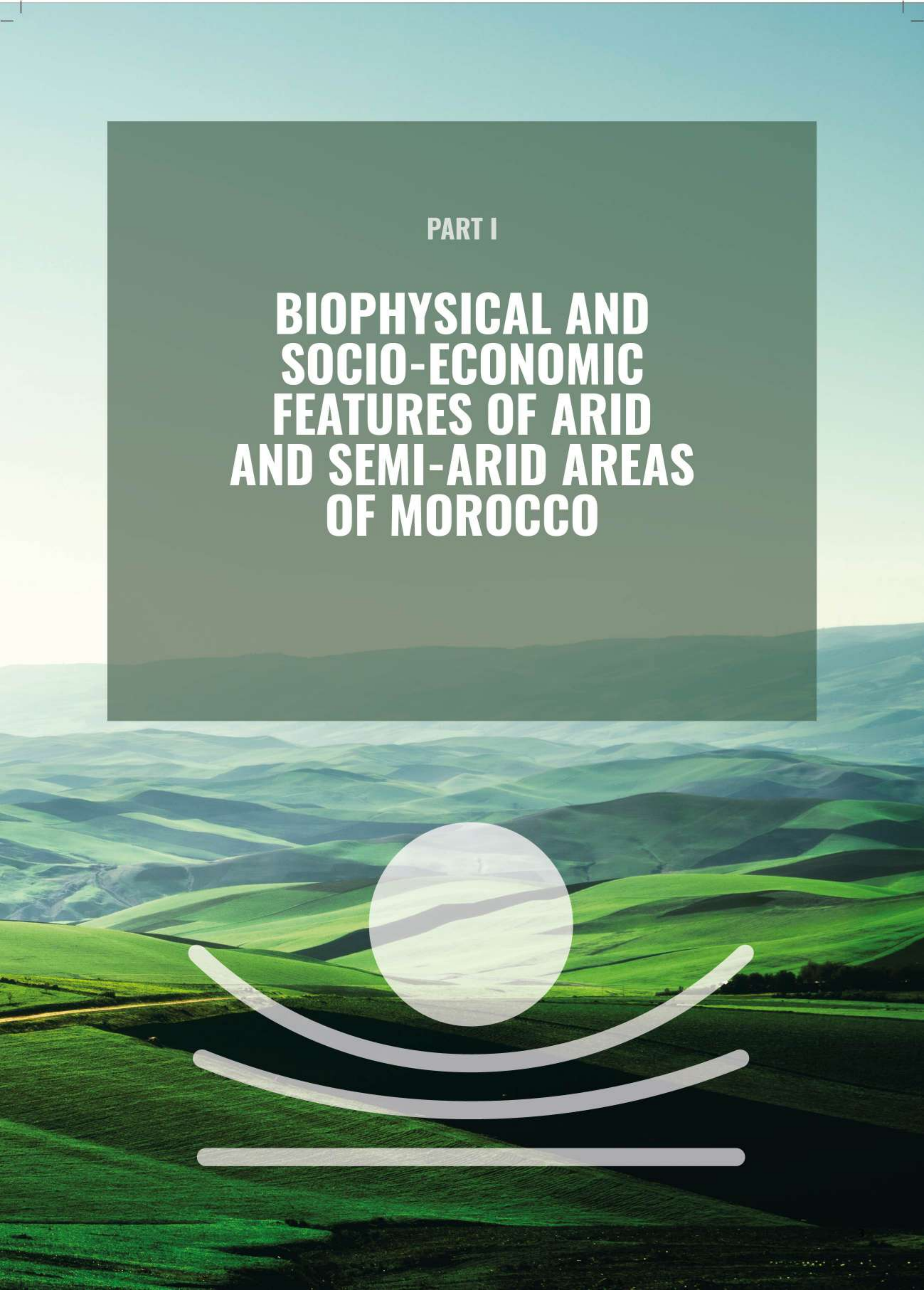

POTENTIAL SOURCES
TO BUILD INCLUSIVE RESILIENCE
(ECOLOGY, TECHNOLOGY,
COMMUNITY EMPOWERMENT, ...)
TREATS
SYSTEM-LEVEL



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).

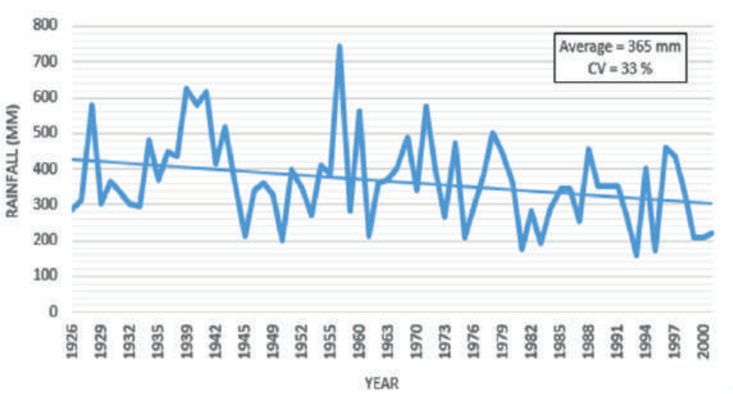

Figure 1: Rainfall evolution at Settat Region

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.

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