Opportunities for improving wheat water productivity in semi-arid areas of Morocco

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Abstract

Wheat is the second most important cereal crop in Morocco after barley. It is grown mainly under rainfed conditions. Its yields are low in general due to low and variable rainfall and to the predominant poor crop management techniques used by most of the farmers. To increase and stabilize yields of wheat in these environments, Moroccan scientists have been developing, since 1980s, improved and more adapted techniques. The results obtained showed the role of the adoption of improved varieties and better technical management in reducing the gap between the farmers' and potential achievable yields. It was proven that early to semi-early cultivars, early planting, narrow row spacing, early weed control, optimum nitrogen application, fallow and supplemental irrigation at tillering and heading increased and stabilized wheat yield. To evaluate the importance of the developed technologies in terms of water productivity (WP) improvement, the approach suggested by Angus and van Herwaarden (2001) was used. This evaluation showed that the gap between WP obtained under improved technologies and the actual one is still high. Consequently, even in our experiments conditions, factors other than water were limiting and there is still room for increasing more water productivity. The only technologies that allowed the closing of water productivity gap were the use of improved varieties and the nitrogen application.

Key words: Wheat, rainfed, yield, water productivity, supplemental irrigation, Morocco.

إمكانيات تحسين إنتاجية الماء في المناطق الشبه الجافة في المغرب

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ملخص

تعد زراعة القمح ثاني أهم زراعة الحبوب في المغرب بعد زراعة الشعير ، وتتم زراعته أساسا تحت الظروف المطرية ، إلا أن مردوديته تظل ، بصفة عامة ، ضئيلة بسبب التساقطات الضعيفة والمتدبدبة وكذلك تغلب استعمال التقنيات الزراعية غير الملائمة من طرف المزارعين.

وللرفع من مردودية زراعة القمح واستقرارها ، قام الباحثون المغاربة منذ سنة 1980 بتطوير تقنيات أحسن وأكثر تلاؤما مع هذه الظروف . ولقد بينت النتائج المحصل عليها عن دور الأصناف المحسنة المعتمدة والتسيير التقني المعقلن في تقليص الفارق بين المردودية المحصل عليها من طرف المزارعين وإمكانية الإنتاج التي تتيحها الظروف الفلاحية.

ولقد اتضح أن الأصناف المبكرة وشبه المبكرة،والزرع المبكر وخطوط الزرع المتقاربة، ومكافحة الطفيليات المبكرة واستعمال كميات ملائمة من الآزوت والأرض المستريحة والري التكميلي عند مرحلتي التفريخ والسنبلة أدت كلها إلا الرفع من مردودية القمح و استقراها.

ولتقييم أهمية التقنيات المتطورة فيما يتعلق بالرفع من إنتاجية الماء، تم استعمال المقاربة المقترحة من طرف أكوس وفان هيرواردين (2001). وقد تبين من خلال ذلك أن الفارق في إنتاجية الماء بين التقنيات المحسنة وتلك المستعملة فعليا لازال مرتفعا . وبالتالي ، فإن عوامل أخرى، غير الماء ، كانت محددة حتى على مستوى التجارب ، ولا يزال المجال متاحا للحصول على إنتاجية أعلى للماء . وتبقى التقنيات الوحيدة التي قلصت فارق إنتاجية الماء هي استعمال أصناف القمح المحسنة والكميات الملائمة من الآزوت.

الكلمات المفتاح : القمح، الظروف المطرية، مردودية، إنتاجية الماء، الري التكميلي، المغرب.

Opportunités pour l'amélioration de la productivité de l'eau en zones semi-arides du Maroc

Résumé

Le blé est la deuxième plus importante céréale au Maroc après l'orge. Il est cultivé essentiellement sous les conditions pluviales. Ses rendements sont faibles en général en raison des précipitations faibles et variables et la prédominance des techniques de gestion des cultures inadéquates utilisées par la plupart des agriculteurs. Pour améliorer et stabiliser les rendements du blé dans ces environnements, les chercheurs marocains ont développé, depuis les années 1980, des techniques améliorées et plus adaptées. Les résultats obtenus ont montré le rôle de l'adoption de variétés améliorées et une meilleure gestion technique dans la réduction de l'écart entre les rendements des agriculteurs et les potentiels réalisables. Il a été prouvé que, les variétés précoces et semi-précoces, les dates de semis précoces, les espacements réduits, le désherbage précoce, les doses d'azote optimales, la jachère et l'irrigation d'appoint au tallage et à l'épiaison ont augmenté et stabilisé le rendement du blé. Pour évaluer l'importance des technologies développées en termes d'amélioration de la productivité de l'eau (WP), l'approche suggérée par Angus et Van Herwaarden (2001) a été utilisée. Cette évaluation a montré que l'écart entre WP obtenue en vertu de technologies améliorées et celles réellement utilisées, est encore élevé. Par conséquent, même dans les conditions de nos expérimentations, des facteurs autres que l'eau ont été limitants et il est encore possible d'accroître davantage la productivité de l'eau. Les seules technologies qui ont permis de combler l'écart de productivité de l'eau sont l'utilisation de variétés améliorées et l'application de l'azote.

Mots clés : Blé, pluvial, rendement, productivité de l'eau, irrigation d'appoint, Maroc.

Introduction

Cereals are important crops in the farming systems of Morocco. They are grown on 99% of the farms and represent around 70% of the total arable land of the country (MADREF, 2001). However, cereals in Morocco are cultivated mostly under rainfed conditions in arid and semi-arid areas occupying more than 80% of the arable land of the country. Despite their important area, their productivity is very variable in time and space and remains low in average due to the low rainfall and high fluctuations of the precipitation. In fact, to meet its population needs, Morocco relies heavily on imports of these commodities, especially that of bread wheat.

In addition to improving wheat grain yield as an objective, there is, recently, a great interest in increasing water productivity (WP=Yield/ET) of rainfed crops. This is due to the increasing competition for water between agriculture and other sectors (Karrou and Boutfirass, 2007) in addition to the fact that drought that is becoming more frequent (MADRPM, 1999). Another reason is that non-irrigated semi-arid and arid areas represent a high percentage of arable land in the country.

To increase and sustain wheat production under scarce water conditions and hence reduce the import costs of this commodity, Moroccan researchers have been looking for adaptable techniques and/or new technologies that can help farmers increase and stabilize yields with limited amounts of rainfall. Many varieties with high yield potential and tolerance to drought (Karrou, 2003), and improved agronomic techniques under limited rainfall conditions have been developed and tested. Despite these promising research results, the gap between the actual and potential achievable yield remains high and the attained water productivity is still low. In this paper, available research data (for the period 1985-86 to 1998-99) on the strategies of crop productivity improvement and on the gap between the actual and attainable water productivity are discussed.

Reasons for low water productivity

Water use efficiency (WUE) is generally defined as the ratio of Output to Input. Consequently, in plant/crop production systems, different definitions have been used depending on the hierarchical scales (from biochemical to crop water use efficiency). However, to assess whether wheat yield is limited by water supply or by other factors, Water productivity, in this paper, is defined as the ratio of grain yield to crop water use (actual evapotranspiration). Water productivity is based on the principle of "more crop per drop" (Singh, 2006).

Crop water production is governed only by transpiration (FAO, 2003). Since it is difficult to separate transpiration from soil evaporation, defining crop water use efficiency (water productivity) using evapotranspiration rather than transpiration makes practical sense at field level.

Since the beginning of the green revolution in early 1960s up to now, water productivity increased by at least 100%. This progress has been due mainly to yield increase (FAO, 2003). For many crops, the yield increase has occurred without increased water consumption and sometimes with even less water. In wheat, yield increase has been mainly due to the improvement of the harvest index through the development of dwarf and semi-dwarf varieties and to the application of nitrogen (Beech and Norman, 1968).

Despite this significant yield improvement, there are still management and environmental causes underlying water loss and hence the gap between actual and attainable water productivity. Under rainfed conditions, soil water evaporation is the most important source of inefficient water use in semiarid areas (Cooper, 1983, El Mourid, 1988). The increase of wheat yield per unit of scarce water requires both better crop management and more adapted cultivars. The challenge is to capture more water for use in transpiration, to use CO_2 more effectively in producing biomass and to convert more of the biomass into grain (Passioura, 2006).

Means of increasing water productivity

1. Planting date and pattern

One source of water loss by evaporation is related to planting period and pattern. As a matter of fact, most of the Moroccan farmers delay wheat planting until it rains enough in Fall season to be able to till and cultivate the soil and hence to prepare a good seedbed and to control the early emerging weeds. Nevertheless, this practice involves wet soil disturbance and consequently increases soil water evaporation. Many experiments conducted on planting dates (Bouchoutrouch, 1993), under rainfed conditions in Morocco showed that the early planting of November is the best because it allows the crop to take advantage of early Fall season rains and to escape terminal drought and heat. Table 1 shows a two-year data of an experiment undertaken in the province of Settat, a semi-arid area of Morocco (latitude: 33^o 00’ N; longitude: 9^o 22’ WW). These results showed that in general, the early planting increased the amount of water used, grain yield and WP. By advancing the planting period from early January to early November, grain yield and water productivity were increased by 50 to 100%. Despite the advantages of the early planting, it is difficult for the farmers in many cases to till their fields when the soil is dry in order to achieve a good seed-bed necessary for proper seedlings emergence. This problem hinders the adoption of early planting by cereals producers. One solution to this technical constraint is the adoption of the no-till system (Bouzza, 1990, Mrabet, 1997) that allows an early planting of seeds in a dry soil without previous cultivation.

Table 1. Effect of planting date on grain yield (GY), actual water use (ETa) and water productivity (WP) of wheat (Bouchoutrouch, 1993)

	384 mm Rainfall			**286 mm Rainfall**		
Planting period	GY	ETa	WP	GY	ETa	WP
1st week of Nov.	2801 c	286 b	9.8 b	3570 b	295b b	12.2 b
1st week of Dec.	1818 b	251 a	7.2 a	3630 b	285 b	12.8 b
1st week of Jan.	1375 a	226 a	6.1 a	1470 a	244 a	6.0 a
LSD (0.05)	378	57	1.1	241	29	1.5

GY, ETa and WP are in $Kgha^{-1}$, mm and Kg ha^{-1} mm^{-1}, respectively.

In semi-arid areas of Morocco, wheat seeds are usually broadcasted and covered using an offset disk. Consequently, these seeds are placed at different soil depths and hence the emergence is heterogeneous and the vigour of seedlings is usually low. The low vigour is also due, under certain circumstances, to very high seeding rates and low nitrogen levels used by farmers (high competition among plants). A study conducted by Karrou (1998) on planting pattern (seeding rate and row spacing) demonstrated that there is no need to apply high seeding rates if the drill is used to sow the seeds and if the spatial distribution of plants (geometry) is homogeneous and ensures an early soil cover to prevent soil evaporation. Table 2 shows that the reduction of row spacing from 24 cm (usually recommended by extension services) to 12 cm increases grain yield and water productivity. However, evapotranspiration is slightly reduced due probably to evaporation reduction. WP's increase varied from 16 to 44% depending on rainfall distribution.

Table 2. Effect of planting pattern on grain yield (GY), actual water use (ETa) and water productivity (WP) or rain-water productivity (RWP) of wheat (Karrou, 1998)

	422 mm Rainfall		**288mm Rainfall**		
Row spacing	GY	RWP	GY	ETa	WP
12 cm	4020 [b]	9.5 [b]	2310 [b]	338 [a]	7.8 [b]
24 cm	3380 [a]	8.0 [a]	1620 [a]	359 [a]	5.5 [a]
LSD (0.05)	274	1.1	382	NS	1.5

GY, ETa and WP (and RWP) are in $Kgha^{-1}$, mm and $Kg\ ha^{-1}\ mm^{-1}$, respectively.

The benefits of rapid use of water early in the season have to be, however, weighed against the depletion of soil water reserves during the critical stages of grain set and filling (Sadras and Connor, 1991; van Herwaarden et al., 1998).

2. Weed control

In addition to soil evaporation, water loss can be due to weeds infestation. In fact, many farmers, especially the smallholders, delay the weeding of wheat crop until the period of stem elongation because these weeds are the source of forages for their livestock. However, these plants compete very strongly with wheat for a limited amount of soil moisture and nutrients mostly during the sensitive phase of wheat stem elongation. Table 3 shows that weed control early in the season (at 3-4 leaf stage of the crop) increased grain yield and water productivity, especially under relatively wetter conditions. Under this situation, WP increase was more than 3-fold as compared to a weedy plot (Tanji and Karrou, 1992). Nevertheless, when it is too dry, the difference between weed-free and weedy treatment is not significant because water deficit which is the most important limiting factor of plants' and even weeds' growth is hindered under these conditions. Data also show that weedy treatment used more water because weeds tend to explore more soil volume because of their deeper root system (Tanji and Karrou, 1992).

Table 3. Effect of weed control on grain yield (GY), actual water use (ETa) and water productivity (WP) of wheat (Tanji and Karrou, 1992)

	180 mm Rainfall			290 mm Rainfall		
Treatment	GY	ETa	WP	GY	ETa	WP
Weed free	1085[a]	161 [a]	6.8 [b]	3021[b]	316 [a]	9.6 [b]
Weedy	994 [a]	182 [b]	5.5 [a]	931[a]	366 [b]	2.7 [a]
LSD (0.05)	NS	33	0.4	763	45	26

GY, ETa and WP are in Kgha^{-1}, mm and Kg ha^{-1} mm^{-1}, respectively.

3. Fertilizers application

Fertilizer management is particularly important in systems where high risk of farming associated with uncertain rainfall is reduced by using a low-input strategy (Sadras and Roget, 2004). Low nutrient supply leading to slow canopy expansion (Cooper et al., 1983; Cooper et al., 1987) and small rainfall events (Sadras, 2003) both contribute to unproductive soil evaporation.

Adequate fertilisation can involve a significant increase of WP largely through the reduction in soil evaporation (Cooper et al., 1987) and can guarantee high yields during wet seasons. Jerry et al. (2001) stated that nutrient management practices could improve water productivity by 15 to 25%.

Among the macro-nutrients needed by plants, nitrogen (N) is the most difficult element to manage in crop production under erratic rainfall. It is susceptible to transformation with temperature and humidity change and can be lost by leaching in the form of nitrate when the soil is too wet. N is also important because it plays an important role in photosynthesis and hence in growth, grain yield and WP of wheat. Consequently, a good management of water and nitrogen applications are the pre-requisites for any improvement in wheat production and wheat water productivity. Abbate et al. (1995) showed that N deficiency in wheat affects negatively the yield component and grain number per spike. Consequently, the availability of adequate amount of nitrogen at critical stages (during stem elongation) can significantly improve the size of the spike and hence the kernel number which is the most grain yield determinant factor and consequently the water productivity. In a study conducted by Karrou (1992) in the semi-arid area of Settat province (Table 4), it was shown that the application of nitrogen fertilizer split into 50% at planting and 50% during tillering tended to increase grain yield, ET and water productivity as compared to the check (without nitrogen application). The increase in WP varied from 10 to 20%. However, the difference between the two N rates tested (60 and 120 Kgha^{-1}) was not significant. Nevertheless, to avoid the early soil moisture depletion that might be due to too high biomass production if high nitrogen rates are applied early in the season, it is necessary to apply N tactically (split N applications). A limited amount of N fertilizer can be applied at the sowing time and a second dose should be provided in mid-tillering or early stem elongation if rainfall and soil moisture conditions are adequate.

Table 4. Effect of Nitrogen rate on grain yield (GY), actual water use (ETa) and water productivity (WP) of wheat (Karrou, 1992)

	Rainfed (297 mm)			**Rainfed + SI (362 mm)**		
N rate	GY	ETa	WP	GY	ETa	WP
0 $KgNha^{-1}$	2162 [a]	240 [a]	9.3 [a]	2454 [a]	308 [a]	8.2 [a]
60 $KgNha^{-1}$	2353 [b]	254 [a]	9.8 [b]	3141 [b]	326 [a]	10.2 [b]
120 $KgNha^{-1}$	2514 [b]	263 [a]	9.9 [b]	3306 [b]	316 [a]	10.6 [b]
LSD (0.05)	171 NS	0.3		685	NS	1.9

GY, ETa and WP are in $Kgha^{-1}$, mm and Kg ha^{-1} mm^{-1}, respectively.

4. Water conservation techniques

Soil nitrogen and moisture content during the growing season of wheat can also be influenced by soil management and land use during the period preceding the cropping of this cereal. Jerry et al. (2001) stated that it is possible to increase water productivity by 25 to 40% through soil management practices that involve tillage machinery. They added that the total evaporation fluxes from tilled fields in Iowa were 10-12 mm for a 3-day period following each cultivation operation in spring. However, for no-tillage fields, they were less than 2 mm over the same period. The difference between tillage and no-tillage treatments was related to mulch or residues management. The importance of no-till (Bouzza, 1990) and residue management (Mrabet (1997) were shown in Morocco in experiment trials. For the land use, El Mejahed (1993) showed for central Morocco (Table 5) that wheat performance was the best after fallow than after chickpea and wheat rotation systems. The second best cropping system was Legume/Wheat, while Wheat/Wheat system was the worst. It seems that fallowing improved residues mineralization and water conservation. However, the legume improved only nitrogen availability in the soil.

Table 5. Rotation effect of on grain yield (GY), actual water use (ETa) and water productivity (WP) of wheat (El Mejahed, 1993)

	1990/91 (280 mm)			**1991/92 (200 mm)**		
Rotation	GY	ETa	WP	GY	ETa	WP
W/F	2694 [b]	290	9.3 [c]	645 [c]	184	3.5 [b]
W/Cp	1483 [a]	209	7.1 [b]	223 [b]	172	1.3 [a]
W/W	1403 [a]	270	5.2 [a]	132 [a]	165	0.8 [a]
LSD (0.05)	151	-	1.65	74	-	0.6

GY, ETa and WP are in $Kgha^{-1}$, mm and $Kg\ ha^{-1}\ mm^{-1}$, respectively.

5. Improved cultivars

The beneficial effect of the best crop management can be hindered by the use of unsuitable old varieties. Richards et al. (2002) described how selecting for large early leaves can produce breeding lines of wheat that develop leaf area twice as fast as standard cultivars. These lines not only reduce evaporation losses, but also inhibit growth of weeds (Lemerle et al., 2001). EL Mourid, (1988) showed the importance of early maturing varieties of wheat in semi-arid areas of Morocco (Table 6). In an experiment where he compared three varieties of wheat, Potam (very early bread wheat), Cocorit (early durum wheat) and Keyperounda (late durum wheat), he found that grain yield increased with the degree of earliness despite the similar amount of water used by the different cultivars. Consequently, WP was also higher for the early cultivar. It seems that the early varieties escape terminal drought and use more water for grain production. However, the latest variety produced twice as much dry matter and its reproductive period coincided with terminal drought and heat. The competition for the limited amount of soil moisture among old tall plants decreased yield and water productivity. However, too early varieties have also a disadvantage because they flower too early and hence they might not have built enough biomass to fill a large number of seeds, especially during relatively wet seasons.

Table 6. Effect of the variety on grain yield (GY), actual water use (ETa) and water productivity (WP) of wheat (El Mourid, 1988).

	286 mm Rainfall			293 mm Rainfall		
Variety	GY	ETa	WP	GY	ETa	WP
Potam (early)	1608 [b]	247 [a]	6.5 [b]	2443 [b]	305 [a]	8.0 [b]
Cocorit (medium)	1420 [a]	245 [a]	5.8 [b]	2338 [b]	300 [a]	7.8 [b]
Keyperounda (late)	586 [a]	234 [a]	2.5 [a]	1421 [a]	316 [a]	4.5 [a]
LSD (0.05)	181	NS	2.4	145	NS	1.8

GY, ETa and WP are in $Kgha^{-1}$, mm and $Kgmm^{-1}$, respectively.

6. Supplemental irrigation

In another experiment (Table 7) where an early (Potam) and a late (Tegyey 32) varieties of bread wheat were exposed to supplemental irrigation at different growth stages, it was shown that the early variety yielded better than the late one and that application of irrigation water at any stage of wheat growth increased yield as compared to rainfed treatment (Boutfirass, 1990). However, the application of supplemental irrigation early during tillering and heading boosted grain yield and water productivity as compared to the other water regimes. Application of water early in the season certainly improved the most important component of yield which is the number of kernels m^{-2}.

Table 6. Effect of the variety on grain yield (GY), actual water use (ETa) and water productivity (WP) of wheat (El Mourid, 1988).

	286 mm Rainfall			**293 mm Rainfall**		
Variety	GY	ETa	WP	GY	ETa	WP
Potam (early)	1608 [b]	247 [a]	6.5 [b]	2443 [b]	305 [a]	8.0 [b]
Cocorit (medium)	1420 [a]	245 [a]	5.8 [b]	2338 [b]	300 [a]	7.8 [b]
Keyperounda (late)	586 [a]	234 [a]	2.5 [a]	1421 [a]	316 [a]	4.5 [a]
LSD (0.05)	181	NS	2.4	145	NS	1.8

GY, ETa and WP are in $Kgha^{-1}$, mm and $Kgmm^{-1}$, respectively.

Moreover, irrigation during grain filling did not probably compensate water deficit during stem elongation where the spike grows and produces fertile spikelets and kernel numbers per spike and per m^2. It is important to mention that supplemental irrigation was managed in a way to bring the total amount of water (rainfall + irrigation) to the long term rainfall average in the region.

Water productivity gap

1. Methodology used

To show if there is any gap between the actual and attainable water productivity of wheat in semi-arid areas of Morocco, the methodological approach of Angus and van Herwaarden (2001) where they used water use efficiency terminology instead of crop water productivity was adopted. These authors showed that yields of dryland wheat in southeastern Australia were usually not limited by water. Sadras and Angus (2006) found that attainable WUE for wheat in this region was described by a minimum soil evaporation of around 60 mm and a maximum transpiration efficiency of around 20 kg grain ha^{-1} mm^{-1}. Using this information, they drew a boundary line with a slope of 22 kg ha^{-1} mm^{-1} and an abscissa-intercept of 60 mm that provided an upper limit for all the data. This boundary function is similar to that proposed by French and Schultz (1984a) for southern Australia, and it seems to be a sensible reference for other dry environments. The actual WUE of most wheat crops in the southeastern Australia was far below this benchmark.

2. Application of the methodology to Moroccan conditions

To apply the methodology of yield gap evaluation described above to the conditions of the semi-arid areas of Morocco, scatter points of grain yield versus seasonal evapotranspiration of wheat, using data from different experiments conducted in semi-arid areas of Settat province, Morocco, were drawn (Figure 1). To avoid the effect of water application, supplemental irrigation data were omitted. In the same figure, we presented the boundary line following the procedure of Sadras and Angus (2006). The figure shows that the minimum and the maximum WP were 2 and 15 kg ha^{-1} mm^{-1}, respectively. The average was 8.7 kg ha^{-1} mm^{-1}. It is lower than that of South-eastern Australia (9.9 kg ha^{-1} mm^{-1}), similar to that of the northern US Great Plains (8.9 kg ha^{-1} mm^{-1}) and higher than that of the Southern Central Great Plains of the USA.

Moroccan data presented in figure 1 showed that the minimum grain yield was obtained at an ETa of 160 mm. Ouhajjou (1991) reported for the same environment (Settat region of Morocco) that the threshold for grain production varied from 65 mm to 123 mm for different varieties of wheat. Moreover, Mazhar (1987) and Bouzza (1990) estimated this threshold to 98 mm and 186 mm, respectively. These results support the hypothetical diagram, Figure 2, developed by El Mourid, Karrou and El Gharous (1996) which shows that the strategy, aiming towards either grain or biomass productions, has to take into consideration the prevailing soil moisture conditions in the region. These authors postulated that yield increases with soil moisture increase above certain level (ETa threshold of 160 mm). And hence, it is more beneficial to invest in the high input technologies (high yielding varieties, fertilizers, pesticides, etc) under these conditions. However, below this threshold, the available soil moisture (low rainfall, shallow soils) is not enough to produce an economic grain yield and hence, it is better to enhance vegetative biomass yield (barley, shrubs, pasture) to feed animals and increase their production.

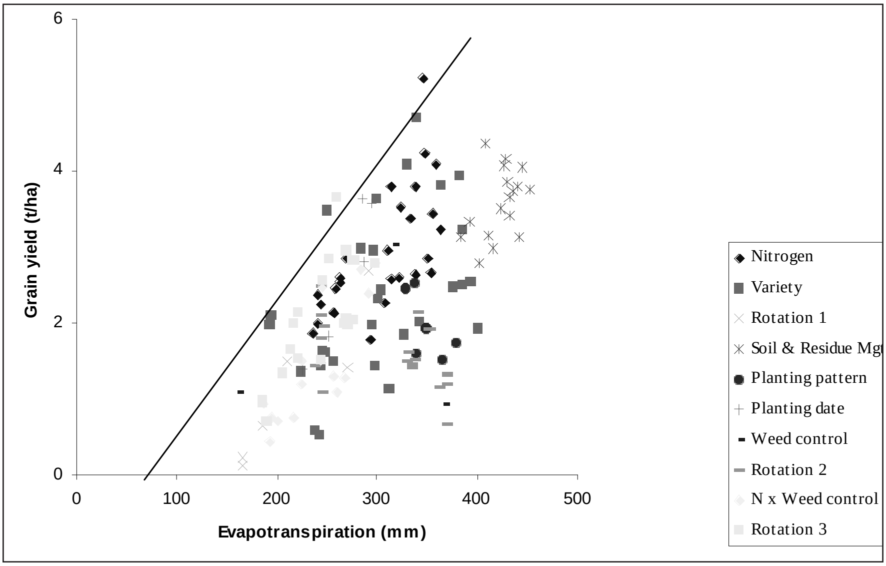

Fig.1. Scatter points of wheat grain yield and seasonal evapotranspiration in semi-arid areas of Morocco

NB: The data used to draw this figure are mainly the ones presented in the tables of this manuscript (supplemental irrigation data are omitted).

Most of the points in figure 1 are under the boundary line even for the experimental treatments where improved technologies were tested except under a high level of nitrogen and an early variety were used. This means that there is still a large gap between the actual yield and attainable water productivity under rainfed conditions. Angus and van Herwaarden (2001) stated that while the line represents the water limited yield, points under the line represent yields that are limited by genetic, environmental or management factors other than water.

Conclusion

Good management practices were necessary; but they are insufficient to achieve high water productivity in the dry environment region of Morocco. Major constraints to attain high efficiencies include: (a) massive water losses through soil evaporation characterizing these areas,;(b) timing of rainfall constraining sowing opportunities and/or the critical physiological process of grain set and filling; and (c) high evaporative demand during flowering and grain filling. Moreover, the progress achieved by researchers in wheat yield using a single technique or technology is not enough because the other components of the agronomic package might not be at their optimum.

To overcome these constraints, there is a need for developing tools for seasonal weather forecast to synchronize the critical stages with rainy periods through the choice of adapted planting dates and varieties and the prediction of suitable time for fertilizer N application. Multi-factorial experiments to identify the best combinations of agronomic technologies and hence building improved packages that reduce water loss by evaporation and water productivity gap is also recommended. Greater efficiencies are achieved when rainfall concentrates around the critical period when kernel set is determined (Fischer, 1985; Sadras et al., 2003). Actual water productivity is therefore the result of interacting management (e.g. fertilization) and environmental (e.g. rainfall pattern) factors.

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