

Improving nitrogen and water use efficiency for wheat production in Mediterranean countries: Case of Tunisia

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1. Introduction

The cereal sector cultivation is deeply rooted in the Mediterranean social and economic farming structure. Indeed, cereals are among the oldest crops in the Mediterranean basin. Currently it occupies a considerable share of agricultural land, estimated at nearly 52% of the arable total and contributes up to 9% of the world production (FAO, 2002).

The majority of the Mediterranean cereal farms are under rainfed regimes. This mode constitutes the essence of the cereal production in these countries. However, the aridity of the climate and the irregularity of annual rainfall represent the typical characteristics of the Mediterranean farming realities, particularly in southern Mediterranean countries which are often endowed with negative water balances. These factors limit the cereal production and represent the major cause of yield irregularity.

In the case of Tunisia, yields remain very low, fluctuating from less than 8 quintals per hectare in the seventies to 10.7 in 2001 to as low as 4.4 quintals per hectare in 2002, the lowest yield ever registered. The highest average

Abstract

Better management of production factors, particularly water and nitrogen utilizations, is likely to improve economic returns of cereal crops in Mediterranean countries. In the framework of the WatNitMED project, Tunisia was chosen as pilot study case where a new nitrogen management technique is tested. The main objective of this work is to compare physical and economic returns obtained using the recommended nitrogen strategy against those obtained using conventional farmers practices. During 2006-2007, a sample of 31 cereal growers was selected for the purpose of testing the nitrogen package recommended by WatNitMED partners.

Statistical results show that grain yields are not significantly different at 5%. However, average straw yields obtained using the recommended strategy is significantly higher than in the conventional case. Moreover, the average gross margin difference between the two management practices is statistically significant at 5%. Hence, the recommended strategy is likely to increase the farmers' profits. Gross margins obtained using the new nitrogen management package are higher by 26% and 32% in the case of irrigated and rainfed areas respectively. Consequently, these results provide a basis for recommending the adoption of the proposed nitrogen technology.

Keywords: Tunisia, Efficiency, Nitrogen, Water, Durum wheat.

Résumé

Une meilleure gestion des facteurs de production et en particulier de l'eau et de l'azote pourrait améliorer le potentiel de production des variétés céréalières. Dans le cadre du projet WatNitMED, la Tunisie a été choisie comme pays pilote dans lequel un nouveau mode de gestion de la fertilisation azotée est testé. L'objectif principal de ce travail consiste à comparer les résultats physiques et économiques entre la gestion conventionnelle de la fertilisation azotée avec celle recommandée par les partenaires du projet WatNitMED. Au cours de la campagne 2006-2007, un échantillon de 31 céréaliculteurs a été sélectionné afin d'appliquer cette nouvelle forme de gestion à la culture de blé dur.

Les résultats statistiques montrent qu'il n'y a pas de différence significative au seuil de 5% entre les rendements en grains obtenus à partir des deux différents modes de gestion. Cependant, il existe une différence significative au seuil de 5% entre les rendements en paille. Les résultats montrent aussi que la moyenne de la différence des marges brutes obtenues à partir du paquet recommandé par le projet et de la méthode conventionnelle est statistiquement significative au seuil de 5%. La marge brute a enregistré une supériorité de 26% et de 32% pour le blé dur en irriguée et en sec respectivement, ce qui milite en faveur de l'adoption du paquet proposé.

Mots clés: Tunisie, Efficience, Eau, Azote, Blé dur.

yield reached 19 quintals per hectare in 2003, following the favourable climatic conditions that prevailed during that year (MARH, 2008). Furthermore, the evolution of the cereals production is largely related to the climatic conditions, in particular rainfall, rather than improvements in yields (Gtari, 2008). According to the World Bank (2006), cereal production in Tunisia is insufficient to meet domestic demand. However, research results and national statistics show that the potential of cereals varieties is underexploited. Indeed, the obtained yields using the same variety vary not only from a region to another but also within neighbouring farmers and on the same farm (Gharbi *et al.*, 1998, Mhadhbi, 1998).

Cereal yields depend on controllable factors (varieties, fertilizers, irrigation water, pesticides, mechanization, etc.) and also on uncontrollable factors such as rainfall and temperature. Hence, a better management of production factors, particularly water

and nitrogen, is likely to improve the production potential of cereal varieties. Passioura (2002) states that soil humidity and nitrogen content represent two important factors determining yields. However, the frequent spreading of nitrogen in large quantities in order to raise output can lead to under-

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utilization of this factor and results in water pollution (Hébrard, 2000). Indeed, when the applied amount of nitrogen exceeds the plant requirements, the excess nitrogen can be found below roots following leaching phenomena and consequently leading to the contamination of water resources. Moreover, the excess of nitrogen consumption results in unnecessary increase in the production cost, in addition to a possible burning of plants.

On the basis of these considerations, the Mediterranean cereal sector has to develop a durable production system guaranteeing a better technical and economic valuing of the most limiting production factors. Increasing water and nitrogen use efficiencies by cereals is an important task that has to be analyzed. Water is recognized to be the most limiting factor in Mediterranean regions, though nitrogen shortages seem to be as important.

Given a certain amount of water in the soil is always present, even if small, it is always desirable to have a "preset quantity of nitrogen" because the water-nitrogen interaction plays a major role in the determination of the cereal yields (Richards, 1996; Slafer and Rawson, 1994). In this context, the WatNitMED¹ project was set up to identify possible improvements in the management of water and nitrogen use efficiency (WNUe). It is a multidisciplinary project involving physiologists, agricultural economists, agronomists, etc. The general objective of the project is to identify and transfer improvements in the management of wheat and barley crops (two strategic crops in the Mediterranean region) through increasing the capture and/or the use efficiency of the most limiting factors determining their productivity (Water and Nitrogen). The objective of the socioeconomic part of this work is to analyze the actual improvements within a sample of farmers in the Region and then identify the required accompanying dissemination devices in order to transfer those findings to other farms.

Tunisia was chosen as pilot case study where a new technological package is tested. The main objectives of the paper are to compare the physical and economic returns between the nitrogen conventional management developed by farmers and the recommended practice by WatNitMED partners and evaluate the overall impacts of the proposed alternative in terms of gross margins (GM) for the cereal growers.

2. Methodology

To achieve the objectives of this study, the work consisted of two steps. The first step aims at identifying the technical behaviour of cereal growers and evaluating their eco-

nomical performances. The second step consists of selecting a sub-sample of farmers who are willing to apply the recommended practices identified by WatNitMED partners. The evaluation of the technological package utilizes the data generated from the sample.

2.1. Data sources

A survey was conducted during July-August 2005 on a sample of 44 Tunisian farmers growing cereals (wheat and barley) in irrigated and rainfed conditions located in three governorates: Béja, Jendouba and Siliana. The questionnaire aims at describing the production systems and particularly the farmers' wheat and barley conventional practices. An emphasis was put on water and nitrogen use (applied quantities, date of application, type of fertilizers and their fractionation). The last part includes open questions allowing farmers to express their opinion regarding the main factors favouring and/or hindering the development of cereal crops (profitability, prices, marketing, etc.).

The survey results allowed the understanding of the current situation in terms of technical practices, economic performances as well as water and nitrogen valuations by the cereal growers. Generally, the revealed yields obtained by farmers are low, compared to the technical potential, as determined by the project, which confirms the existence of possible substantial improvements through more effective use of water and nitrogen. The results also revealed a great disparity between farms. The latter can be mainly explained by natural variability in endowments and by the farmers' know-how.

The most used wheat varieties by cereal growers are Karim, Razak and Khiair which are adopted by 62%, 24% and 12% respectively of the farmers sample and the rest use other varieties (2%). We also point out that 55% of farmers use certified durum wheat seeds, against 36% who use a mixture of seeds and only 9% utilize ordinary seeds.

Socio-economic factors such as the farmer advanced age, land fragmentation, low educational level, and financial problems are the most important factors hindering the adoption of new technologies aiming at optimizing WNUe. During the survey, farmers never mentioned technical problems related to nitrogen fertilization or irrigation. The frequently mentioned constraints deal with financial difficulties, increasing factor costs and the inefficiency of the institutional organization of the cereal sector which is characterized by the Cereal Office monopoly at all the value chain levels.

During the season 2007-2008, a sub-sample composed of 31 Tunisian farmers distributed between Beja (15) and Siliana (16) was selected in order to apply the new technological package proposed in the framework of the WatNitMED project on durum wheat. Eleven farmers had access to irrigation water and the rest operated in rainfed conditions².

Several visits were made to farmers and each one devoted a plot of 1 hectare on which the experiment was tested. A complement of investigation was carried out in order to

¹ WatNitMED project (Management Improvements of Water and Nitrogen Use Efficiency of Mediterranean Strategic Crops (Wheat and Barley) is funded within the framework of the EU FP6.

² The reduction of the sample size is explained by budgetary considerations: the monitoring and supervision of all farm operations of the entire farmers sample from sowing to harvesting imply high expenditures which cannot be afforded by the WatNitMED project; soil analysis before sowing and after harvesting, compensation of farmers as for the fertilizers applied on the experimental plots and for any output loss, etc.

get information on the agronomic history of each plot (previous crops, the best obtained yield in the past, amount of applied fertilizers, etc.). Moreover, three soil samples were taken from each plot and analyzed in terms of texture, nitrogen content, saturation point, field capacity, wilting point etc.

On the basis of the information gathered on each plot, the experiment was designed as follows:

Soil preparation is identical to the conventional practices

Date and dose of sowing are also the same as the conventional practices

In view of the high nitrogen content of the soils revealed by the analysis, it was recommended to both groups of farmers (irrigation and rain fed) to apply 240 kg/ha of Diammonium Phosphate (DAP), two to three days before sowing.

Then, a single visit of the scientific staff of the Wat-NitMED project took place in mid-January 2008³ in order to observe the state of the plant growth and recommend to each farmer the amount of nitrogen to be applied⁴.

Based on the potential yield of each plot, the state of plant growth and nitrogen soil content, it has been decided for each farmer the application of a specific amount of nitrogen in one time and no later than the week following the three-leaf stage.

During June-July 2008 and just before harvesting, several field visits to each farmer took place. We took a sample of durum wheat of two square meters (that is 4 diagonal samples of 0.5 m² each one if the vegetation is homogeneous and 8 samples in cases where it was deemed heterogeneous) from each plot (experimental and conventional) in order to estimate grain and straw yields⁵.

2.2. Test of the technological package

To evaluate the efficiency of the tested technological package, *ceteris paribus*, we proceed by a descriptive, cost-benefit analysis and a Student's *t* test on two samples associated in pairs in order to check the hypothesis that the average difference between the two alternatives is zero. This statistical test is appropriate when the samples are dependent; that is, a single sample is tested twice (before and after the experiment) or when there are two samples that have been paired (Dagnelie, 1998). Hence, we calculate a Student *t*-test to compare the average difference between two treatments when the observations have been obtained in pairs. So, if represents the mean difference between two treatments, the hypotheses are:

– Null hypothesis H_0 : The average difference between two treatments is zero $\bar{D}=0$

– Alternative hypothesis H_a : The average difference between two treatments is different from zero $\bar{D}\neq 0$

The difference between the paired values is assumed to be normally distributed, and the null hypothesis that the expectation of the difference is zero is tested by Student *t*-test. If the calculated *t* is higher (lower) than critical *t* with *n*-1 degrees of freedom at the chosen significance level, there is evidence to reject (accept) the null hypothesis.

3. Results and discussion

3.1. Comparison of yields

In this section we compare, *ceteris paribus*, the obtained yields with and without applying the technological package. Table 1 synthesizes grain and straw average yields and shows that farmers' yields are variable according to the management method. The average durum wheat yield in rain fed conditions is about 37 q/ha, against 32 q/ha, in irrigated conditions, and 31 q/ha, against 29 q/ha in rain fed conditions, in experimental and conventional plots, respectively. Average yields in the experimental as well as conventional plots are higher in Béja than in Siliana in view of the respective sub-humid and semi-arid nature of the climate. Indeed, in irrigated conditions, the average yield is 44 q/ha in Béja against 29 q/ha in Siliana, whereas in rainfed conditions, the average yield is about 38 q/ha in Béja compared to 27 q/ha in Siliana.

Table 1- Durum wheat grain and straw average yields in Béja and Siliana.

	Grain yields (q/ha)				Straw yields (bale/ha)			
	Irrigated		Rainfed		Irrigated		Rainfed	
	Exp*	Conv*	Exp*	Conv*	Exp*	Conv*	Exp*	Conv*
Béja	44.17	40.90	38.43	35.09	293	245	321	201
Siliana	28.9	28.23	27.35	22.41	154	107	134	103
Region average	36.51	31.65	31.04	28.58	223	176	196	136

*Exp and Conv refer to experimental and conventional plots.

On the other hand, average straw yields obtained in the experimental plots are estimated at 223 bales/ha and 196 bales/ha, respectively in irrigated and rainfed conditions. These yields are much higher than those obtained by cereal growers with their conventional practices. On average, straw yields are higher by approximately 28% and 44% respectively in irrigated and rainfed conditions.

3.2. Comparison test of average yields

The average of grain yield differences between the two samples (experimental versus conventional) is about 4.9 q/ha and 2.5 q/ha respectively in irrigated and rainfed conditions (cf. Table 2).

³ At this period, plants were at three-leaf stage.

⁴ Unfortunately, twelve farmers withdrew from the project for various reasons

⁵ We also took soil samples after harvesting in order to estimate the soil nitrogen content. Grain and straw samples were also analyzed in the laboratory in terms of nitrogen content allowing the completion of the nitrogen balance diagram.

The application of the Student *t* test on the observed grain yields (two paired samples) makes possible the non rejection of the null assumption H_0 at the 5% significance level. In other terms, the average difference between the two alternatives in irrigated and rainfed conditions is not statistically significant from 0. That is grain yields obtained with the proposed nitrogen management package are not statistically different from those generated by the farmer's conventional practices. Indeed, the calculated student *t*-test is lower than its critical value both in irrigated and rainfed areas (cf. Table 2).

3.3. Comparison test of average gross margins

In addition to testing the significance of physical results, a profitability analysis is needed to examine whether the recommended strategy is beneficial to farmers or not. The gross margin (GM) expressed as the difference between the gross product value, including straw and variable costs⁶ for the experimental and conventional plots, and the difference is tested using Student *t* test. The GM indicator is appropriate since that only variable costs change according to the management practice. The average gross margin is evaluated at 1859 TND⁷/ha and 1624 TND/ha respectively in irrigated and rainfed conditions (cf. Table 4). These values are higher than those obtained using conventional practices which are estimated at 1467 TND/ha and 1226 TND/ha respectively in irrigated and rainfed areas.

The average of GM differences between the two samples is approximately 382 TND/ha and 399 (TND/ha) respectively in irrigated and rainfed areas. Based on Student's *t* test values (Table 4), we reject the null hypothesis H_0 in the case of irrigated and rainfed conditions at the 5% significance level which means that the GM average difference between the two alternatives is significantly different from zero at 5% level. Hence the recommended strategy is likely to increase GM and consequently the farmers' profits. We also point out that the impacts on GM are more pronounced in rainfed than in irrigated conditions. This can be explained by the fact that in conventional practices farmers usually tend to apply low quantities of nitrogen depending on rainfall. However, the recommended nitrogen quantities on the experimental plots were much higher than those applied by farmers on the rest of their land.

4. Conclusion

This work was designed in the framework of the WatNitMED project that has the objective of improving water and nitrogen use efficiency in wheat. The paper aims at comparing the physical and economic results between the conventional nitrogen management generally practiced by Tunisian farmers and the strategy recommended by the WatNitMED project partners.

Statistical results show that grain yields are not significantly different at the 5% level. However, average straw yields obtained using the recommended strategy is significantly higher than the conventional practice. Moreover, in economic terms the average of gross margin differences between the two management practices is statis-

⁶ To calculate the gross margin, we used the current output and input prices.

⁷ TN : 1 Tunisian dinar equals approximately 0.8 USD.

Table 2 - *Durum* wheat grain yields.

Yield averages	Experimental (A)	Conventional (B)	Difference (D=A-B)
Irrigated average yield (q/ha)	36.51	31.65	4.87
No statistical significance			$T_{cal}=1.74$
Rainfed average yield (q/ha)	31.04	28.58	2.46
No statistical significance			$T_{cal}=0.75$

*The critical value of Student's *t* test at the 5% significance level is 2.3

With regard to straw, the average of the difference between the two samples is about 47 bales/ha and 60 bales/ha respectively in irrigated and rainfed conditions (cf. Table 3). Moreover, these differences are statistically different from zero at threshold significance of 5% allowing the rejection of the null hypothesis H_0 . Hence the recommended strategy generates higher straw yields than the farmer's conventional practices.

Table 3 - *Durum* wheat straw yields.

Yield averages	Experience (A)	Conventional (B)	Difference (D=A-B)
Irrigated average yield (bale/ha)	223.6	176.44	47.15
Statistical significance			$T_{cal}=2.4$
Rainfed average yield (bale/ha)	196.66	136.56	60.10
Statistical significance			$T_{cal}=2.95$

*The critical value of Student's *t* test at the 5% significance level is 2.3

Table 4 - *Durum* wheat gross margins.

Gross margins	Experiment (A)	Conventional (B)	Difference (D=A-B)
Irrigated average GM (TND/ha)	1859.07	1467.28	381.78
Statistical significance			$T_{cal}=3.11$
Rainfed average GM (TND/ha)	1624.62	1225.91	398.71
Statistical significance			$T_{cal}=2.47$

*The critical value of Student's *t* test at the 5% significance level is 2.3

tically different from zero at 5% significance level. Gross margins obtained using the new nitrogen management are higher by 26% and 32% in the case of irrigated and rainfed areas respectively. Hence, these results can be used as a basis to recommend the adoption of the recommended nitrogen package.

We draw two general implications from this study. First, the current nitrogen management by Tunisian farmers is not optimal and there is a need to adjust the amount and the appropriate application periods in order to improve the output and consequently water productivity. Second, the positive outcome of the project cannot be implemented without a strong implication of the Tunisian Ministry of Agriculture and Hydraulic Resources (MARH) and particularly its extension department, which has to disseminate these results at the farmer level. The need to change the nitrogen management practices highlights the importance of farmer training and extension services in order to improve the competitiveness of the cereal sector.

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