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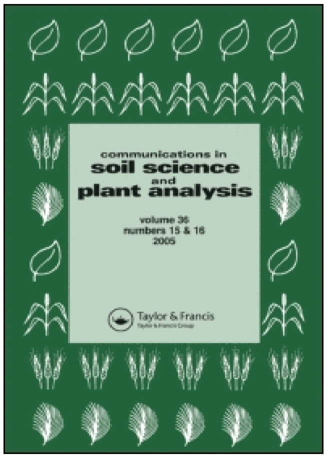

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Nitrogen Uptake by Malting Barley Grown under Conditions Found in Buenos Aires Province, Argentina

María Aurora Lázzari
Center of Renewable Natural Resources of the Semi-arid Area
(CERZOS), Consejo Nacional de Investigaciones Científicas y Técnicas
of Argentina (CONICET), San Andrés 800, Bahía Blanca, Argentina

María Rosa Landriscini
Consejo Nacional de Investigaciones Científicas y Técnicas of Argentina
(CONICET), San Andrés 800, Bahía Blanca, Argentina

Marcelo Echagüe
Center of Renewable Natural Resources of the Semi-arid Area
(CERZOS), Consejo Nacional de Investigaciones Científicas y Técnicas
of Argentina (CONICET), San Andrés 800, Bahía Blanca, Argentina

Abstract: There is a lack of data associated with applications of nitrogen (N) fertilizer to increase yield while not increasing seed protein to levels exceeding those acceptable for malting barley (*Hordeum vulgare* L.) in the Buenos Aires province of Argentina. The effect of rates and timing of N application on yield and grain N concentration of malting barley was evaluated at eight sites in 1999 and 2000. Aboveground dry matter accumulation and N-uptake pattern through the growing season were evaluated. Dry matter production and N-uptake were measured at four sampling times: tillering, head emergence, grain filling, and maturity. The N fertilizer increased grain yield, but its response varied between sites. Under appropriate conditions, the yield increased and maintained the grain N concentration within a

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Address correspondence to María Aurora Lázzari, Center of Renewable Natural Resources of the Semi-arid Area (CERZOS), Consejo Nacional de Investigaciones Científicas y Técnicas of Argentina (CONICET), San Andrés 800 Bahía Blanca, Argentina. E-mail: alazzari@criba.edu.ar

desirable range for malting barley. Split applications were as effective in increasing grain yield as one addition at emergence, but they invariably increased grain N concentration. The season affected the yield response to N fertilizer and its levels in the grain, but the nitrogen harvest index was not affected by the rate of N application.

Keywords: *Hordeum vulgare*, urea, soils, Buenos Aires Province

INTRODUCTION

Barley is grown on more than 250,000 ha under rain-fed conditions in Buenos Aires province, Argentina. This region supplies approximately 80% of the annual barley production for Argentina, which was 118,000 in 1989 and 925,000 tons in 2002 (FAO 2003). More than 90% of this barley is sown for malting purpose. Grain nitrogen (N) concentration is a very important factor in determining malting quality; generally it should be between 1.60 and 1.92% N, and management strategies for malting barley must therefore maintain a balance between achieving economic yield responses and maintaining the grain protein concentration within a desirable range, which is possible under appropriate conditions of N application (Fathi, McDonald, and Lance 1997). The efficacy of the N addition varies considerably depending upon the native soil N supply, previous N uptake, plant development when supplemental N is applied, and yield potential (Birch, Fukai, and Broad 1997; Conry 1986; Gallagher, Doyle, and Dilworth 1987; Otegui et al. 2001; Strong 1986).

In Buenos Aires province, the N fertilizer is usually applied to malting barley after sowing, when the need for fertilizer is more assured, and the amount generally used by farmers varies between 25 and 60 kg N ha^{-1} for the studied cultivar. Some farmers use split applications involving equal quantities of N applied to soils after sowing and at the tillering growth stage. However, with the current management practices, the protein content is not consistent for malting purposes, and the lack of well-documented data about this matter creates serious difficulties for the farmers. Limited prior experimentation indicated that the response in grain yield and grain N concentration to N application was variable and depended on the environmental conditions under which the plants were grown (Echagüe et al. 2001). In pot and field experiments, Lázzari et al. (2001) showed that the N uptake from urea varied among soils and was related to the supply of soil N.

The objectives were to determine, under field conditions, (i) how N fertilizer levels and timing of N application, similar to those used by farmers, affect grain yield and grain N concentration of malting barley grown in Buenos Aires province and (ii) to study at each site the above-ground dry matter accumulation and N-uptake pattern through the growing season. The data will serve as a useful guide to sound fertilizer practices in this region.

MATERIALS AND METHODS

Experimental Sites

Field experiments were conducted in Buenos Aires province, Argentina, with malting barley and urea applications at four locations in 1999: San Mayol (S38° 23′, W60° 17′), Coronel Suárez (S37° 28′, W61° 56′), Bordenave (S37° 51′, W63° 01′), and Alberti (S35° 08′, W60° 13′), and at four locations in 2000: Cascallares (S38° 30′, W60° 28′), Puán (S37° 33′, W62° 46′), Bordenave, and Alberti. The soils were classified (Soil Survey Staff 1999) as Petrocalcic Paleudoll (San Mayol), Typic Argiudoll (Puán), Entic Haplustoll (Bordenave), and Typic Hapludoll (Coronel Suárez, Alberti, and Cascallares).

Cultural Practices

The Quilmes Palomar two-row barley cultivar was released in Argentina, registered in 1994, and used in this experiment because it is currently grown in Buenos Aires province. The levels and timings of fertilization were 0 (0N), 30 (30e), and 60 (60e) kg N ha^{-1} applied as a whole at plant emergence (ca. first leaf 50% emerged stage of growth), 30 (30t) and 60 (60t) kg N ha^{-1} applied as a whole at early tillering (approximately at fourth leaf 50% emerged), and 60 (30 + 30) applied in split applications involving equal quantities of N applied at plant emergence and tillering growth stages. The six treatments were arranged in a randomized complete block design with four replicates. The area of each of the six plots was 20 m^2 (4 × 5 m), separated from each other and from block boundaries by discard areas of 0.5 m and 2 m, respectively. A basal application of phosphorus (P) at a rate of 20 kg ha^{-1} as triple superphosphate was drilled with the seed at sowing (30 kg ha^{-1} to San Mayol and Alberti soils in 1999). Weeds were controlled by the use of herbicides and were not considered to be a factor in the yield responses. Previous to the P fertilization and sowing, soil samples were taken (0- to 20-, 20- to 40-, and 40- to 60-cm depths) for moisture content and soil property determinations (Table 1). The barley was sown using the usual tillage practices in the region (chisel plow and disking). The average plant population was 200 m^{-2} in 1999 and 220 m^{-2} in 2000. The required amount of urea fertilizer was broadcast and then incorporated into the soil at emergence or at tillering. At each sampling time—tillering (T), head emergence (H), grain filling (GF), and physiological maturity (PM)—all aboveground plant

Table 1. Principal soil characteristics at eight sites used in the experiment over 2 years in Buenos Aires province, Argentina

		1999				2000			
Parameter	Depth (cm)	San Mayol	Cnel. Suárez	Bordenave	Alberti	Cascallares	Puán	Bordenave	Alberti
OM^a (%)	0–20	4.4	4.2	2.4	2.7	2.6	4.0	1.4	3.0
	20–40	2.9	3.4	1.8	2.4	1.5	2.5	0.9	2.7
	40–60	1.5	1.9	1.7	1.6	0.8	2.0	0.5	1.6
N (%)	0–20	0.225	0.185	0.140	0.161	0.130	0.210	0.074	0.159
	20–40	0.165	0.194	0.076	0.157	0.089	0.136	0.061	0.137
	40–60	0.099	0.111	0.050	0.106	0.056	0.109	0.045	0.094
NO_3^--N (kg ha^{-1})	0–20	34	35	32	44	27	35	4	9
	20–40	25	46	13	46	48	4	0	2
	40–60	17	11	3	32	30	20	0	4
NH_4^+-N (kg ha^{-1})	0–20	18	19	23	16	32	8	0	0
	20–40	4	10	16	11	22	14	0	0
	40–60	30	8	16	20	13	15	0	0
P^b (mg kg^{-1})	0–20	9.9	13.3	15.0	3.0	14.4	11.0	16.1	15.7
	20–40	5.8	13.7	8.0	6.0	30.5	3.2	7.9	12.2
	40–60	2.3	14.1	5.5	5.2	2.9	3.6	6.0	5.0

pH[c]	0–20	5.2	6.0	6.8	5.3	6.3	6.4	6.6	5.9
	20–40	5.6	6.1	7.2	5.4	6.6	6.6	6.9	6.0
	40–60	6.1	6.1	7.7	5.5	6.8	6.7	6.8	6.2
Clay[d] (%)	0–20	22.5	17.5	15.6	17.5	15.0	25.0	10.0	20.0
	20–40	27.5	20.0	12.5	16.9	20.0	27.5	12.5	21.3
	40–60	30.0	19.4	12.5	17.5	17.5	30.0	10.0	20.0
Silt[d] (%)	0–20	12.5	15.0	8.8	3.8	7.5	15.0	2.5	5.0
	20–40	10.0	11.3	10.0	7.5	7.5	12.5	5.0	7.5
	40–60	7.5	8.8	10.0	5.0	5.0	11.3	5.0	10.0
Sand[d] (%)	0–20	65.0	67.5	75.6	78.8	77.5	60.0	87.5	75.0
	20–40	52.5	68.8	77.5	75.6	72.5	60.0	82.5	71.2
	40–60	62.5	71.9	77.5	77.5	77.5	58.5	85.0	70.0
D_b[e] (Mg m^{-3})	0–20	1.13	1.16	1.39	1.28	1.29	1.16	1.46	1.33
	20–40	1.25	1.23	1.28	1.27	1.42	1.16	1.42	1.40
	40–60	1.21	1.25	1.15	1.27	1.28	1.09	1.42	1.34

[a] Organic matter (Walkley and Black 1934).

[b] Modified Bray 1-extractable P (Bray and Kurtz 1945).

[c] Soil–water ratio 1:2.5

[d] Particle size analysis (Gee and Bauder 1986).

[e] Bulk density.

material from four 0.5-m sections of a row were hand sampled from the plots, cutting at ground level for aerial dry matter (DM) production. In particular at PM, the stems and leaves were separated from the spikes, dried, and weighed; previously, a subsample of 20 plants was randomly selected from the bulk sample to determine the N-uptake patterns. At the same plant sampling dates (with the exception of GF growth stage in 2000), two soil samples were taken from each plot with a semicylindrical auger (2.5 cm diameter) at 0- to 20-, 20- to 40-, and 40- to 60-cm depths. Soil subsamples were stored moist at 5°C until nitrate —N (NO_3^-N) and ammonium-N (NH_4^+-N) analysis, and the rest of the soil was dried at 105°C for moisture content determination. Two months after sowing, bulk density determinations were made for each sampled layer using cylinders (5 cm diameter × 7 cm depth). Finally, an area of 1 m × 4 m of each plot was harvested with a plot harvester at maturity, leaving 0.5-m unharvested area at the four sides for border effects. The long-term annual average precipitation and temperature, previous crops, and details of the field operations during the growing seasons are summarized in Table 2. The rainfall and the monthly mean temperature during the plant sampling times are given in Table 3.

Analysis

All plant materials were dried to a constant weight at 60°C in a forced-draft oven, weighed, and ground to pass 0.4-mm sieve, except for grain yields at harvest in Table 4, which are expressed at 88% DM. Total N was determined by semimicro Kjeldahl analysis (Bremner 1996). Soil mineral N was extracted by shaking 10 g (oven-dry basis) of fresh soil with 50 mL of 2 M KCl solution for 1 h at room temperature and filtering the mixture through a Whatman no. 42 filter paper. Soil NH_4^+-N and NO_3^--N were measured separately on the extracts by the steam distillation method with MgO and Devarda's alloy (Mulvaney 1996).

Statistical Analysis

Because of the wide range of soil and climatic conditions and the comparatively small number of sites and overall analysis of treatments, combining sites will be carried out at a later stage in this project. All data collected were analyzed for each experimental site separately by the ANOVA procedure according to Steel and Torrie (1980), because of the wide range of soil and climatic conditions and the small number of sites. If the ANOVA indicated significant differences, comparisons among the treatment means were conducted by a significance difference test (LSD). Separate ANOVAs were conducted on seasonal aboveground DM, N content, and each form of soil N. Differences were considered significant when detected at $P \leq 0.05$.

Table 2. Long-term annual averages rainfall and temperature, previous crop, and details of the field operations during the malting barley growing season at eight sites over 2 years in Buenos Aires province, Argentina

	1999				2000			
Parameter	San Mayol	Coronel Suárez	Bordenave	Alberti	Cascallares	Puán	Bordenave	Alberti
Rainfall (mm)	794	852	662	962	855	769	662	962
Temperature (°C)	14.2	13.5	15.0	16.2	14.2	13.5	15.0	16.2
Previous crop	Wheat	Soybean	Millet	Oat	Wheat	Sorghum	Wheat	Soybean
Sowing date	24 June	22 July	22 July	30 June	26 July	17 July	18 July	30 June
Interrow spacing (cm)	17.5	20.0	17.5	20.0	16.0	20.0	20.0	20.0
1st fertilization	18 Aug. (11)[a]	12 Aug. (11)	12 Aug. (11)	22 July (11)	28 Aug. (11)	18 Aug. (11)	14 Aug. (11)	25 July (11)
2nd fert., 1st sampling	21 Sept. (14)	9 Sept. (13)	8 Sept. (13)	19 Aug. (14)	25 Sept. (14)	14 Sept. (20)	12 Sept. (21)	29 Aug. (21)
2nd sampling	21 Oct. (41)	29 Oct. (55)	26 Oct. (57)	13 Oct. (57)	25 Oct. (45)	31 Oct. (59)	31 Oct. (59)	18 Oct. (59)
3rd sampling	16 Nov. (77)	18 Nov. (77)	18 Nov. (77)	2 Nov. (75)	24 Nov. (77)	17 Nov. (77)	17 Nov. (77)	15 Nov. (77)
4th sampling	10 Dec. (91)	9 Dec. (89)	7 Dec. (91)	19 Nov. (89)	12 Dec. (91)	11 Dec. (91)	Dec. 7 (91)	Dec. 6 (91)

[a] In parenthesis, two-digit code for growth staging in barley (Zadoks, Chang, and Konzak 1974).

Table 3. Amount of rainfall between barley growth stages and monthly mean temperature during seasons at eight sites over 2 years in Buenos Aires province, Argentina

	1999				2000			
Time period	San Mayol	Coronel Suárez	Bordenave	Alberti	Cascallares	Puán	Bordenave	Alberti
Rainfall (mm)								
1 month previous sowing	73	10	23	10	68	10	18	2
Sowing–tillering	170	76	44	35	124	139	97	17
Tillering–heading	8	41	55	97	119	140	125	137
Heading–grain filling	44	48	109	30	70	37	42	212
Grain filling–maturity	91	48	134	14		9		58
Total	386	223	365	185	381	335	282	426
Mean temperature (°C)								
September	11.2	11.7	11.5	14.4	10.0	10.1	10.1	13.7
October	14.6	15.4	14.6	16.7	12.7	13.4	13.2	16.3
November	18.3	18.8	17.6	20.1	15.4	16.9	16.3	18.4
December	21.2	22.4	20.5	23.3	20.1	21.4	21.4	23.4

Table 4. Grain yield and grain N concentration in malting barley grown at eight sites over 2 years, with different rates (0, 30, and 60 kg N ha^{-1}) and timing (e, plant emergence; t, tillering growth stage) of N application: 30 + 30: 30 kg N ha^{-1} added at plant emergence plus 30 kg N ha^{-1} added at tillering growth stage

	1999								2000							
	San Mayol		Coronel Suárez		Bordenave		Alberti		Cascallares		Puán		Bordenave		Alberti	
Added N	Yield (kg ha^{-1})	N (%)	Yield (kg ha^{-1})	N (%)	Yield (kg ha^{-1})	N (%)	Yield (kg ha^{-1})	N (%)	Yield (kg ha^{-1})	N (%)	Yield (kg ha^{-1})	N (%)	Yield (kg ha^{-1})	N (%)	Yield (kg ha^{-1})	N (%)
0N	1386a[a]	1.72a	4106a	1.70a	783a	2.12a	3735a	1.91a	3667a	1.60ab	4592a	1.52a	1865a	1.32a	3472a	1.81a
30e	2440bc	1.69a	4643a	1.70a	1084b	2.06a	3613a	2.18ab	4260bc	1.54a	5048b	1.53a	3354bc	1.36a	3774a	1.85a
30t	2114ab	1.70a	4385a	1.81ab	1129b	2.10a	3375a	2.30b	4096ab	1.63ab	5079b	1.72ab	2899b	1.36a	4075b	1.75a
60e	3260c	1.74ab	4588a	1.93c	1218b	2.18a	3098a	2.29b	4622c	1.73bc	5045b	1.80b	3868c	1.38a	4296b	1.81a
60t	2532bc	1.97c	4529a	1.96c	1201b	2.17a	3373a	2.46b	4030ab	1.89c	5147b	1.76b	2916b	1.39a	4097b	1.86a
30 + 30	2790bc	1.86bc	4578a	1.90bc	1387c	2.19a	3194a	2.38b	4419bc	1.84c	5207b	1.91b	3387c	1.49b	4264b	1.85a

[a] Means in each column with the same letter are not significantly different ($P \leq 0.05$).

RESULTS AND DISCUSSION

Grain Yield and Nitrogen Concentration at Harvest

The climatic conditions during the study ranged from poor to very favorable for malting barley growth (Table 3). Adverse conditions included a frost before the GF stage of growth (Bordenave, 1999), scarcity of rainfall during the entire cycle (Coronel Suárez and Alberti, 1999) or from H to maturity (Puán), and excess of soil moisture (Alberti, 2000). Nevertheless, Table 4 shows that Puán and Coronel Suárez sites gave the greatest mean grain yield (5019 and 4471 kg ha^{-1}, respectively), followed closely by Cascallares (4181 kg ha^{-1}), and far by San Mayol (2420 kg ha^{-1}). The last two sites are considered to have favorable climatic conditions for malting barley production for their respective zones. Lodging in Alberti, 2000 (3996 kg ha^{-1}, average), caused grain yields lower than expected. Conversely, the scarcity of rainfall in Alberti, 1999, was the principal factor determining low yields (3398 kg ha^{-1}, average). At Bordenave, 2000, with the lowest soil fertility (Table 1), grain yields were high for the zone (Ron and Loewy 1996) and averaged 3114 kg ha^{-1}, whereas in 1999 the frost hindered high yields (1133 kg ha^{-1}, average).

Nitrogen fertilization affected grain yield and grain N concentration in different ways (Table 4). In San Mayol and Cascallares, the yield increases with the addition of 30 and 60 kg N ha^{-1} at the emergence of the plants (30e and 60e) did not cause an increase in the grain N percentage; from the N applications at tillering growth stage, only 60t increased both yield and grain percentage of N. In Puán, the yield increased similarly in all fertilized treatments, and 60 kg N ha^{-1} increased the grain N percentage to a satisfactory value for malting. At these experimental sites, split N applications were as effective for grain yield as one application of 30 kg N ha^{-1} at emergence, which invariably increased grain protein concentration in a manner similar to 60t addition.

In 2000 at the Bordenave site, a high yield was observed with N applications at emergence and in split applications (Table 4). However, the grain N concentrations were so low that it was impossible to reach the acceptable standard for malting. Only $30 + 30$ increased the N percentage, and this would seem its chief advantage for barley under these soil and environmental conditions. In 1999, on November 9, 9 days before the plant sampling at GF, a frost (-5.5°C at 5 cm and -0.3°C at 150 cm from the soil surface) was registered, which forced physiological maturity of the barley plants, and the N fertilization had little effect on high grain N concentration (Table 4). The plots with $30 + 30$ gave the highest yield, and the others similarly differed when compared with 0N.

At Coronel Suárez, the precipitation was scarce (Table 3), and the N fertilization did not have an effect on the grain yields, whereas the application of 60 kg N ha^{-1} increased grain N percentage (Table 4). At the Alberti site in

1999, the added N did not increase grain yields; the grain N concentrations were high and the control plot only produced grains acceptable for malting. Conversely, in 2000, the lodging recorded did not adversely affect the yield response to N. However, in plots receiving 60 kg N ha^{-1}, lodging was probably responsible for a yield reduction; all treatments yielded grains of excellent malting quality, and fertilization did not affect the grain N concentration.

Aboveground Dry Matter Accumulation

In San Mayol, the rate of aboveground DM accumulation in 0N treatment was almost constant from T to PM (Figure 1); in most of the fertilized plots, DM increased from H to GF, and at the GF stage of growth, the 30e and 60e treatments gave significantly more DM than 0N. Generally, there was an increase of DM from GF to PM. This was observed in all sites where there were not adverse conditions as mentioned previously. In Puán, the DM curves were similar to those of San Mayol; the more abundant precipitation occurred in the T–H period of longer duration, lower mean temperature (Table 3), and higher DM accumulation (Figure 1). In Cascallares, with heavy rainfall and very low air temperature until H, a higher rate of DM accumulation was observed at the Alberti site in 2000; higher plant development was observed after H because of more abundant rainfall. Figure 1 shows the significant DM response with 60 kg N ha^{-1} after the H growth stage.

The lack of soil moisture during the entire plant cycle in Coronel Suárez (Table 3) hindered any significant difference among treatments after H, and a cessation of growth between GF and PM was shown (Figure 1). At the Alberti site in 1999, the cessation of growth generally occurred after H; however, significant differences between treatments were shown at H and GF stages of growth.

At the Bordenave site in 2000, under favorable environmental conditions, the fertilized plots at emergence (including $30 + 30$) gave significantly more DM than 0N, but 60e plants supported a cessation of growth in the last period (Figure 1). On the other hand, Bordenave in 1999 was the sole site where a significant decline in DM between GF and PM in all treated plots was observed; the frost by GF produced premature leaves senescence. Considering the eight sites, timing of N applications generally did not influence the plant DM accumulation.

Aboveground Nitrogen Content

The N accumulation by barley grown without N addition reflected the seasonal N supply from soil, under the conditions of these experiments. In San Mayol, the 0N plants showed a cessation of N uptake in the H–GF period of increment of plant growth (Figure 2). This was related to soil N-limiting

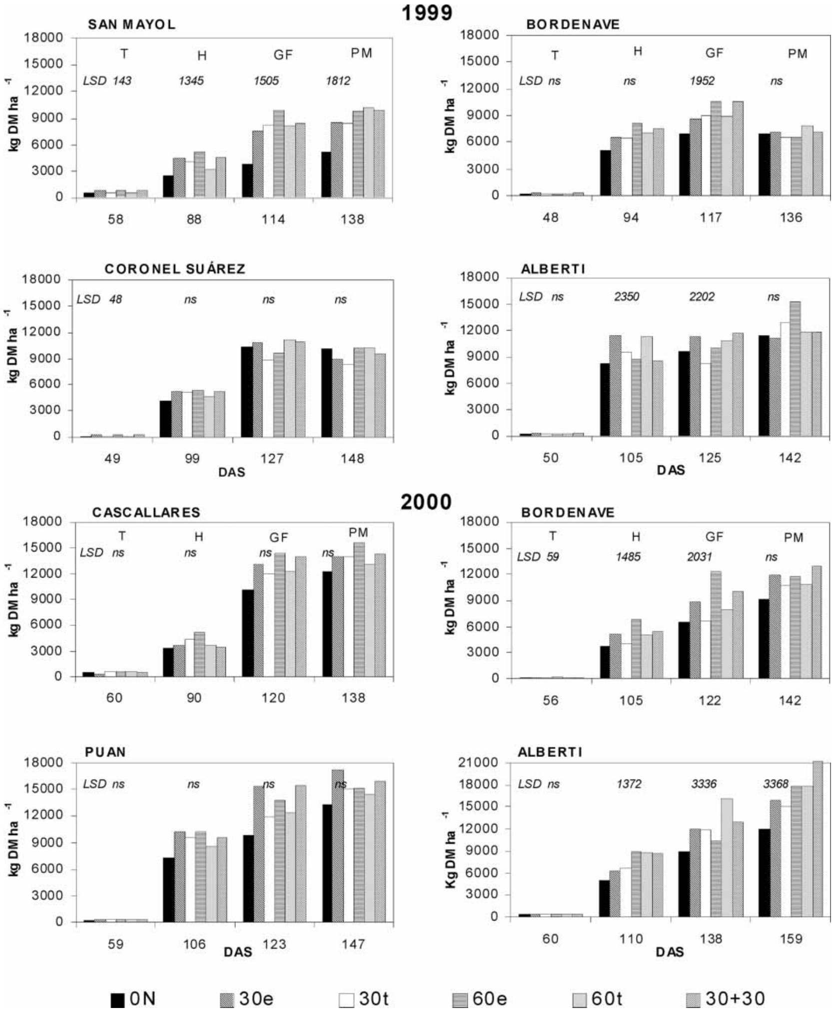

Figure 1. Aboveground dry matter (DM) accumulation in malting barley grown at eight sites over 2 years for different rates (0, 30, and 60 kg ha^{-1}) and timing (e, plant emergence, and t, tillering growth stage) of N applications: 30 + 30: 30 kg N ha^{-1} applied at plant emergence plus 30 kg N ha^{-1} applied at tillering growth stage, T, H, GF, and PM: tillering, heading, grain filling, and physiological maturity growth stage, respectively. DAS: days ofter sowing. The LSD at $P \leq 0.05$ is provided; ns: not significant.

conditions, as reported by Karrou and Maranville (1994) using wheat grown in a greenhouse. It should be noted that N uptake by plants continued until maturity (particularly in 60t, N-uptake response was linear over time) as reported by Harper et al. (1987) in wheat, whereas others reported cessation

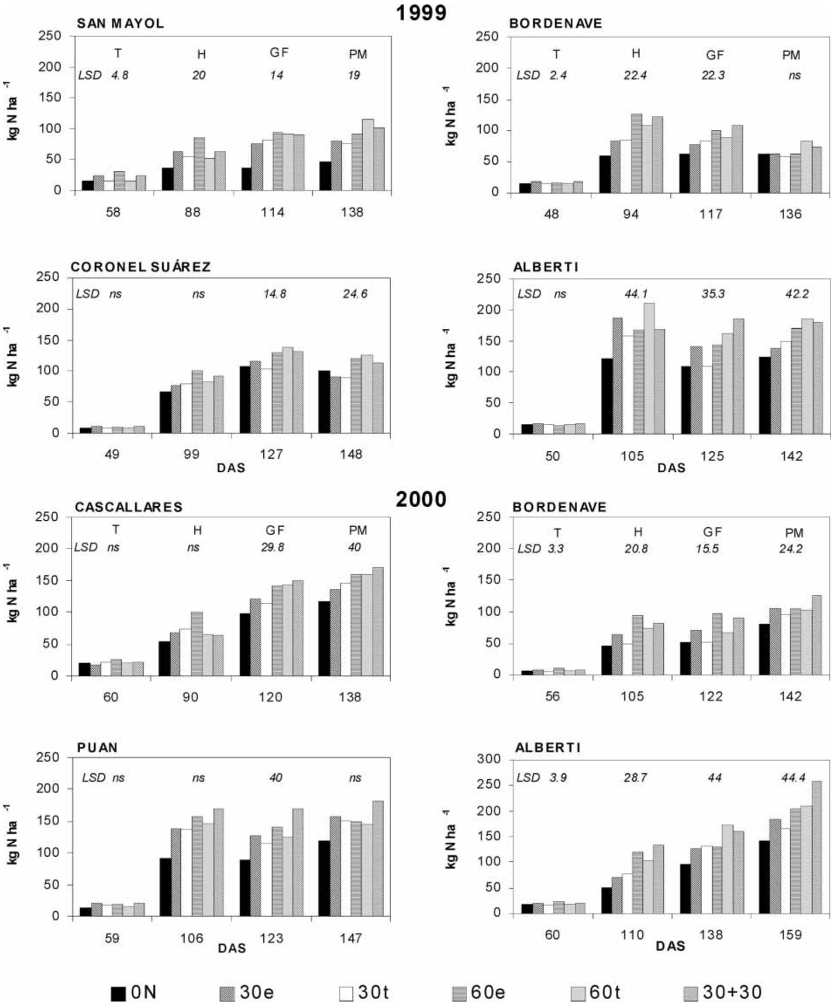

Figure 2. Aboveground nitrogen (N) content in malting barley grown at eight sites over 2 years for different rates (0, 30, and 60 kg ha^{-1}) and timing (e, plant emergence, and t, tillering growth stage) of N applications: 30 + 30: 30 kg N ha^{-1} applied at plant emergence plus 30 kg N ha^{-1} applied at tillering growth stage. T, H, GF, and PM: tillering, heading, grain filling, and physiological maturity growth stage, respectively. DAS: days ofter sowing. The LSD at $P \leq 0.05$ is provided; ns: not significant.

of uptake during the senescence period (Gregory, Crawford, and McGowan 1979). These differences are possibly due to external factors such as soil water or soil and air temperature conditions. In San Mayol, soil water conditions were favorable throughout the season, and there was little change in air temperature between GF and PM (Table 3). On the other hand, the rate of soil N mineralization was too slow to provide 0N plants grown with sufficient

N to favor a continued rate of N uptake (Figure 2), as occurred in most of the fertilized plots, and significant N-uptake responses to the N additions were observed in all sampling dates. The cessation of N uptake was observed in Puán from H to PM, in all plots (Figure 2); the soil N-limiting conditions were more severe than that in San Mayol because of the higher plant growth and N uptake until H. Nevertheless, some significant differences between treatments were observed at GF stage. In Cascallares and Alberti, 2000, the curves of plant growth (Figure 1) and N uptake (Figure 2) had a similar pattern, both continuing from T to PM. This continued N uptake until maturity suggested that N in the grain was derived primarily from further absorption from the soil rather than by translocation from other plant parts (Harper et al. 1987). In Cascallares, the fertilizer addition significantly increased the N uptake at the GF stage. At the Alberti site in 2000, the plant N content significantly increased after T with the additions of N fertilizer.

In spite of the scarcity of rainfall (Table 3) and the cessation of growth between GF and PM in Coronel Suárez, and between H and PM at the Alberti site in 1999 (Figure 1), the addition of 60 kg N ha^{-1} increased the N uptake after GF or H growth stages, respectively (Figure 2). These results suggested that (i) the available N from soil and fertilizer was taken up by plants regardless of environmental conditions and (ii) high N fertilizer rate, particularly when applied in seasons of adverse conditions, resulted in high plant N uptake and, consequently, excessive grain N concentration (Table 4). Moreover, in Coronel Suárez, the amount of available NO_3^--N plus NH_4^+-N (0- to 60-cm depth) at sowing (Table 1) was similar than that found in San Mayol, but the N uptake of barley plants in 0N was twice the N uptake in 0N at the San Mayol site. Thus, N response was affected by the inherent soil N fertility more than by the climatic conditions.

At the Bordenave site in 2000, fertilized treatments increased the N uptake during the entire cycle (Figure 2). The plants in all plots showed a cessation of N uptake in the H–GF period; this soil N-limiting condition was probably due to NO_3^--N losses by leaching. By the same reason, at the same location in 1999, all plants showed a cessation of N uptake from H to GF. After this stage, N was lost from the plants probably through aerial NH_3 transport during premature plant senescence and inefficient redistribution of N within the plant (Harper et al. 1987), as a consequence of the frost near the GF stage. However, the 0N plots which experienced less frost effect did not lose N.

Regarding the split N applications, in 1999, they tended to be less effective in increasing plant N uptake than 60t plots; however, in 2000, 30 + 30 tended to be more effective.

Nitrogen Harvest Index

Generally, the nitrogen harvest index (NHI) (grain N yield/total N content) was not affected by the rate of N application (Table 5). Papakosta and Gagianas

Table 5. Nitrogen harvest index of malting barley grown at eight sites over 2 years with different rates (0, 30, and 60 kg N ha^{-1}) and timing (e, plant emergence; t, tillering growth stage) of N applications: 30 + 30: 30 kg N ha^{-1} added at plant emergence plus 30 kg N ha^{-1} added at tillering growth stage

Added N	1999				2000			
	San Mayol	Coronel Suárez	Bordenave	Alberti	Cascallares	Puán	Bordenave	Alberti
0N	0.65a[a]	0.76c	0.60a	0.71c	0.75a	0.81a	0.87a	0.74a
30e	0.70a	0.76c	0.57a	0.66bc	0.74a	0.82a	0.88a	0.75a
30t	0.75a	0.76bc	0.57a	0.65abc	0.79a	0.81a	0.88a	0.73a
60e	0.72a	0.73abc	0.52a	0.64abc	0.80a	0.79a	0.84a	0.70a
60t	0.72a	0.72a	0.59a	0.63ab	0.74a	0.83a	0.86a	0.71a
30 + 30	0.73a	0.73ab	0.57a	0.58a	0.77a	0.78a	0.87a	0.70a

[a] Means in each column with the same letter are not significantly different ($P \leq 0.05$).

(1991) concluded from the data of other investigators that this index is constant for rice, maize, and wheat over a wide range of N regimes. Particularly, the NHI was affected by N application at sites with scarce rainfall during the growing season, namely Coronel Suárez and Alberti, 1999. The lower NHI, with high N application rate and high plant ability to uptake the available N in soil, suggested that this ability to incorporate N in the grain had reached a limit. Thus, as N rate increased to 60 kg N ha^{-1}, NHI declined, especially when the fertilizer was added in split applications. At Bordenave, 1999, the lowest NHI was observed and related to the frost by GF stage of growth.

CONCLUSIONS

According to this study, N application generally increased grain yield, but the response varied from site to site. Under appropriate conditions it was possible to increase grain yield and still maintain the grain N concentration within the desirable range. Split N applications were as effective to grain yield as one N addition at the plant emergence but invariably increased grain N concentration. This would seem to be its chief advantage for barley in coarse-textured soil.

The season affected the yield response to N fertilizer and the levels of N in the grain. Adverse conditions encountered in 1999 included drought and frost prior to kernel filling; both factors contributed to lower grain yields and higher grain N concentrations than those obtained in 2000.

In plants grown with no drought or frost, DM accumulation and N uptake continued until maturity, and the differences in plant N uptake and grain N concentration between sites cannot be fully accounted for by seasonal effects. The inherent soil N fertility could be a more important factor than the climatic conditions controlling the N content in the aerial biomass. When plants were grown in soil with high N availability, N additions had little effect on plant growth and marked effect on plant N content.

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