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Nitrogen Fertilizer Response of Some Barley Varieties in Semi-Arid Conditions in Morocco

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ABSTRACT

The West Asia-North Africa region, which is characterized by a typical Mediterranean climate, is the center of origin of cereals, notably wheat (*Triticum spp.*) and barley (*Hordeum spp*). However, cereal production, which is primarily rainfed, is mainly constrained by drought due to the low rainfall accompanied by high temperatures. Cereals have been traditionally grown following a fallow period in order to achieve acceptable yields on stored soil moisture, but they are increasingly grown either continuously or in rotation with legumes, either food or forage. Barley is grown throughout the Mediterranean region, generally in the drier zones and often on shallow soils and with application of minimum or no fertilizers. The medium-rainfall zone of central Morocco (200-500 mm yr^{-1}) is typical of the region as a whole. In order to provide a rational basis for barley fertilization, especially as regards nitrogen (N), a field trial was established near Settat, involving five barley varieties (ACSAD-60, Tessaout, Asni, Arig-8, and ACSAD-176), along with four N application at four levels (0, 40, 80, and 120 kg N ha^{-1}), grown on a shallow soil (Petrocalcic Palexeroll) for two growing seasons that varied in terms of total rainfall (Year 1, 261mm and Year 2, 302 mm) as well as within-season distribution. There were considerable differences between crop years, with significantly higher yields in the second growing season when rainfall was heavy at the critical tillering and stem-elongation growth stages. Nitrogen consistently increased dry matter and grain yields in either year, generally being significant up to 80 kg ha^{-1}. There were significant differences observed among varieties, as well as interactions of varieties with years. The six-row variety Arig-8 was consistently the best while the two-row Asni, the lowest yielding variety. Where an economic analysis was done on yield data (Year 1), N fertilization up to at least 80 kg ha^{-1} was considered as profitable. Crop N uptake varied with varieties and increased with increasing fertilizer. N Recovery was variable and generally less than 50%. In contrast to many other fertilizer trials with barley in the region, this trial from central Morocco showed highly significant yield increases in response to applied N for barley varieties, most of which performed similarly. Therefore, N fertilization of barley in Morocco's semi-arid cereal-producing zone on shallow soils, where root growth and moisture-holding capacity are limited, should be promoted.

Keywords: Dryland barley, Moroccan agriculture, Nitrogen fertilization.

INTRODUCTION

Barley (*Hordum vulgare*), one of the world's most important cereal crops, has been cultivated as a food and feed source from the beginning of settled agriculture and is widely adapted to a broader range of environments, especially low rainfall environments. An important aspect of its versatility is its drought resistance. Its water requirement per unit cereal grain production is lower than those for other cereals, due to its relatively low transpiration rate (Poehlman,

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1985). Where soils are shallow, drought-prone barley is more likely than wheat to produce tolerable yields of forage as well as grain, if the year is favourable. Such characteristics explain its ubiquity in the semi-arid areas of the world.

The North Africa-West Asia zone, with a typical Mediterranean climate is a marginal rainfall area adapted to barley growing (Cooper *et al.,* 1987). Despite the normally narrow range of mean annual rainfall, the region is characterized by wide ecological diversity and indeed considerable inter-regional and inter-annual climatic variations (Kassam, 1981). As a consequence of such ecosystems, a large range of cultivars has evolved. Barley tends to be grown in areas below 350 mm yr^{-1} of rainfall and durum wheat in the 350-450 mm zone (Anderson, 1985); over 90% of the region's rainfed barley yields are low, ranging from 0.6 tons ha^{-1} (Jordan and Iraq) to 1.8 tons ha^{-1} (Turkey). Inappropriate crop rotation, low fertilizer input, poor weed control, late sowing, and use of unimproved local varieties account for such low yields.

Despite efforts to intensify outputs in the past two decades, the West Asia-North Africa region is still a food-deficit one, with the exception of Turkey and, of late, Syria. Due to rapid population growth rates, this projection is likely to be on the increase for the foreseeable future. The demand for barley is attributed to increasing demand for livestock products and therefore for animal feed, as incomes rise in some sectors of society. Much of the applied research in cereals in general and barley in particular has been designed to enhance production in an integrated crop-livestock system. Thus, research from around the Mediterranean involved adaptation of barley to the drought-stressed, semi-arid conditions in Spain (Cantero-Martinez *et al*., 1995), Cyprus (Papastylianou, 1995), Lebanon (Yau *et al.,* 2003), Jordan (Tawaha *et al*., 2005) and Syria (Jones and Singh, 2000; Mazid and Bailey, 1992). Despite the risk inherent in fertilization of barley in marginal areas, application of nitrogen (N) and phosphorus (P) is economical in most years (Mazid and Bailey, 1992; Jones and Wahbi, 1992). Various studies (Christiansen *et al*., 2000) have shown the complementarity of barley in rotation with forage legumes, notably vetch (*Vicia sativa*).

As the major barley producer in North Africa, Morocco has several social, economic and agro-ecological characteristics common to the region as a whole. However, it also has unique circumstances which are worthy of some detailed consideration. Barley constitutes some 50% of all cereal-growing areas in Morocco (Shroyer *et al*., 1990) and has a major role in the county's farming systems, being grown for straw and grain as livestock feed, as well as for human consumption as bread. Largely associated with drier areas, the sheep-barley system generates some return even in the worst years and; as a result, the area planted to barley is more sustaining than the area planted to wheat, and has shown a slight but consistent increase over the past decades.

In Morocco, field trials addressed economic and technical issues related to barley (ACSAD, 1986). Various production zones were recognized, while productivity varied from year to year and was invariably low, mainly attributed to the predominance of landraces of low yield potential and disease susceptibility. Yield-related data suggests that further increases could be achieved based on higher yield per hectare rather than extending the barley-growing area. Fertilizer use, particularly with N, could have an obvious and immediate impact on barley yields. However, responses of barley to N have varied considerably, often with conflicting results, which can be attributed to the seasonal rainfall and the crop rotation, which highly influence soil N availability (Abdel Monem *et al*., 1990a)).

In view of the fact that no soil test data were provided for any of these either on-station or on-farm trials, it is possible that the lack of response may be due to adequate levels of mineral N, mainly nitrate, in the sites prior to cropping (Ryan *et al*., 1993). Therefore, we conducted a 2-year on-farm trial on a shallow soil in a medium-rainfall site in central Morocco (normal mean annual rainfall range, 300-400 mm) and evaluated the yield response to the varying rates of applied N of five barley varieties of different genetic parentage as well as agronomic characteristics.

MATERIALS AND METHODS

Based on adaptability and yield potential, five important and commonly grown barley cultivars were chosen to represent the variable of variety in the study (Table 1). These were: Tessaout, Asni, Arig-8, ACSAD-60, and ACSAD-176. They varied in origin, type of adaptation as well as days-to-heading. The site was a shallow (< 35 cm) Petrocalcic Palexeroll, near Settat, representing a widespread soil type in the Chaouia region (Stitou, 1985) and typical of shallow soils devoted to barley. Wheat rather than barley is mainly grown on deeper soils. The site was cropped the previous year to barley and, as a consequence, was low in nitrate-N, i.e., 2.0 mg kg^{-1}. Other relevant soil properties were clay texture; $CaCO_3$, 31%; organic matter, 4.3%; and either available or $NaHCO_3$-extractable P, 4.0 mg kg^{-1}. The available K was adequate at 230 mg kg^{-1}.

The site was prepared for planting using an offset tandem, tractor-drawn disc harrow. Fertilizer was then applied as broadcast by hand to the plots (1.8 m wide×5 m long) and incorporated through one pass of the disc harrow. As P was not a variable, triple superphosphate was applied at 30 kg P ha^{-1} to all plots. Nitrogen, as ammonium nitrate, was applied at 0, 40, 80 and 120 kg ha^{-1}. An adjacent field that had been in barley and similarly low in nitrate-N, and with similar background properties, was used for the second season's cropping. A randomized complete block design was used. The seeding rate, using a "Wintersteiger" experimental plot planter, was 100 kg ha^{-1} for each variety, with planting dates around mid November. After crop emergence, weeds were controlled chemically as were foliar diseases.

As is typical of the area, rainfall was variable and unevenly distributed. In Year 1, the season's rainfall (260 mm), as recorded in a station about 20 km from the site, was distributed as follows: Oct., 33 mm; Nov., null; Dec., 48 mm, Jan., 54 mm; Feb., 37 mm, Mar., 49 mm,; Apr., 19 mm; May, 10 mm; and June, 11 . In the second cropping year, a total rainfall of 302 mm was distributes as: Oct., 11 mm, Nov., 20 mm; Dec. 54, Jan., null; Feb., 81mm; Mar., 93 mm; 35 mm in April, and 8 in May.

June was the general harvest month; one early variety, Tessaout, was harvested in May. The procedure involved hand-cutting of two 5-m inside rows from each plot. A separate 1-m row section was taken for N analysis to measure crop N uptake as well as to estimate crop N-use efficiency. Subsequently, samples were threshed using a stationary thresher.

In the one year that an economic evaluation was done on the response of barley to N fertilization (Year 1), information was

Table 1. Characteristics of barley cultivars.

Cultivar	Row number	Release year/ original	Type of adaptation	Days-to-heading
Arig-8	6	1976 INRA[a]	General	105
Asni	2	1984 INRA	High rainfall	100
ACSAD-60	2	1983 ACSAD[b]	Semi-arid	85
ACSAD-176	6	1983 ACSAD	Semi-arid	95
Tessaout	2	Unregistered	Arid	72

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obtained on fertilizer prices (124 Dh per 100 kg ammonium nitrate, 33.5% N) and an market value of both grain (1 Dh kg^{-1}) as well as straw (0.25 Dh kg^{-1}). At the time of the study, one US dollar was equivalent to nine Moroccan dirhams. Subsequently, revenues were calculated for both yield components along with benefit-cost (B/C) ratios. The normal criterion for profitability estimation is a B/C ratio of 2 or above.

RESULTS

The analysis of variance for grain and dry matter yields over the two cropping seasons is presented in Table 2. As expected, the main factors N and variety significantly affected either on the yield parameters. The interactions were less consistent; varieties behaving significantly different with the two years, but the interaction of Year and N was not significant, i.e., the effect of N was consistent for variety in either year. There were significant differences observed between years for grain yield but not total dry matter yield. Despite N and year being both significant, the interaction between the two was significant only for the dry matter yield trait.

As there was no interaction effect between cropping year and N application observed for grain yield, and the interaction for total biomass yield was significant only at a 5% level, the overall mean effect of N on yield parameters is presented here, as well as the harvest index (Table 3). Total biomass yield consistently increased with increasing 40 kg increments of N, up to a maximum of 120 kg N for total biomass yield. There was more than a doubling of biomass yield observed at the highest N rate. However, differences between the 80 and 120 kg ha^{-1} N rates were shown not to be significant. Corresponding grain yields increased from 0.99 Mg ha^{-1} without added N to 1.97 Mg ha^{-1} at the rate of 80 kg N ha^{-1} with no further yield increase with added N. There was no consistent trend observed in harvest index with N

Table 2. Analysis of variance for barley grain and dry matter yield for two cropping seasons.

Source	Degrees of freedom	Yield	
		Grain	Dry matter
Year	1	***	N.S
Replicates	4	***	N.S
Nitrogen	3	***	***
Year × Nitrogen	3	N.S	**
Variety	4	***	***
Variety × Year	4	***	***
Variety × Nitrogen	12	NS	NS

***= P≤ 0.01; **= P≤ 0.05.
Ns: Non significant.

Table 3. Mean effect of nitrogen fertilizer application rates on barley yield parameters over two growing seasons.

Nitrogen application rate	Total dry matter yield	Grain yield	Harvest index
Kg ha^{-1}	Mg ha^{-1}	----------------- %	------------------
0	2.37	0.99	41
40	3.62	1.50	41
80	4.58	1.97	43
120	5.07	1.93	38

Table 4. Differential response of the barley varieties after two cropping season.

Varieties	Grain yield Year 1	Grain yield Year 2	Grain yield Mean	Biomass yield Year 1	Biomass yield Year 2	Biomass yield Mean
	Mg ha $^{-1}$			Mg ha $^{-1}$		
ACSAD-60	1.41	1.92	1.66	4.08	4.33	4.20
Tessaout	1.14	2.01	1.58	3.01	3.92	3.47
Asni	1.16	1.53	1.34	3.72	3.39	3.56
Arig-8	1.37	2.13	1.75	5.07	4.15	4.61
ACSAD-176	1.22	2.12	1.67	3.66	3.78	3.72
LSD (5%)	0.22	0.22	0.15	0.71	0.48	0.42

fertilization.

There were significant interactions of variety and year observed in terms of both grain and dry matter yields (Table 4). Thus, in Year 1 Arig-8 significantly outyielded the other varieties, followed by ACSAD-60, Asni, and ACSAD-176, with Tessaout yielding the lowest. In Year 2, the ranking changed, with ACSAD-60 outyielding Arig-8, but not significantly so. In contrast to Year 1, when Tessaout was the lowest yielding, Asni did poorest in the second year in terms of biomass yield. As for grain yield, ACSAD-60 and Arig-8 performed the highest in Year 1, and while Tessaout the lowest. In Year 2 Tessaout performed as well as Acsad-176 and Arig-8, while Asni yielded the poorest. Discrepancies in ranking between biomass and grain yields are attributed to variation in harvest index for the varieties. Though both experimental years ranked below the long-term mean annual rainfall, the substantially higher yields in Year 2 are probably due to the favourable share of rainfall for the months of February and March, which coincide with the stages of rapid growth of the crop.

The assessment of the economy of using fertilizer N is depicted in Table 5, whereby benefit/cost ratio as based on individual cost and revenue of grain and straw are indicated for the individual barley verities in relation to N application rates. As a B/C value of 2 is considered a benchmark value for profit, it was clear that under input/output conditions in Year 1, when the assessment was made, N fertilization was profitable for most varieties at least up to the 80 kg N ha^{-1} of application rate. While B/C values for Tessaout were inconsistent, the most profitable varieties when fertilized were ACSAD-60 and Asni. Though an analysis was not made for the second year, the results would most probably have come out to be similar.

As an important consideration is the extent to which the crop takes up from the applied fertilizer N, and the extent of fertilizer depletion from the soil. Uptake and apparent N

Table 5. Economic assessment of nitrogen fertilization of barley varieties (Year 1).

Variety	Nitrogen application rate, kg ha^{-1} 0	40	80	120
		Benefit-Cost ratio		
ACSAD-60	-	5.3	4.2	2.3
Tessaout	-	2.0	1.4	3.0
Asni	-	3.8	3.2	2.5
Arig-8	-	2.9	2.8	1.9
ACSAD-176	-	2.2	2.1	1.5

Table 6. Nitrogen uptake and apparent recovery for the five varieties (Year 1).

Nitrogen kg ha^{-1}	ACSAD-60	Tessaout	Asni	Arig-8	ACSAD-176	Mean
	---------kg ha^{-1}---------					
0	20.1 (-)	15.6 (-)	18.2 (-)	28.7.(-)	24.0 (-)	21.3 (-)
40	36.5 (41)	23.7 (20)	32.3 (35)	45.7 (42)	30.5 (16)	33.7 (31)
80	47.5 (34)	31.4 (19)	36.0 (22)	49.9 (27)	38.8 (18)	40.7 (24)
120	56.2 (30)	67.9 (43)	55.4 (31)	62.3 (28)	48.4 (20)	58.0 (30)

[1] Apparent recovery percentage in parentheses

recovery by the five varieties is presented in Table 6 in relation to N application rates in Year 1 of the study. Uptake from the soil with added N varied considerably among varieties, e.g., uptake of Arig-8 was almost double that of Tessaout. While uptake increased with added N, apparent recovery of the fertilizer from soil tended to decrease for the varieties, except of ACSAD-176 and Asni in which there was no change observed.

DISCUSSION

Despite the fact that the response of barley to applied N is less pronounced under rainfed than under irrigated conditions (Baldridge *et al.,* 1985), responses under the present limited moisture regime were significant, with consistent yield increases up to N application of 80 kg ha^{-1}. Similarly, Anderson (1985) found that yield responses to N varied from 40 to 120 kg ha^{-1} depending on site, season, seed rate and variety. The stepwise increase in dry matter yield (Table 3) suggests that further responses in dry matter yields might be achieved using still higher N levels. However, it seemed that this was about maximum for grain yield since differential effect of N on grain was reflected in a lower HI at the highest N rate. As N response is season-specific, i.e., depending on rainfall, responses to higher N levels would be expected if rainfall had been more favourable as well as favourably distributed. Indeed, yields in Year 2 were consistently higher at all levels of N because of more favourably distributed rains during tillering and stem elongation stages.

The marked response of any of varieties to N was not surprising in view of trial results from the rainfed Mediterranean region (Anderson, 1985; Brown *et al*., 1987). However, that such strong and consistent responses to applied N should occur in each year was unexpected in view of the relative shallowness of the soil in contrast with other barley fertilizer trials conducted elsewhere on deeper soils, mainly at experiment stations (Jones and Singh, 2000; Papastylianou, 1995; Yau *et al*., 2003). Apart from soil depth, irrespective of the year's rainfall, responses of barley to N are related to the initial nitrate-N levels in the root penetrating zone, i.e., to a depth of 60 cm (Abdel Monem *et al*., 1990 a). A critical level of 40 kg NO^-_3N (14.4 mg N kg^{-1}) was identified in these trials. In view of the extremely low content of NO^-_3N (2.0 mg kg^{-1}) prior to this study, for both cropping seasons, the magnitude of the N response was not surprising.

The apparent contrast between our results and those reported for barley trials in this area of Morocco have to be reconciled in terms of initial soil NO^-_3N levels. Prior to the initiation of soil test calibration studies, few if any field trials reported soil nutrient analysis. The most plausible reason for this absence of an N response at experiment stations was a buildup of NO^-_3N (Ryan *et al*., 1990), in contrast to generally lower N levels in farmers' fields (Abdel Monem *et al*., 1990b). Indeed, the variable response to N with barley on farmers' fields may be explained as based on the previous crop. Where a legume was previously grown, soil

N levels may be adequate for maximum yield without any addition of fertilizer (Abdel Monem *et al*., 1990a). Had soil samples been analyzed for N, this would have been readily detected.

However, it can be safely assumed that if a cereal crop had been planted the previous year, a response to N would be likely. Fertilization of barley with N has to be seen in a cropping system's context, i.e., the influence of the preceding crop on soil N, available soil moisture and thus crop growth and response to fertilizer. While most studies from Syria (Jones and Singh, 1995 and 2000; Christiansen *et al*., 2000), Cyprus (Orphanos, 1994) and Lebanon (Yau *et al.,* 2003) dealt with a legume-barley system, the system in central Morocco involves continuous barley or barley after "weedy" fallow rather than a forage legume. Except where chickpea (*Cicer arietinium*) or lentils (*Lens culinaris*) are grown, there is unlikely to be any N enrichment from the weedy fallow and little if any residual moisture, which is mainly depleted by the weeds.

The study highlighted significant differences among barley varieties. Brown *et al*. (1987) also detected varietal differences; even though they found no difference in dry matter response to N for a local two-row landrace and an improved six-row variety, but the local one yielded higher grain. In our study, the short-season variety Tessaout yielded low, while the longer season one Arig-8 yielded the highest.

Despite the commonalities and similarities in the Mediterranean environment for barley growing, the study highlighted the variability in various environments in the region which, allied to variable total and within-season rainfall, is always going to produce varied yields from different crop varieties. Actual testing of varieties, as in this study, in a stressed environment is in line with the arguments of Ceccarelli *et al*. (1998) for selection in such environments and involving the farmer in the process of identifying favourable varieties for their particular agroecosystem (Ceccarelli *et al.,* 2001). In addition to showing favourable N response in a low-rainfall environment, this study demonstrated that a shallow soil *per se* need not be too an adverse factor in Mediterranean barley production.

The N uptake data (Table 6) serve to illustrate differences in efficiency of N utilization among varieties. Average apparent N recovery was about 31%. In other words, 69% of the N was not used up by the year's crop. Most of it was probably still remaining in the soil in organic form either in the roots or microbial biomass or as NH_4 and/or NO_3 forms. Losses of N are likely to have been low, even with urea, which is susceptible to volatility losses. In field studies in a typical dryland Mediterranean area in northern Syria, volatility N losses were moderate, only ranging from 11 to 18% of the N applied (Abdel Monem, 1986). As ammonium nitrate is not very prone to volatility loss and was incorporated immediately, and as rainfall was not sufficient to leach NO_3 from the root zone, little actual loss could have occurred. Thus, the unused N could be stored to be used up by the succeeding crops.

In summary, this 2-year trial with barley showed the crop's significant and consistent responses to N up to 80 kg ha^{-1}. As limited fertilizer is used on barley in semi-arid areas of Morocco (Crawford and Purvis, 1986), these results suggest that output could be considerably improved by general use of fertilizers, particularly N. It thus complements other studies from the semi-arid area of Morocco which show positive responses of triticale to applied N (Ryan *et al*., 1995). The economic analyses support the conclusion that N use would be profitable to the farmer when applied at the normally recommended range of application rates.

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واکنش ارقام جو به کودهای نیتروژنه در شرایط نیمه خشک کشور مغرب

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چکیده

منطقه غرب آسیا و شمال آفریقا با خصوصیات آب و هوایی مدیترانه‌ای مرکز اصلی پیدایش غلات بویژه گندم (*Triticum ssp.*) و جو (*Hordeum ssp.*) است. ولی تولید غلات که غالباً به صورت دیم کشت می‌شود تحت تأثیر خشکی به علت بارندگی کم و حرارت بالا قرار دارد. کشت غلات با هدف تولید قابل قبول و حفظ ذخیره مرطوب معمولاً بعد از آیش انجام می‌شود ولی به طور روزافزونی کشت غلات به صورت متوالی و یا در تناوب با گیاهان خانواده لگومینوز (حبوبات و علوفه) مورد توجه قرار گرفته است. کشت جو به طور عمده در مناطق کم باران در اراضی کم عمق با مصرف حداقل و یا بدون کود شیمیایی رایج است. منطقه مرکزی مغرب با بارندگی متوسط (۲۰۰ تا ۵۰۰ میلیمتر در سال) به عنوان یک منطقه تی‌پیک برای کشت غلات منطقه مدیترانه مورد بررسی قرار گرفت. لذا به منظور ارائه یک مبنای اصولی برای مصرف کود نیتروژن در کشت جو یک آزمایش صحرایی در نزدیک شهر ستات با ۵ واریته جو و ۴ سطح نیتروژن (۰، ۴۰، ۸۰ و ۱۲۰ کیلوگرم در هکتار) در روی یک خاک کم عمق (Petrocalcic palexeroll) در دو فصل زراعی با میزان و توزیع بارندگی متفاوت (سال اول ۲۶۱ میلیمتر و سال دوم ۳۰۲ میلیمتر) به مرحله اجرا درآمد. تفاوت قابل ملاحظه‌ای در تولید محصول در سال دوم آزمایش به علت بارندگی بیشتر و توزیع مناسب آن در مرحله پنجه زدگی و ساقه رفتن گیاه مشاهده شد. نیتروژن باعث

افزایش تولید ماده خشک و دانه بویژه در سطح ۸۰ کیلوگرم در هکتار در هر دو سال گردید. تجزیه و تحلیل اقتصادی در سال زراعی اول نشان داد که مصرف کود نیتروژن تا میزان ۸۰ کیلوگرم در هکتار سوددهی داشته است. جذب نیتروژن در ارقام مختلف جو متفاوت بوده و با مصرف بیشتر کود نیتروژن افزایش یافت. بازیافت نیتروژن متفاوت و به طور کلی کمتر از ۵۰ درصد بود. برخلاف بسیاری از آزمایشهای صحرایی انجام شده روی کشت جو در منطقه این آزمایش، در منطقه مرکزی کشور مغرب نشان داد که افزایش تولید محصول ارقام مختلف جو در اثر مصرف کود نیتروژن وجود دارد. بنابراین می‌توان نتیجه گرفت که مصرف کود نیتروژن در منطقه مرکزی مغرب در خاکهای کم عمق که رشد ریشه گیاه و ظرفیت نگهداری رطوبت در آنها محدود است باید مورد توجه قرار گیرد.