Nitrogen fertilization and fupplemental irrigation for yield and protein of Syrian wheat varieties

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Abstract

In the past few decades considerable emphasis has been placed on improving dryland agriculture in the Mediterranean region, especially focusing on cereal cultivars. Two major developments have underpinned the yield increases that had occurred in recent years; fertilization, especially with nitrogen (N), and, increasingly, supplemental irrigation to stabilize crop yields by compensating for inadequate and erratic winter-spring rainfall. The dryland area of northern Syria typifies such developments in the region as a whole. While the prime focus has been grain and, to a lesser extent, straw yield, less attention has been given to quality, especially protein content. In this 2- year field trial, we evaluated newly developed or improved bread wheat (Cham-4) and durum wheat (Cham-1, Cham-3, Gezira-17) varieties and a traditional durum variety or landrace (Haurani), in relation to N fertilization (0, 50, 100 kg/ha^{-1}) and varying irrigation levels, i.e., rainfed, and 20, 40, 60, 80, and 100% of full irrigation. Yield parameters consistently increased with increasing irrigation levels and by N up to 50 kg ha^{-1}. Seasonal rainfall influenced overall yields and relative responses to N and irrigation, with differences between varieties. While irrigation consistently decreased protein concentration in grain and straw, it was partially counterbalanced by the added N. Irrigation increased kernel weight but decreased the Sodium Sedimentation test., i.e., gluten strength. Nitrogen tended to increase kernel weight and the gluten strength test, effects that varied with the season. In addition to yield, aspects of grain quality are also important because of nutritional considerations in Syria where per capita cereal consumption is one of the highest in the world and where a minimum protein standard is required for grain export.

Key Words*: Nitrogen fertilization of wheat; supplemental irrigation; cereal grain quality*.

تأثير التسميد الأزوتي والري التكميلي على مردودية وجودة أصناف القمح بسوريا

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ملخص

خلال السنوات العشر الأخيرة تم إعطاء الإهتمام والأسبقية للزراعات البعلية في المناطق الزراعية المتوسطة وخاصة لزراعة الحبوب. عنصران أساسيان كانا وراء تحسين المردودية خلال السنوات الأخيرة، نذكر منها الري التكميلي التسميد وخاصة التسميد الأزوتي ...
المناطق البعلية لشمال سوريا هي أحد هاته المناطق المتوسطية التي عرفت تطور مهم في إنتاجية الحبوب ، في الوقت التي تم إعطاء معظم الإهتمام للمردودية وخاصة تلك المتعلقة بالحبوب أقل أهمية أعطيت لجودة هذه الحبوب وخاصة نسبة البروتين. في هذه الدراسة التي أجريت خلال سنتين على أصناف جديدة من القمح الطري (شام4) والقمح الصلب (شام1-شام3-جزيرة17) بجانب الشاهد المحلي الحوراتي. تم إعطاء كميات الأزوت التالية 50-0 و100كلغ/هكتار مع كميات مختلفة لمياه السقي (شاهد بعلي)40-20-و100 في المئة من كميات مياه السقي والتسميد الأزوتي إلى غاية 50كلغ/هكتار. موسمية الأمطار أثرت على تجاوب الأصناف مع كميات الأزوت . وتم الرفع من جودة ونسبة البروتين في الحبوب والتبن . كميات مياه السقي رفع من وزن الحبة ولكن أثرت سلبا على اختبار ترسبات الصوديوم، قوة الغلوتين في الوقت الذي كان تأثير الأزوت إيجا بياعلى وزن الحبة وقوة الغلوتين والذي تغير مع المواسم. وبالتالي يمكن الرفع من إنتاجية الأقماح مع تحسين جودة المنتوج.

الكلمات المفتاح : التسميد الأزوتي، الري التكميلي أصناف القمح الزراعة المتوسطية سوريا

Résumé

Au cours de ces dernières années, une importance considérable a été donnée pour l'amélioration de l'agriculture dans les zones arides de Méditerrané, en particulier les cultivars de céréales. Les deux développements majeurs qui ont été étudiés au cours de ces dernières années afin d'améliorer les rendements sont : la fertilisation azotée et l'irrigation supplémentaire pour stabiliser les composantes des rendements des cultures en cas de précipitations insuffisantes et irrégulières. Les zones arides situées dans le nord de la Syrie caractérisent sont typiques de l'ensemble de la région. Bien que la première importance a été donnée aux céréales et, de moindre mesure, au rendement de la paille, moins d'attention a été accordé à la qualité des ces produits, spécialement la teneure en protéines. Dans cette étude, au cours de deux années d'essai sur terrain, on a pu évaluer certain nombre de variétés de blé tendre (Cham-4) et de blé dur (Cham-1 , Cham-3 , Gezira 17) ainsi qu'une variété traditionnelle du blé dur (Haurani) en relation avec la fertilisation azotée (0, 50, 100 Kg/ha) et en variant le taux d'irrigation pluviale 20, 40, 60, 80 et 100% d'irrigation totale. Les paramètres de rendement ont augmentés constamment en augmentant la quantité d'eau d'irrigation et la quantité d'azote au-delà de 50kg/ha. Les précipitations saisonnières ont influencées la majorité des rendements par rapport à l'azote et à l'irrigation, avec des différences entre les variétés utilisées. Bien que l'irrigation a diminué la concentration en protéines dans les grains et la paille, elle a été partiellement contrebalancée par l'ajout de l'azote. L'irrigation a augmenté le poids des grains, par contre elle a diminué le test de sédimentation de sodium et le test de fermeté de gluten. L'azote a tendance d'augmenter le poids des grains ainsi que le test de fermeté de gluten. Ces effets varient selon la variété et la qualité des grains.

Mots clefs *: Fertilisation azotée, irrigation de complément, blé, agriculture méditerranéenne, Syrie*

Introduction

Cereals, which evolved in the Near East region have, been crucial to mankind's survival. Despite the advances that have been made in global food production, hunger and malnutrition still haunt many of the world's poor, particularly in Africa (Borlaug, 2003). Wheat has always been important in the Middle East, where bread, along with *burghul*, is the main staple food for human consumption, and where straw is important as an animal feed. However, most countries of the region, with the notable exception of Turkey and, more recently, Syria, are considerably less than self-sufficient in grain production.

Not surprisingly, major efforts have been made by the national research programs (e.g., Iran, Morocco, and Turkey), often in conjunction with the International Center for Agricultural Research in the Dry Areas (ICARDA), to improve wheat production. The main thrust of research has been production of drought-tolerant and high-yielding, disease-resistant varieties; introduction of irrigation where water sources are available; and fertilizer use, especially nitrogen (N) in both rainfed and irrigated cropping. The key to sustainable wheat production is an integrated approach (Pala *et al*., 2004) with due consideration of the complex cereal/legume/fallow cropping system which is invariably constrained by drought (Cooper *et al*., 1987).

While the main focus of research has been to increase grain yields, quality of the grain in terms of protein for human nutrition and the various cereal products (bread, pasta, *burghul*, and couscous) has been a secondary consideration, but is of increasing importance. Various studies from several countries of the Mediterranean region have focused on N fertilization, e.g., Spain (Lopez-Bellido *et al*., 2000) and Morocco (Mossadaq and Smith, 1994, Ryan *et al*.,1997a). With the increasing importance of irrigation, especially supplemental irrigation, a major consideration is the interactions between N and water in relation to wheat production (Oweis *et al*., 1998, 1999; Garabet *et al*., 1998). While those studies showed consistent grain yield responses to applied N in all but the driest years, higher responses occurred when the adequate irrigation was given. As a result, N fertilization is a feature of all irrigated cereal cropping.

As wheat varieties differ widely in their responses to environmental factors, the quest of the national breeding programs was to develop varieties that maximize use efficiency of N and water (Anderson , 1985). Currently, most countries of the Mediterranean region have a wide range of wheat varieties in cultivation, ranging from traditional varieties and landraces to modern ones. Given the wide variation in the region's agro-ecologies, the genetic x environments concept in wheat breeding is of major importance. Thus, wheat-cultivars have to be assessed in their own environment with respect to N and water regimes.

The emphasis on wheat genetic improvement centered on factors affecting quality (Pagnotta *et al*., 2004) and on advanced techniques in breed for cereal quality (Amri *et al*., 2000; Baum *et al*., 1998; Nachit and Eloufi, 2004; Maali *et al*., 1998).

Particular attention was given to grain protein in durum wheat (Nachit *et al*., 1995; Porceddou *et al*., 1998; Impiglia *et al*., 1998) and techniques for analysis (El Haramein *et al*., 1998). In view of well established interactions of N and crop yield and quality (Grunes and Allaway., 1985) and the negative interaction of irrigation and grain protein concentration (Eck, 1988; Randall *et al*., 1990; Mohamed *et al*., 1990), the trial described in this study sought to evaluate during two growing seasons some improved and traditional Syrian wheat varieties under rainfed (control) conditions and a range of irrigation levels and N fertilizer application rates.

Materials and methods

The two-year field trials (1989/90, 1990/91) were conducted at Tel Hadya, the main experimental station and headquarters of the International Center for Agricultural Research in the Dry Areas (ICARDA), near Aleppo in northern Syria. The climate of the area is a primarily a Mediterranean one (Kassam, 1981), with some features of a continental climate. Considerable variability within seasons and between seasons is a feature of the climate, not only in terms of rainfall, but also with respect to temperatures, and thus evapo-transpiration. While the mean annual rainfall is about 350 mm, it can range from as low as 150 to over 500 mm (Harris, 1995).

The two years of the study occurred in a period of below-average rainfall. On the first cropping season, which was unusually dry and cold, annual rainfall, mainly in the cropping period from November to May/June, only amounted to 201 mm. The seasonal rainfall distribution (in mm) was as follows: 8 (Oct.), 68 (Nov.), 32 (Dec.), 28 (Jan.), 48 (Feb.), 2 (Mar.), 10 (Apr.), and 5 (May). The second cropping season was better in terms of total rainfall (290 mm), but still lower than normal. The seasonal distribution (in mm) was as follows: 6 (Oct.), 47 (Nov.), 16 (Dec.), 67 (Jan.), 28 (Feb.), 64 (Mar.), 41 (Apr.), and 21 (May). The second year was warmer than the previous year.

The experimental design of the trial was a split-split plot with three replications. The irrigation treatments constituted the main plots for logistical reasons; these involved a rainfed treatment and the five levels of supplementary irrigation based on 20, 40, 60, 80, and 100% the water required for full irrigation (fully compensating for the water consumption, i.e., evapo-transpiration, to reach 100% of field capacity when the available water had decreased to 50% of field capacity). A sprinkler system was used to irrigate the plots. A neutron probe was placed in selected plots to monitor soil moisture levels and thus irrigation needs. Application of irrigation started about mid March in each year, giving a total of 256 mm for the 100% field capacity level in Year 1 and 163 mm in the relatively more favorable Year 2.The sub-plots consisted of 15 treatments in a factorial distribution of five wheat varieties.

The wheat varieties were mainly bred for high yields and wide environmental adaptation, i.e., 4 varieties of durum wheat (three improved lines and one landrace) and one improved bread wheat variety:

- Cham-1 (bred by ICARDA in the 1980s for high yields with high yield stability; resistant to yellow rust, but susceptible to leaf and stem rust; poor gluten strength but good semolina color; adapted to moderate rainfall and irrigated conditions; widely adapted and used in most Mediterranean countries, e.g., North Africa, Syria, Sudan, etc).
- Cham-3 (ICARDA variety; drought and heat tolerance; widely adapted, especially to continental areas; grown on 75% of the durum area in Syria and also extensively grown in Algeria, Cyprus, Turkey, and Iraq; good grain quality, especially gluten strength, good for semolina; good to moderate disease resistance (leaf rust, *septoria*, yellow rust) ,
- Gezira-17 (older Syrian variety bred from Italian stock in the 1970s; susceptible to leaf and yellow rust and bacterial leaf fire; adapted to irrigated areas; replaced by the ICARDA-bred Cham varieties)
- Haurani (Middle East landrace; tall; adapted to dryland conditions; good cold and heat tolerance; good quality for burghoul)
- Cham-4 (ICARDA bread wheat; high yield potential; good disease resistance; adapted for irrigated conditions.

These wheat varieties were combined with three levels of N fertilizer; 0 (control), and 50 and 100 kg N ha^{-1} applied broadcast as ammonium sulfate.

The soil at the station has been classified accordingly to Soil Taxonomy and described in detail (Ryan *et al*., 1997b); it varies from being a Calcixerollic Xerochrept to having more typical features of a Vertisol, i.e., Calcixerert. It is described as being deep, clay, thermic, montmorillonitic. The high clay content, generally over 50%, is a dominant feature, with deeps cracks occurring in late spring and summer as the soil dries out. The soil is also calcareous with a pH of 8.1 and 15-25% calcium carbonate in the topsoil, increasing with profile depth up to 2 m. Organic matter is generally low, i.e., about 1%, and is typical of Mediterranean soils in general (Matar *et al*., 1992). However, the soil is generally well structured, probably because of the high iron oxide content.

Prior to planting, the land was prepared by plowing with a moldboard plow after harvesting the previous season's chickpea crop. After fallowing over summer, the land was disked and harrowed in October. Phosphate fertilizer, as triple superphosphate, was broadcasted at 26 kg P ha^{-1} and incorporated at the final pre-planting cultivation. The wheat varieties were planted with a drill (Oyjord) at 120-kg seed rate per ha and a width of 17.5 cm between rows. The N fertilizer was applied in split application, half at sowing and half top-dressed at tillering. Weed control was by chemical herbicides once each season.

Following harvesting, grain and straw yields were recorded, and both components were analyzed for total N by the standard Kjeldahl procedure with protein percentage calculated. The grain was subjected to some quality tests, i.e., kernel weight (g/1000-grains) and sodium sedimentation test (Axford *et al*., 1978). The experimental data were subjected to analysis of variance, with treatment differences differentiated by least significant differences (LSD).

Results

The data for the two years of the study are reported in terms of dry matter, protein content of grain and straw, and grain quality parameters.

Dry Matter and Grain Yields

The main effects of the three main factors, varieties, irrigation levels and N application rates were significant, along with their interactions, and are presented in Table 1. A number of trends and observations were evident. Clearly, all yields were higher in the second cropping year, which had higher rainfall than the first one. As a consequence, mean variety yields in the second year were about 60% more than in the first year. This was similarly reflected in the seasonal means for the effects of both irrigation and N.

Table 1. Overall mean effects of the main factors on wheat dry matter yield Mg/ ha^{-1} for two growing seasons.

Factor	Year						
Varieties		Haurani	Cham-1	Cham-3	Cham -4	Gezira-17	
	1	4.1	5.8	4.7	6.2	4.9	
	2	7.6	8.1	8.2	8.0	8.1	
Irrigation		Rainfed	20%	40%	60%	80%	100%
	1	2.3	2.4	-	6.1		9.8
	2	6.2	6.5	7.5	8.3	9.3	9.9
Nitrogen (kg/ha)		0		50		100	
	1	4.1		5.7		5.7	
	2	7.3		9.3		8.3	

LSD (5%)= Varieties (0.65, 0.21); Irrigation level (0.73, 0.42); and N rate (0.45, 0.21)

Differences between varieties were particularly evident in Year 1, where the durum wheat Cham-1 and the bread wheat Cham-4 were the highest yielding varieties, being significantly higher than Cham-4, Gezira-17, and the older Haurani landrace. Under the more favorable conditions of Year 2, the Cham varieties and Gezira-17 were similar but significantly higher than Haurani.

As might be expected, irrigation increased yields, the relative increase being greater in the drier year. While the lowest irrigation level (20%) had no effect in Year I, yield at 60% water level increased yield threefold, with a further yield increase to fivefold with full irrigation. By contrast, the unirrigated yield in Year 2 was about three times that of Year 1. While irrigation increased yield from the 40% level, the maximum yield at full irrigation was the same as in Year 1; in other words, irrigation had compensated for the lack of moisture from rainfall alone.

The overall responses to applied N across varieties, relative to irrigation water level for the two cropping years were significant. There was a response to applied N, with no further increase after the first N increment, i.e., 50 kg ha^{-1}, with a similar yield at the 100 kg N rate in Year 1 and a decrease in Year 2. The general response pattern was similar in Year 1 between the two N application rates, with both being responsive to irrigation water, increasing up to the maximum irrigation level. It was clear that there were differential responses with varieties. In the more favorable Year 2, the response curves for the different N rates were similar, with little differences between varieties.

Grain yield data generally fallowed the pattern for dry matter or total biomass, and therefore are not presented. However, the main factors had some influence on the harvest index on the proportion of grain in the harvestable yield. The harvest index tended to increase as the irrigation water increased compared to rainfed conditions, up to full irrigation. However, the effect of N fertilizer was to reduce the harvest index, along with increases in both grain and dry matter yield.

Grain and Straw Protein

As a critical, but neglected aspect of cereal production is quality, especially protein, the main focus of the study was on the extent to which the various factors influence protein in grain, given the importance of protein for human consumption and the process of baking, and for straw for animal nutrition. The dataset indicated significant interactions for N and irrigation on grain protein of the five cereal varieties (Table 2). The main observations from the dataset are as follows:

- There were significant differences between varieties with respect to protein level; these varied with the level of both N and irrigation water and were masked by them.
- Significant differences occurred between the two cropping seasons.

- Under rainfed conditions, the protein content of the unfertilized treatments in the drier first year was consistently higher than in the more favorable second year. The addition of N eliminated this difference between years.
- Without fertilization, and as irrigation water increased, there was a consistent decline in protein content, e.g., from 15.8% for Haurani under rainfed conditions to 8.6% with maximum irrigation. This pattern was reflected with the other four varieties as well.
- The decline in protein with irrigation level was only partially compensated by the added N, even at the higher level (100 kg ha^{-1}) which did not on average, produce higher yields than the 50 kg N level.
- The protein levels with irrigation from 60-100% were generally lower than under rainfed conditions and the low irrigation level.
- Nitrogen fertilization, in general, tended to maintain protein levels above 12%, especially the 100 kg N level.

The data representing protein in the harvested straw (Table 3) followed a similar pattern as grain protein, but was considerable lower. Again, the differences between years were obvious, especially without added N fertilizers, and between wheat varieties. The effect of added irrigation water significantly and consistently reduced straw protein. This was especially apparent with irrigation of 40% and more i.e., the range that produced marked yield increases. While the fertilizer increased straw protein with increasing application rates (50 to 100 kg N ha^{-1}), it was not sufficient to compensate for the negative effect of irrigation and to maintain protein levels comparable to straw harvested from rainfed conditions.

Table 2. Protein concentration (%) in five wheat varieties in response to irrigation and N fertilization for two cropping seasons.

Irrigation	Nitrogen	Haurani		Cham-1		Cham-3		Cham-4		Gezira-17	
	kg/ha	1	2	1	2	1	2	1	2	I	2
Rainfed	0	15.8	11.3	13.7	10.1	12.1	9.8	10	7.9	14	10.6
	50	15.9	16.4	14.9	14.6	13.6	16.3	13.6	12.6	18.3	16.3
	100	16.3	18.3	16.1	18.4	16.1	19.2	15.3	16.2	18.1	18.6
20%	0	12.4	11.6	11.1	11.4	11.4	10.3	8.9	8.3	9.7	18.5
	50	16.1	16	15.1	14	14.8	18	12.4	14.3	17.6	18.9
	100	17.6	18.5	16.3	18.2	16.1	20.1	15.3	16.6	17.7	20.3
40%	0	9.2	13.9	8.5	12.6	8.7	9.8	7.8	7.6	7.8	9.3
	50	12.4	15.7	12.7	18.6	12.1	14.1	10.3	13.1	13.7	17.2
	100	14.9	18.7	14.8	22.1	14.7	20.9	13.6	15	16.2	21.1
60%	0	8.1	14	7.6	11	8	9.9	6.8	9.3	7.1	8.5
	50	11.1	15.6	10.9	16.7	9.8	13.4	9.1	13.9	11.5	14.7
	100	13.8	20.1	12.9	19.8	12.8	20.5	12	16.1	13.1	22.3
80%	0	8.5	11.2	7.7	9.5	7.8	9.2	7.4	8.5	7.1	8.3
	50	9.8	15.4	8.7	12.1	8.9	11.9	8	11.7	9.8	11.1
	100	12.6	17.8	10.7	19.2	11.1	20.9	10.3	14.4	11.7	18.8
100%	0	8.6	9.7	7.6	10.7	7.9	11.4	7.8	9.8	7.3	12.9
	50	9.3	13.8	8.5	13.1	8.3	13.9	7.8	10.9	8.9	14.1
	100	11.5	16.9	10.2	17.9	10.2	18.5	9.6	13.5	9.8	17.8

Year 1 and 2: LSD(5%)= Irrigation (0.95, 1.24); Varieties (0.51, 0.57); N (0.37, 0.39); Varieties x Irrigation (1.25, 1.25); N x Irrigation (0.92, 0.95); N x Variety (0.84, 0.87); Irrigation based on relative percentage of full irrigation to achieve field capacity.

Table 3. Protein concentration (%) in straw of five wheat varieties in response to irrigation and N fertilization for two cropping seasons.

Irrigation	Nitrogen	Haurani		Cham-1		Cham-3		Cham-4		Gezira-17	
	kg/ha	1	2	1	2	1	2	1	2	1	2
Rainfed	0	5.3	1.6	4.3	1.1	3.3	1.4	3.1	1.1	3.8	2.1
	50	7.1	3.6	6.3	3.0	5.9	3.9	4.5	2.8	7.1	3.7
	100	8.5	5.0	7.3	4.6	7.5	6.4	7.2	4.6	9.1	4.8
20%	0	3.6	1.9	3.4	2.1	2.9	1.8	2.3	1.4	2.5	1.7
	50	5.2	3.6	5.1	2.6	5.1	3.6	3.2	3.2	5.9	2.7
	100	7.3	5.0	7.1	4.7	7.2	6.5	6.3	5.6	7.5	5.6
40%	0	2.5	2.0	1.8	1.7	1.6	1.4	1.6	1.1	1.6	1.2
	50	3.6	2.4	4.2	3.9	3.3	2.3	2.5	2.5	3.6	2.7
	100	5.6	3.4	5.1	4.9	5.8	5.5	5.9	3.3	5.2	4.4
60%	0	1.9	1.5	1.4	1.4	1.6	1.3	1.5	1.3	1.7	1.1
	50	2.9	2.7	2.9	1.5	2.1	2.4	2.6	2.7	2.9	2.2
	100	3.4	5.2	3.4	2.9	3.9	4.8	3.5	3.3	3.5	5.4
80%	0	1.5	1.3	1.1	1.4	1.1	1.5	1.2	1.3	1.1	1.4
	50	1.8	2.2	1.6	1.5	1.5	2.1	1.5	1.9	1.8	2.4
	100	3.7	2.9	2.1	3.8	2.5	5.1	3.1	3.3	3.5	3.7
100%	0	1.5	1.3	1.4	1.5	1.3	1.7	1.3	1.7	1.2	1.5
	50	1.7	1.8	1.8	1.7	1.9	2.7	1.7	2.6	2.1	2.1
	100	3.1	3.1	2.2	3.7	2.3	4.2	2.2	2.6	2.3	4.0

Year 1: LSD (5%) = Irrigation (0.6, 0.4); Varieties (0.4, 0.3); N (0.0.3, 0.2); Varieties x Irrigation (0.9, 0.7); N x Variety (0.5, 0.5)

Other Grain Quality Parameters

In addition to grain protein, there are other indicators of quality, including physical measurements such as kernel size as well as a test for gluten. The relevant data are presented for the overall influence of varieties, N and irrigation. With respect to the wheat varieties (Table 4), there were differences between varieties in kernel weight, e.g., 35.9 for Haurani to 29.1 for Cham-4 in Year 1 But the differences were even more marked with year, all being consistently lower in Year 2 (22.7) than in Year 1 (31.6). While the sodium sedimentation test again reflected varietal differences, the effect of year, or cropping season, was reversed, with values for the second year being almost double those of the first year.

Table 4. Mean effects of varieties on grain quality parameters averaged over irrigation and nitrogen treatments for the two cropping seasons.

Test	Year	Haurani	Cham-1	Cham-3	Cham-4	Gezira-17	Mean
Kernel weight (g/1000 grains)	1	35.9	32.4	31.7	29.1	31.1	31.6
	2	22.8	21.3	24.9	19.4	24.8	22.7
Sodium Sedimentation	1	24	17	22	-	22	21
	2	42	27	38	-	37	36

LSD (5%) of the respective year = Kernel weight (1.2, 1.4); Sodium Sedimentation (1, 3).

The mean effect of irrigation water level on the quality parameters is shown in Table 5. Given the consistent effect of season observed for the mean of varieties, there was a consistent effect on kernel weight and sodium sedimentation. The 1000-grain test weight increased from 26.9 g with rainfed wheat up to 39 g at the full irrigation levels in Year 1. The pattern was also expressed in the second year, e.g., 21 g under rainfed conditions to 25.1 g under the maximum water level. The sodium sedimentation test, in contrast to kernel weight, showed a consistent decrease with increasing water levels, but with seasonal differences, i.e., from 26.3 in rainfed conditions to 15.7 with 100% irrigation in Year I. The corresponding values for test weight were 38.1 to 34.0 in Year 2.

In contrast to irrigation, the effects of N were inconsistent between seasons (Table 6). For example, in Year I, there was no significant change on pattern for kernel weight. However, in Year 2, which was more favorable for crop growth conditions, the kernel weights decreased from 21.7 with 50 kg N ha^{-1} and 18.5 at the higher N level. The effect of N was more pronounced than that of irrigation on sodium sedimentation test values, with consistent increases with added N in both cropping seasons.

Only selected observation was made on grain samples with respect to vitreous kernels or "yellow berry", a negative trait in the grain endosperm. However, not enough assessments were made to make some generalization. Some of the factors seemed to increase the percentage of such vitreous kernels and others to decrease it. Irrigation tended to increase the proportion of vitreous kernels, while N tended to decrease vitreous kernels, but there were no differences between the two N lev els

Table 5. Mean effects of irrigation water level on grain quality over varieties and nitrogen for two cropping seasons.

Test	Year	Rainfed	20%	40%	60%	80%	100%	Mean
Kernel Weight	**1**	26.9	28.8	28.8	30.4	35.8	39	31.6
(g/1000 grains)	**2**	21	21.4	21.6	22.2	24.7	25.1	22.7
Sodium Sedimentation	**1**	26.3	25.3	23	20	17	15.7	21.2
	2	38.1	39	37	35	30	34	34.5

LSD (5%) = Kernel Weight (1.9, 2.6), Sodium Sedimentation (2.2, 4.1).

Table 6. Mean nitrogen effects on grain quality averaged over varieties and irrigation treatments for two cropping seasons.

		Nitrogen, kg ha^{-1}			
Test	Year	0	50	100	Mean
Kernel Weight	**1**	32.5	31.4	31.2	31.5
(g/1000 grains)	**2**	27.8	21.7	18.5	22.7
Sodium Sedimentation	**1**	16	22	26	21.3
	2	28	36	45	36.3

LSD (5%) for Years 1 and 2 = Kernel Weight (0.9,0.9); Sodium Sedimentation (1,2).

Discussion

While considerable details emerged from these 2 years' comprehensive field trials from a typical Mediterranean-type of cereal-production environment, a number of key issues became apparent. Despite the fact that both cropping seasons had below-average rainfall, as well as variation in distribution and temperature, the seasonal differences so characteristic of Mediterranean agriculture (Cooper *et al.*, 1987; Kassam, 1981; Harris, 1995) were expressed, particularly in the absence of irrigation. Nevertheless, with differences in rainfed yields between years, the response patterns to increasing irrigation water were different as shown by similar studies in Syria (Oweis *et al.*, 1998, 1999; Garabet *et al.*, 1998).

Despite the fact that four of the five varieties varieties were "improved" and one traditional, the overall ranking in yield did not conform to expectation; the disparity between varieties varied with the season. In fact, in the second season, Gezira-17, considered to be responsive to irrigation, performed the same as the improved Cham varieties. The higher response to N in the "wetter" of the two years coincides with observations of Lopez-Bellido *et al.*, (2000). That N fertilizer application beyond 50 kg ha^{-1} did not increase yields has to be treated with caution as it does not consider residual N in the soil or mineral N in the irrigation water. Nevertheless, the important issue was the extent to which the additional N increment affected quality, especially protein.

There were clear differences between varieties with respect to decreasing protein percentage as the irrigation water increased, thereby exhibiting the predictable inverse relationship between N and water (Barber and Jessop, 1987; Eck, 1988). Even though the added N counter-balanced the decline, it did so only partially, in many cases failing to maintain the desirable level of 12%, which is a criterion required for wheat exported from Syria. While the obvious implication of protein in wheat centers on the grain for human consumption, any increase in straw protein has considerable implications for animal nutrition especially in the Middle East where livestock is heavily dependent on cereal straw and other crop residues.

The dichotomy between N and water is related to the extent to which the available pool of N in soil, whether from the residual mineral N or N mineralized from organic matter, or from at external sources (fertilizer, atmospheric deposition, or contained in irrigation water) is diluted by the increased biomass yield induced by the irrigation water. Indeed, crop sequences, e.g., following a legume can influence the N by water response (Gan *et al.*, 2003). While farmers are mainly interested in economic responses to N fertilizer in terms of yield increases, whether the farmer uses additional N beyond that which produces yield increases in order to raise the level of protein in the grain depends upon whether the extra quality is compensated in the grain price system. The incentive to use additional N for protein increase applies where a minimum level of protein is required to sell the grain. In order to reconcile yield and quality considerations, the response data in our trial provides useful guidelines.

Rather than applying additional N in the early stages of crop growth to improve protein levels, the timing of fertilizer application could be delayed later growth stages (anthesis, post-anthesis), which would increase N uptake and protein concentration (Wuest and Cassman, 1992., Bulman and Smith, 1993). Balancing the demands of yield and protein concentration requires good crop management. However, even if additional N does not increase either yield or quality, the unused N in the soil is likely to be carried over to the next crop, especially as N losses are minimal in dryland cropping, or with limited irrigation.

While protein reflects nutritional quality of the grain, its content accounts for 30-40% of the variability in cooking quality (Amri *et al*., 1998); this trait is also reflected by the quality of the protein, especially gluten strength as reflected by the sodium sedimentation test (Nachit *et al*., 1995). An encouraging outcome of our trial was the positive effect of N on protein quality, despite a negative influence of irrigation. The only positive effect of irrigation on other quality parameters was on 1000-kernel weight. As with yield and protein, the additional quality parameters were highly season–dependent.

In conclusion, this study highlighted the phenomenon of reduced grain protein content when cereal yields are increased by irrigation using on four durum varieties and one bread wheat variety in Syria. It identified the importance of compensating for this decreased protein by increasing the amounts of N applied, and indicated the implications of the N by irrigation interaction on other grain quality parameters. With decreasing supplies of irrigation water, almost everywhere in the Mediterranean area, the precise amount of fertilizer N needs to be identified for varying irrigation levels. Future N management will have to balance irrigation inputs for achieving both acceptable crop yields and meeting quality standards for the export market as well as baking criteria. Future research might usefully focus on N and irrigation on the many criteria that affect bread quality.

Acknowledgement

We thank Drs. A.E. Matar, formerly Soil Scientist at ICARDA, and Dr. Z. Abbas, Faculty of Agriculture, Aleppo University, who served on Mr. Mikhail’s M.S. Thesis Committee.

Literature cited

ANDERSON, W.K.1985. Grain yield responses of barley and durum wheat to split nitrogen applications under rainfed conditions in a Mediterranean environment. Field Crop Res. 12:191-202.

AMRI, A., M. BANJNAH, N. NSARELLAH, M. TAGHAUTI, AND M.M. NACHIT. 1998. Genetic and agronomic approaches to improve durum wheat quality in Morocco. *In* Proceedings of the SEWANA Durum Research Network Meeting, 20-30 March 1995. ICARDA, Aleppo, Syria. pp.543-547.

AXFORD, D.W.E., E.E. M[C]DERMOTT, AND D.G. REDMAN. 1978. Small-scale tests of bread-making quality. Milling, Feed and Fertilizer 161: 18-26.

BARBER, J.S. AND R. JESSOP. 1987. Factors affecting yield and quality in irrigated wheat. J. Agric. Sci. (Cambridge) 109: 19-26.

BAUM, M., M. LABHILILI, M.M. NACHIT, R. D'OVIDEO, AND E. PORCEDDU. 1998. Use of PCR – analysis in durum wheat to screen for quality parameters. *In* Proceedings of the Sewana Durum Wheat Network Meeting *(Eds.:* M.M. Nachit, M. Baum, E. Porceddu, P. Monneveux, and E. Picard), 22-23, March, 1995, ICARDA, Aleppo, Syria. ICARDA, Aleppo, Syria. pp. 280-286.

BORLAUG, N.E. 2003. Feeding a world of 10 billion people: The TVA/IFDC legacy: Travis P. Hignett Memorial Lecture, March 14, 2003. Muscle Shoals, Al, USA.

BULMAN, P., AND D.L. SMITH. 1993. Grain protein response of spring barley to high rates and post-anthesis application of fertilizer nitrogen. Agron. J. 85: 1109-1113.

COOPER, P.J.M., P.J. GREGORY, D. TULLY, AND H.C. HARRIS. 1987. Improving water – use efficiency of annual crop in the rainfed farming systems of West Asia and North Africa. Expl. Agric. 23: 113-158.

ECK, H.V., 1988. Winter wheat response to nitrogen and irrigation. Agron. J. 80: 902-908.

EL-HARAMEIN, F.J., A. IMPIGLIA, AND M.M. NACHIT. 1998. Recent applications of near-infrared spectroscopy to evaluate durum wheat grain quality. *In* M.M. Nachit, M. Baum, E. Porceddu, P. Monneveux, and E. Picard (Eds.) Proceedings of the Sewana Durum Wheat Network Aleppo, Syria. pp. 329-334.

GAN, Y.T., P.R. MILLER., B.G. MCCONKEY., R.P. ZENTNER, F.C. STEFENSON, AND C.L. MCDONALD. 2003. Influence of diverse cropping sequences on durum wheat yield and protein in the semiarid northern Great Plains. Agron. J. 95: 245-252.

GARABET, S., M. WOOD, AND J. RYAN. 1998. Nitrogen and water effects on wheat yield in a Mediterranean–type climate. Dry matter yield and nitrogen accumulation. Field Crops Res. 57:309-318.

GRUNES, D.L., AND W.H. ALLAWAY. 1985. Nutritional quality of plants in relation to fertilizer use. *In* Fertilizer Technology and Use (3rd Ed), Soil Sci. Soc. Amer., Madison, WI, USA. pp.589-599.

HADJICHRISTODOULOU, A. 1979. Genetic and environment effect on vitreousness in durum wheat. Euphytica 28: 711-716.

HARRIS, H.C. 1995. Long–term trials on soil and crop management at ICARDA. Adv, soil Sci. 447-469.

IMPIGLIA, A., G. NACHIT, M.M. NACHIT, D. LAFIANDRA, E. PORCEDDU, AND L.M. MARTIN. 1998. Storage proteins in the durum landraces. p.309-318. *In* M.M. Nachit, M. Baum, E. Porceddu, P. Monneveux, and E. Picard (Ed.) Proceedings of the Sewana Durum Wheat Network Meeting, 2-23, March, 1995, ICARDA, Aleppo, Syria. ICARDA, Aleppo, Syria.

KASSAM, A. H. 1981. Climate, soil and land resources in the West Asia and North Africa region. Plant & Soil 58: 1-28.

LOPEZ-BELLIDO, L., R.J. LOPEZ-BELLIDO, J.E. CASTILLO, AND F.L. LOPEZ-BELLIDO. 2000. Effects of tillage, crop rotation and nitrogen fertilization on wheat under rainfed Mediterranean conditions. Agron. J. 92: 1054-1063.

MAALI, S.H., M. DUWAYRE, AND M.M. NACHIT. 1998. Use of *Triticum Dicoccoides* to improve grain quality in durum wheat. p.319-323. *In* M.M. Nachit, M. Baum, E. Porceddu, P. Monneveux, and E. Picard (Ed.) Proceedings of the Sewana Durum Wheat Network Meeting, 2-23, March, 1995, ICARDA, Aleppo, Syria. ICARDA, Aleppo, Syria.

MATAR, A.E., J. TORRENT, AND J. RYAN. 1992. Soil and fertilizer phosphorus and crop responses in the dryland Mediterranean zone. Adv. Soil Sci. 18: 82-146.

MAHDI, L., C.J. BELL, AND J. RYAN. 1996. Non–vitreousness ("yellow berry") in durum wheat as affected by both sowing depth and date of planting. Cereal Res. Commun. 24: 347-352.

MOHAMAD, M.A. J., J. STEINER, S.D. WRIGHT, M.S. BHANGOO, AND D.E. MILLHOUSE. 1990. Intensive crop management practices on wheat yield and quality. Agron. J. 82: 701-707.

MOSSADAQ, F., AND D.H. SMITH. 1994. Timing nitrogen application to enhance spring wheat yields in a Mediterranean climate. Agron. J. 86: 221-226

NACHIT, M.M., M. BAUM, A, IMPIGLIA, AND H. KETATA. 1995. Studies on some grain quality traits in durum grown in Mediterranean environments. OPTIONS Mediterraneenes. Series A; Seminaires Mediterraneens, Numero 22, p.81-187.

NACHIT, M.M., AND I. ELOUFI. 2004. Durum wheat adaptation in the Mediterranean dryland: breeding, stress physiology and molecular markers. p. 203-218. *In* R. Rao and J. Ryan (Ed.) Challenges and strategies of dryland agriculture. Crop Sci. Soc. A. Special Pub. No. 32, Madison, WI, USA.

OWEIS, T., M. PALA, AND J. RYAN. 1998. Stabilizing rainfed wheat yields with supplemental irrigation in the Mediterranean region. Agron. J. 90: 672-681.

OWEIS, T., M. PALA, AND J. RYAN. 1999. Impact of supplemental irrigation, nitrogen and planting data on yield and quality of durum wheat. Eur. J. Agron. 11:255-266.

PAGNOTTA, M.A., A. IMPIGLIA, O.A. TANZARELLA, M. NACHIT, AND E. PORCEDDU. 2004. Genetic variation of durum wheat landrace Haurani from different agro-ecological regions. Gen. Resour. & Crop Evol. 51: 8623-869.

PALA, M., J. RYAN., A. MAZID., O. ABDALLAH, AND M. NACHIT. 2004. Wheat farming in Syria: an approach to economic transformation and sustainability. Renewable Agric. & Food Systems 19:30-34.

PORCEDDU, E., T. TURCHETTA, S. MASCI, R. D'OVIDEO, D. AFIANDRA, D.D.KASARDA, A. IMPIGLIA, AND M. NACHIT. 1998. Variation in endosperm protein composition and technological quality proportions in durum wheat. Euphytica 100: 197-205.

RANDALL, P.J., J.R. FRENEY, C.J. SMITH, H.J. MOSS, C. WRIGLEY, AND I.E. GALBALLY. 1990. Effect of addition of nitrogen and sulfur to irrigated wheat at heading on grain yield, composition and milling and baking quality. Aust. J. Exp. Agric. 30: 95-101.

RYAN, J., N. NSARELLAH, AND M. MERGOUM. 1997a. Nitrogen fertilization of durum wheat cultivars in the rainfed area of Morocco: biomass yield and quality components. Cereal Res. Commun. 25: 85-90

RYAN, J., S. MASRI, GARABET, J DIEKMANN, AND H. HABIB. 1997b. Soils of ICARDA agricultural experiment station and soils: Climate, classification, physical-chemical properties, and land use. Tech. Bull. ICARDA, Aleppo, Syria.

WILLIAMS, P.C., F. JABY EL-HARAMEIN, A. SAYEGH, M. NACHIT, AND J.P. SRIVASTAVA. 1989. Durum wheat utilization in west Asia/North Africa. p.555-565. *In*: Proceedings of an international conference. Lahti Research and Training Center, Lahti, Finland.

WUEST, S.B., AND K.G. CASSMAN. 1992. Fertilizer nitrogen use efficiency of irrigated wheat. Agron. J. 84: 682-688.