# Crop water use and water use efficiency under semi-arid conditions of Morocco

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## Abstract

Semi-arid and arid areas of Morocco are characterized by low rainfall and its high fluctuations. Drought in these zones occurs at any time. The effect of drought on crop production is aggravated by heat stress occurring usually late in the season. Low water storage capacity of soils and non adapted cultural practices and varieties used by farmers are other parameters that affect crop yields. To increase and stabilize yields under these situations, agronomists and crop physiologists have been searching for means of improving soil water conservation and crop water use efficiency (WUE). Results showed that early planting of wheat, when compared to late planting, can increase WUE by 25 to 50 % . To be more successful, this practice requires a good seed bed preparation which is difficult to obtain under dry conditions. The alternative to seed bed preparation is the use of no-till drill that does not require any soil preparation and prevents soil evaporation. The reduction of competition among plants by using adequate seed rates, controlling weeds and by providing adequate amounts of nitrogen has been shown to improve WUE. Water use efficiency of corn can be increased three times if low plant populations are used. Weed control in wheat can increase WUE from 27 to 96 Kg grain/cm of used water when the infestation is high. Supplemental irrigation is an other practice that can double WUE ratio. Studies have shown also that triticale uses water more efficiently than durum and bread wheat. Genotypic variations for drought tolerance were also observed for different crops including chick peas. The mechanisms used by plants to tolerate drought and improve WUE are discussed.

**Key words :** Wheat, barley, chickpea, deficit, conservation, efficiency, drought

## Résumé

### Amélioration de l'efficience d'utilisation des cultures sous les conditions semi-arides du Maroc

Les zones semi-arides et arides du Maroc sont caractérisées par des faibles précipitations et une forte fluctuation inter et intra annuelle des pluies. La sécheresse dans ces zones peut survenir à n'importe quel moment de l'année. L'effet de la sécheresse sur la production des cultures est accentué par le stress thermique causé par les hautes températures qui souvent coïncident avec la fin des cycles des cultures. La faible capacité de stockage d'eau des sols et les variétés et techniques culturales non adaptées pratiquées par les agriculteurs constituent les autres paramètres affectant les rendements. Pour augmenter et stabiliser les rendements dans ces zones, la recherche de moyens d'amélioration du stockage d'eau dans le sol et de l'efficience d'utilisation de cette ressource naturelle (EUE) est nécessaire. Les résultats obtenus montrent que le semis précoce du blé peut augmenter l'EUE de 25 à 50 % par rapport au semis tardif. Pour réussir cette opération, il est indispensable de bien préparer le lit de semences, chose qui est difficile à réaliser sous des conditions sèches. L'alternative à la préparation du lit de semence est le semis direct à l'aide d'un semoir non labour. Il a été aussi démontré que la réduction de la compétition entre plantes par le choix d'une dose de semis adéquate, le contrôle des mauvaises herbes et par l'apport de doses optimales d'azote améliore l'EUE. L'EUE du maïs peut être triplée si des densités de peuplements faibles sont pratiquées. La lutte contre les mauvaises herbes peut augmenter l'EUE du blé de 27 à 96 Kg de grains/cm d'eau utilisée lorsque l'infestation est élevée. La pratique de l'irrigation d'appoint est un autre moyen qui peut facilement doubler l'EUE. Les études menées ont montré aussi que le triticale utilise l'eau d'une façon plus efficiente que les blés dur et tendre. Des différences génotypiques de tolérance à la sécheresse ont été aussi observées pour différentes cultures y compris le pois chiche. Les mécanismes impliqués dans la tolérance à la sécheresse et l'amélioration de l'EUE sont discutés.


**Mots-clés :** Blé, orge, pois-chiche, variété, sécheresse, tolérance

# ملخص

## استخدام الماء من طرف النبات والإستخدام الجيد للماء تحت الظروف شبه الجافة في المغرب

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تتميز المناطق الجافة و شبه الجافة بقلة الماء و تدبدب الأمطار. في هذه المناطق يمكن أن يكون هناك جفاف في أي وقت من السنة. تأثير هذا الجفاف على مردوديات المزروعات يزيد حدة بسبب ارتفاع الحرارة الذي يصادف في أحيان عدة أواخر مراحل نمو المنتوجات. يعد عدم القدرة على خزن الماء في الأرض واستعمال الأصناف النباتية والتقنيات الفلاحية غير الملائمة من طرف الفلاحين من العوامل الأخرى التي تسبب نقصا في الإنتاج. لأجل رفع و استقرار المردود في المناطق الجافة وشبه الجافة يجب البحث على وسائل تحسين خزن الماء في الأرض واستعمالها لأجل الزيادة في الإنتاج. تبين النتائج المحصل عليها أن الزرع المبكر إذا قورن بالزرع المؤخر يمكن من رفع مؤشر استعمال الماء (الإنتاج/كمية الماء المستعملة) من 25 إلى 50 % للوصول إلى هذا الهدف يجب تهيء فراش البذور الملائم للإنبات قبل تهاطل الأمطار الخريفية الأولى، الشيء الذي يصعب الحصول عليه حينما تكون التربة يابسة. لهذا يعتبر استعمال البذارة في الزرع المباشر بدون خدمة الأرض بديلا لتهيء فراش البذور. لقد لوحظ كذالك أن النقص من المزاحمة بين النباتات باستعمال كميات ملائمة من البذور والأسمدة النيتروجينية وكذالك محاربة الأعشاب من الوسائل التي تساهم في رفع قيمة مؤشر استعمال الماء ثلاث مرات إذا ما استعملت كثافة نباتية قليلة. أما محاربة الأعشاب فتتسبب في الرفع من قيمة هذا المؤشر من 27 إلى 96 كغم حبوب/سم ماء مستعمل في حالة وجود أعشاب بكثرة. هذا ومن جهة أخرى فإن السقي التكميلي يمكن أن يضاعف قيمة مؤشر الماء. بينت الدراسات التي قمنا بها كذالك أن التريتكال يستعمل الماء بطريقة أكثر اقتصادا من القمح الطري والقمح الصلب، فوارق صنفية لوحظت عند الحبوب، الذرة والحمص. لقد نوقشت كذلك في هذا المنشور العوامل المتعلقة بتكيف النبات مع الجفاف.

**الكلمات المفتاحية** : القمح، الشعير، الحمص، نقص الماء، الحفاظ على الماء، الإسخدام الجيد للماء، الجفاف

## Introduction

Semi-arid and arid areas of Morocco are characterized by low rainfall and high fluctuations of the precipitations. Drought in these zones can occur at any time during the growing season. However, two periods of drought are very likely (Watts and El Mourid, 1988); drought that occurs usually during spring and affects seed set and development, and early drought that occurs, less frequently, during emergence and seedling stages.

High percentage of shallow soils aggravates the situation in these regions. These types of soil have low water storage capacity. Consequently, water cannot be conserved to be used by the following crop or during later stages.

Lack of water late in the growing season is usually associated with heat stress so that yields are usually reduced because of the erratic conditions. Crop yields are also highly variable from one year to another. The coefficient of variation can reach 47 % (Lamine *et al.* 1993). Potential yields simulated by models are also highly fluctuant. Consequently, the risk of crop failure is very high in these areas and varies from one region to another (El Mourid 1991). In Abda for example, probabilities of crop failure is 2 years over 10.

In addition to the environmental factors effects, crop yields are also affected by non adapted cultural practices and varieties used by farmers.

In the arid and semi-arid areas we can say that scientists as well as farmers are faced with a challenging environment.

In this paper, research strategy and results on crop water use and water use efficiency in dryland areas of Morocco are discussed.

## Research strategy

To alleviate effects of drought, the most limiting factor of crop production in rainfed areas, to increase and stabilize crop yields and to improve water use efficiency, the research strategy in the arid and semi-arid areas of Morocco has been oriented towards 1) the characterization of the environment and its variability in order to target research thrusts and to orient farm management towards the better use of the available water, 2) the development of water (and soil) conservation techniques that allow the decrease of run-off and evaporation (and erosion) and the increase of soil water availability to plants and 3) the implementation of techniques that allow the use of plant available water more efficiently.

To reach these objectives, studies were conducted on crop rotations, tillage, water harvesting, planting date and plant population, weed control, fertilizers use, supplemental irrigation and genotypes/species adaptation.

In this review the techniques and methods mentioned above will be presented.

## Water conservation : increase of soil water storage and plant available water

In the semi-arid areas, water losses are not allowed and every droplet of rain has to be used immediately by plants or stored in the soil in order to be available for cultivated plants when they need it. Water conservation can be obtained through cultural practices.

Studies conducted showed that water can be transferred from one season to another if appropriate rotations and soil management practices are used. Wheat, following black fallow can benefit from residual water stored during the preceding year. With chemical fallow where weeds are controlled only by herbicides and where evaporation is reduced because of no soil cultivation, it is shown (Bouzza, 1990; Kacemi 1994) that up to 75 mm of water can be stored and that wheat yields and water use efficiency are substantially improved especially during dry years. The positive effect of fallow as a preceding crop for wheat is more significant when no-till or minimum tillage techniques are used for wheat. These techniques reduce evaporation and increase water infiltration in the soil. Kacemi (1992) however, found that minimum tillage tended to allow more available water and higher water use efficiency than no-till. This latter author explained this difference by the fact that residue mulch on no-till plots was less efficient than the dust mulch on minimum tillage plots in reducing evaporation. Water harvesting technique where depressions are made in the soil by a modified off-set disk is also tried (Benouda and Karrou,1993).

## Water use efficiency

Water use efficiency (WUE) is defined agronomically as the ratio of the quantity of dry matter produced per unit area over the amount of water used or evapotranspired. Consequently, WUE can be increased either by increasing the nominator or decreasing the denominator. Both terms are influenced by the cultural practices and by the cultivar used.

## Cultural practices : increase plant available water

In the semi-arid areas of Morocco, most of rain is usually received between November and February. The seeding dates of fall planted crops are often delayed by farmers until the first major rains are received. However, although working the wet soil late ensures the control of the first emerging weeds, it has the disadvantage of returning the soil and increasing soil moisture loss by evaporation. To take advantage from all water received during the growing season and to escape late drought and heat stress, these crops need to be planted early during the first week of November. In fact, early planting of wheat was shown (Table 1) to increase yields (50 %) and water use efficiency (25 to 50 %) and to make more water available for plants during the growing season. However, early planting is often more susceptible to high weed infestation than late planting.

Weeds compete with cultivated plants for the small amount of water that is available and create an early water deficit. Studies conducted in arid and semi-arid areas of Morocco (Table 2) show that although weedy wheat extracted more water than weed-free wheat, crop yields and WUE were improved only when weeds were controlled early in the season. During a dry year (203.5 mm of rain), weed control increased grain yield by 8.4 %. However, during a relatively wet season (469.2 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.

Water deficit can be created not only because of weed infestation but also if plant population of the crop is very high. Competition among these plants can reduce seed production per unit of water used. Table 3 shows that for corn, water use efficiency index was more related to grain yield than to the quantity of water used. This index increased three times when low plant populations (20.000 plants/ha) were used under dry conditions. Because of low competition among plants for water, water deficit was postponed and hence plants escaped drought and used water more rationally. Under more favorable conditions, WUE was relatively less affected by plant population variation; but as far as grain yield was concerned, the intermediate plant population (40.000 plants/ha) was economically justified.

Mineral nutrition is another aspect neglected by farmers in dryland areas. Barley and corn, for example, do not receive any input. However, nutrients availability in the soil is very important for crop growth and development. Nitrogen for example is a nutrient that affects the early vigor of plants (Karrou and Maranville 1993a). In cereals it increases tillering, leaf area development and hence the early soil covering. The early soil shading can reduce evaporation (Cooper *et al.* 1987a) and increase water use efficiency. However, severe water stress inhibits N uptake and hence nitrogen effect on plants. Studies conducted in Sidi El Aidi (Table 4) showed that adequate amounts of nitrogen can increase WUE under different soil moisture conditions. However, the increase is more significant under less stressful situations. The increase for different varieties is 0 to 16, 21 to 23 and 41 to 48 % for non, moderately and well irrigated conditions.

Although drought can occur at any time during the growing season of crops, some stages are more sensitive to water deficit than others. For farmers that have access to limited amount of irrigation water, it is possible to increase and stabilize yields and also improve WUE if water is supplied at the right time. In fact for wheat, it was shown (Table 5) that applying 60 mm of water either at tillering or at flowering increased grain yields by 31 to 60 % and WUE by 10 to 29 % . Application of 180 mm of water splitted into 1/3 at tillering, 1/3 at heading and 1/3 during grain filling doubled grain yield in Sidi El Aidi (Boutfirass, 1990) .

## Species and varieties : Increase the output or yield

In addition to cultural practices, 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 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 at the Aridoculture Center have been developing improved varieties. These varieties have been tested to verify their performances under different soil moisture conditions and to identify mechanisms involved in drought resistance and WUE. In fact it was shown that triticale (Ouhajjou, 1991) used water more efficiently than wheat and that the late and old durum (Kyperounda) and bread (Florelle) wheats and barley (Arig 8) did not perform like the earlier cultivars Cocorit, Potam and Acsad 60, respectively (Table 6). Moreover, Samir (1993) confirmed this result when she compared a relatively early durum wheat (Marzak) with the relatively later cultivars Karim and Oum Rabia.

For corn (Table 7), early (Pioneer 3969 and Pioneer 3994) and medium (Funks 4065) hybrids 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, (Table 7) 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 (Table 8). 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 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 and corn Pioneer 3969 and Pioneer 3994, 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 late drought. The early vigor 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). In addition to the earliness, some of the varieties mentioned above and others tolerate also drought. As a matter of fact Samir (1993) and Dahan (1993) respectively found that durum wheat Marzak and Oum Rabia and chickpea PC-46 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 1994 and Samir 1994). 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.

## Prospects

As described above, the first phase of our program was oriented towards the quantification of water use efficiency and characterization of existing cultivars under different soil moisture conditions and research of mechanisms involved in drought resistance. Our objectives in the future are 1) to test developed technologies under other environments and proceed to their transfer in collaboration with extension services, 2) to develop and validate models for research and technology transfer programs orientation, decision making and predictions, 3) to help breeders use some of the identified criteria, such as early vigor, canopy temperature and grain filling rate, in their screening programs for drought resistance. In fact, a program has been carried out recently on bread and durum wheat; 4) to identify and test other parameters related to drought resistance, like plant phenology, rooting systems, osmotic adjustment, etc; 5) to identify mechanisms involved in heat tolerance and fertilizers use efficiency; 6) to find ways of harvesting water and improving its infiltration and use efficiency in the sloppy lands; 7) to look for techniques of improving water management and water use efficiency under irrigation. In addition to these objectives, research will be focused also on environment conservation and sustainability.

**Table 1.** Water use efficiency (WUE), water use (WU) and grain yield (GY) of wheat as influenced by planting date variation (Bouchoutrouch 1994)

| Site and Year | Sidi El Aïdi 84/85 (384.4 mm/rain) | | | Sidi El Aïdi 85/86 (286 mm rain) | | |
|---|---|---|---|---|---|---|
| Planting date | WUE (kg/mm) | WU (mm) | GY (kg/ha) | WUE (kg/mm) | WU (mm) | GY (kg/ha) |
| November : week 1 | 9.8 | 286.0 | 2801 | 12.2 | 295.0 | 3570 |
| December : week 1 | 7.2 | 251.0 | 1818 | 12.8 | 285.0 | 3630 |
| January : week 1 | 6.1 | 226.1 | 1375 | 6.0 | 244.0 | 1470 |

**Table 2 :** Water use efficiency (WUE), water use (WU) and grain yield (GY) of wheat as influenced by weed control at Sidi El Aidi Expriment Station (Tanji and Karrou 1994)

| Year | | 1986 - 87 (203 mm rain) | | | 1987 - 88 (469 mm rain) | |
|---|---|---|---|---|---|---|
| Treatment | WUE (kg/mm) | WU (mm) | GY (kg/ha) | WUE (kg/mm) | WU (mm) | GY (kg/ha) |
| Weed free wheat | 6.80 | 161 | 1085 | 9.58 | 316 | 3021 |
| Weedy wheat | 5.51 | 182 | 994 | 2.66 | 366 | 931 |

**Table 3 :** Water use efficiency (WUE), water use (WU) and grain yield (GY) of corn as influenced by plant population variation in Sidi El Aidi (SEA) and Jamaa Shaim (JS) Experiment Stations (Karrou *et al.* 1992)

| Year | SEA 1985 | | | SEA 1986 | | | JS - 1985 | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | WUE kg/mm | WU mm | GY kg/ha | WUE kg/mm | WU mm | GY kg/ha | WUE kg/mm | WU kg/mm | GY kg/ha |
| 20.000 plants/ha | 9.53 | 147 | 1398 | 3.90 | 101 | 385 | 8.20 | 107 | 885 |
| 40.000 plants/ha | 11.06 | 154 | 1698 | 2.05 | 101 | 197 | 11.10 | 113 | 1246 |
| 80.000 plants/ha | 11.01 | 153 | 1678 | 1.25 | 114 | 148 | 11.55 | 126 | 1455 |

**Table 4 :** Water use efficiency (WUE) and grain yield (GY) of wheat as influenced by soil N variation under different soil moisture regimes (Karrou 1994)

| | | Nesma | | Merchouch 8 | | Saada | |
|---|---|---|---|---|---|---|---|
| Water Regime | N rate kgN/ha | WUE kg/mm | GY kg/h | WUE kg/ha | GY kg/ha | WUE kg/mm | GY kg/ha |
| Dry regime | 0 | 9.56 | 2248 | 10.30 | 2379 | 7.86 | 1859 |
| (297 mm of | 60 | 10.12 | 2464 | 10.64 | 2610 | 8.77 | 1987 |
| water) | 120 | 11.31 | 2856 | 9.76 | 2538 | 8.70 | 2147 |
| Intermediate | 0 | 8.50 | 2609 | 9.83 | 2968 | 6.41 | 1785 |
| regime | 60 | 10.4 | 3373 | 12.46 | 3787 | 7.70 | 2262 |
| (362 mm of | 120 | 111.09 | 3530 | 12.43 | 3807 | 8.26 | 2582 |
| water) | | | | | | | |
| Wet regime | 0 | 7.57 | 2661 | 7.89 | 2634 | 8.31 | 2857 |
| (417 mm of | 60 | 11.84 | 4091 | 11.13 | 3996 | 8.89 | 3222 |
| water) | 120 | 12.86 | 4232 | 15.17 | 5223 | 9.94 | 3431 |

**Table 5 :** Water use efficiency (WUE) and grain yield (GY) of wheat as influenced by supplementary irrigation in Sidi El Aidi experiment station (Boutfirass et El Mourid 1994)

| Treatment | W U E (kg/mm) | G Y (kg/ha) |
|---|---|---|
| Check : No irrigation (294 mm of Rain) | 11.82 | 3382 |
| Irrigated at tillering (Rain + 60 mm of water) | 15.25 | 5421 |
| Irrigated at heading (Rain + 60 mm of water) | 12.85 | 4417 |
| Irrigated during grain filling Rain + 60 mm of water) | 12.26 | 4204 |

**Table 6 :** Water use efficiency (WUE) of different varieties of bread wheat and barley under different soil moisture conditions (El Mourid, 1988).

| | Dry | Intermediate | Wet |
|---|---|---|---|
| Variety | | Kg/mm | |
| Bread wheat Potam (early) | 6.5 | 8.0 | 10.5 |
| Bread wheat Florelle (late) | 2.2 | 3.6 | 6.5 |
| Durum wheat Cocorit (early) | 5.8 | 7.8 | 10.3 |
| Durum wheat Keyperounda (late) | 2.5 | 4.8 | 6.6 |
| Barley ACSAD 60 (early) | 6.1 | 9.9 | 10.6 |
| Barley Arig 8 (late) | 2.9 | 8.6 | 11.8 |

**Table 7 :** Water use efficiency (WUE), water use (WU) and grain yield (GY) of different hybrids of corn in Sidi El Aidi and Jamaa Shaim Experiment Stations (Karrou *et al.* 1992)

| Year/site | Sidi El Aidi 85 | | | Sidi El Aidi 86 | | | Jamaa Shaim 86 | | |
|---|---|---|---|---|---|---|---|---|---|
| Hybrid | WUE kg/mm | WU mn | GY kg/ha | WUE | WU | GY | WUE | GY | WU_ |
| DRA 400 (Late) | 16.1 | 156 | 2520 | 2.02 | 143 | 290 | | | 430 |
| Tx 21 (Late) | 14.5 | 172 | 2250 | 1.50 | 144 | 220 | 5.46 | 175 | 950 |
| HT 308 (Late) | 16.5 | 164 | 2690 | 2.44 | 133 | 330 | 3.22 | 172 | 580 |
| Funks 4065 (intermediate) | 16.0 | 149 | 2340 | 4.06 | 154 | 640 | 5.91 | 182 | 1070 |
| Pioneer 3969(early) | 17.6 | 150 | 2650 | 5.13 | 126 | 650 | 6.31 | 172 | 1090 |
| Pioneer 3994 (early) | 15.8 | 153 | 2420 | 4.37 | 143 | 630 | 7.52 | 171 | 1230 |

**Table 8 :** Water use efficiency (WUE), water use (WU) and grain yield (GY) of chickpeas varieties in Sidi El Aidi Experiment Station (Dahan 1994).

| Variety | WUE (kg/mm) | WU (Kg/ha) | GY |
|---|---|---|---|
| Flip 84 - 92 C | 1.76 | 109 | 192 |
| Flip 83 - 48 C | 1.89 | 106 | 200 |
| PC - 46 | 0.75 | 109 | 82 |
| Flip 84 - 182 C | 2,57 | 112 | 288 |

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