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European Journal of Agronomy 17 (2002) 73–79

European Journal of Agronomy

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Sunflower nitrogen requirement and ^{15}N fertilizer recovery in Western Pampas, Argentina

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Received 25 October 2000; received in revised form 26 November 2001; accepted 26 November 2001

Abstract

In order to avoid nitrogen overfertilization, fertilizer rates must be adjusted to meet crop requirements. Two field experiments with sunflower (*Helianthus annuus* L.) were performed in the western part of the Pampas, Argentina, to: (i) assess nitrogen fertilization effects on seed yield, grain oil content, and plant lodging, (ii) determine N requirement per unit of yield, crop recovery of fertilizer N, and whether these two parameters were affected by N and other nutrient additions. Nitrogen fertilization increased the seed yield only by 17% at one site. Crop nitrogen requirement per unit yield (b-value) increased from 37 to 42 kg Mg^{-1} due to nitrogen fertilization only at the site where there was not a yield response. Therefore, if a yield response is expected, it is not necessary to use different b-values for non fertilized or fertilized crop. Reduction of seed oil content due to N addition was relatively small (2–5%), and was overcompensated by the seed yield increase at the responsive site. Recovery of fertilizer ^{15}N was of 51%. This efficiency of absorption should be considered for making fertilizer recommendations. Application of further nutrients including P and K had no influence on seed yield. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Sunflower; b-Value; Nitrogen fertilization; ^{15}N recovery

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1. Introduction

Overfertilization with nitrogen is one of the main causes of groundwater contamination with nitrates (Magdoff et al., 1997; Strong, 1995). In order to avoid a negative environmental impact, it is necessary to develop sound diagnosis and recommendation programs, that adjust fertilizer rates to crop requirements (Robertson, 1997). Excessive nitrogen fertilization of sunflower not only generates that environmental risk, it may also affect the grain quality, decreasing its oil content (Merrién and Milan, 1992) and reduce yield through an increase of plant lodging (Hussein et al., 1980).

The western part of the Pampas is one of the main sunflower production zones of Argentina (USDA, 1994). Predominant soils within that region are coarse textured (Typic and Entic Hapludolls), which facilitates water drainage and nitrate leaching. Even though several experiments study-

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PII: S1161-0301(01)00147-2

ing sunflower response to fertilization have been carried out within this zone (Duarte et al., 1999; Scheiner and Lavado, 1999), a program of diagnosis and recommendation has not been developed yet.

The balance-sheet method is a relatively simple way to adjust nitrogen fertilizer recommendations to crop requirements in order to avoid overfertilization. In this method, the calculation of crop nitrogen requirement is based on expected yield and a factor usually called 'b-value' (Neeteson, 1995). The b-value is the amount of N absorbed per unit of yield. This method also takes into account the soil ability to provide part of the crop N needs, based on a measure of the initial soil N availability (usually nitrates) and an estimate of soil N mineralization during the crop cycle. The difference between crop requirement and soil supply estimates is the fertilizer recommendation, once adjusted to account for fertilization efficiency.

Crop N requirement per unit of yield (b-value) may vary due to nitrogen fertilization if N addition affects grain N concentration or N partition between grain and stubble. Working with wheat, Makowski et al. (1999) observed great variability of b-value due to a variation of grain protein content. Addition of nutrients other than N may affect fertilizer N use efficiency if any of these other nutrients is deficient (de Wit, 1992). Loubser and Human (1993) reported an increase of N absorption by sunflower due to phosphorus fertilization.

A common practice for evaluating the initial soil N availability is to measure nitrate content in the top soil, up to 20 or 60 cm deep. A maximum depth of 60 cm is routinely used by advisors for soil sampling to diagnose nutrient availability. Deeper sampling is usually discarded due to practical reasons. In coarse textured soils, where nitrate mobility is high, nitrate content below 20 cm may represent an important part of the initial soil N availability. Crop recovery of N fertilizer added can be calculated using a ^{15}N source (Smith et al., 1989).

Our objectives were to: (i) assess nitrogen fertilization effects on seed yield, seed oil content, and plant lodging, (ii) determine N requirement per unit of yield, crop recovery of fertilizer N and whether these two parameters were affected by N and other nutrients additions.

2. Materials and methods

Two field experiments were conducted during two successive years at two nearby fields within the Rivadavia department (35° 30′ S, 62° 59′ W) in the western region of Buenos Aires province. The soil was a Typic Hapludoll with some differences in the organic matter level and time from last pluriannual pasture (alfalfa based) between sites (Table 1). Soil samples were taken at 20-cm intervals up to a depth of 60 cm one week before sowing. Nitrate extracted in 2 M KCl was determined by steam distillation (Mulvaney, 1996). Concentration of phosphorus (Bray1) and boron (hot water) in soil extracts were determined by colorimetry (Kuo, 1996; Keren, 1996). Soil organic matter and particle-size distribution were determined by the Walkley–Black procedure (Nelson and Sommers, 1996) and the pipet method (Gee and Bauder, 1986), respectively.

Table 1
Some site and soil characteristics

	Site 1 (1996/1997)	Site 2 (1997/1998)
Years from last pasture	2	5
Organic matter (0–20 cm, g kg^{-1})	32	25
Texture (0–20 cm)	Loam	Loam
Clay (0–20 cm, g kg^{-1})	235	230
Silt (0–20 cm, g kg^{-1})	400	420
Sand (0–20 cm, g kg^{-1})	365	350
pH (0–20 cm, soil:water 1:2.5)	6.0	6.2
N–NO$_3$ (kg ha^{-1})		
0–20 cm	27.6	24.5
20–40 cm	25.7	20.5
40–60 cm	22.3	19.6
0–60 cm	75.6	64.6
P (0–20 cm, μg g^{-1})	11	13
B (0–20 cm, μg g^{-1})	1.5	1.2

Sowing and harvest dates were 10 November 1996 and 16 March 1997, at Site 1, and 19 October 1997 and 3 March 1998, at Site 2. Both experiments were planted after the usual till practices in the region (chisel plow and disking). Row spacing was 70 cm, and plant density was 6 plants per m^2.

A factorial design with three levels of nitrogen availability, two levels of other nutrients, and two sunflower (*Helianthus annuus* L.) hybrids were used for both experiments. Nitrogen levels were: N0, non fertilized, N150, fertilized to adjust soil available N at sowing (soil NO_3–N + fertilizer–N) to 150 kg ha^{-1} and N300, fertilized to adjust soil available N at sowing (soil NO_3–N + fertilizer–N) to 300 kg ha^{-1}. Soil nitrogen content (as nitrates) in the 0–60 cm layer was measured one week before sowing (Table 1). The difference between 150 or 300 kg N ha^{-1} and the soil nitrogen content (as nitrates) was added to N150 and N300 treatments, respectively. Two levels of other nutrients were obtained with and without the addition of: 20 kg ha^{-1} of phosphorus, 25 kg ha^{-1} of potassium, 30 kg ha^{-1} of sulfur, 16 kg ha^{-1} of magnesium, 2.5 kg ha^{-1} of boron, 0.5 kg ha^{-1} of manganese, 0.2 kg ha^{-1} of molybdenum and 0.4 kg ha^{-1} of zinc. At sowing, Nitrogen (as urea) was broadcast while other nutrients were band applied about 5 cm below and to the side of the seed. Sunflower hybrids were 'Paraíso 4' and 'Paraíso 6', two hybrids widely used in the region. Treatments were arranged in a randomized complete block design with four replicates. Plots had an area of 21 m^2.

In the 1996–1997 season (Site 1) ^{15}N fertilizer recovery was evaluated using additional plots (6.3 m^2) close to the main experiment, and using only one hybrid (Paraíso 6). Treatments were: T1, fertilized with 75 kg ha^{-1} with ^{15}N urea at sowing; and T2, fertilized with 75 kg ha^{-1} with ^{15}N urea and other nutrients at sowing. The Nitrogen level reached by this N addition was the same as the N150 treatment. Treatments were arranged in a randomized complete block design with three replicates. Labeled urea had 0.4643% ^{15}N atom excess.

We estimate that volatilization losses of fertilizer–N were low because it rained soon after fertilizer applications at both Sites. At Site 1 it rained 40 mm two days after urea application and at Site 2 it rained 16 mm three days after urea application and 25 mm within the next week.

At maturity, aboveground biomass was harvested, separated into seed and straw, dried at 70 °C, and weighted. Nitrogen concentration of seed and straw was determined by colorimetry in Kjeldahl digests (Baethgen and Alley, 1989), the percentage of ^{15}N atom excess by emission spectrometry (IAEA, 1983), and seed oil content by Soxhlet method. The b-value was calculated as the absorbed nitrogen divided by seed yield.

The percentage of N derived from fertilizer (Ndff) was calculated as:

$$\text{Ndff} = \frac{\%\ ^{15}\text{N atom excess in the plant}}{\%\ ^{15}\text{N atom excess in the fertilizer}} \times 100$$

In the 1997–1998 season (Site 2), the percentage of lodged plants was determined at 81 days after sowing. Plants were considered lodged when the angle between the main stem and the soil surface was less than 45°.

Data collected were statistically analyzed by factorial ANOVA. When interaction between main factors (Nitrogen, other nutrients and hybrid) was not significant ($P \geq 0.05$) LSD (Student's t-test) was used to compare the means of the different N treatments.

3. Results and discussion

Both cropping seasons were relatively humid and rainfall amount and distribution during crop cycle was adequate to meet crop needs.

Nitrogen fertilization affected the seed yield only on Site 2 (Table 2). Yield increased by 17% when N was added, regardless of fertilizer rate (Fig. 1). The number of seeds per head was the yield component most affected by N fertilization, while individual seed weight did not vary (data not shown). Yield of both hybrids was not different (Table 2). Even though the initial soil mineral nitrogen (nitrates) was similar at both Sites, a larger N mineralization during the crop cycle is

Table 2
Analysis of variance of grain yield, and oil and protein content

	Grain yield		Oil content		Protein content	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Main effects						
Nitrogen	ns	**	**	**	**	**
Other nutrients	ns	ns	ns	ns	*	ns
Hybrid	ns	ns	*	**	**	**
Interactions[a]						
N × O	ns	ns	ns	ns	ns	ns
N × H	ns	ns	ns	ns	ns	ns
O × H	ns	ns	ns	ns	ns	ns
N × O × H	ns	ns	ns	ns	ns	ns

[a] N, nitrogen; O, other nutrients; H, hybrids.
*, **, Significant at the 0.05 and 0.01 probability levels, respectively; ns, non significant.

expected in Site 1 than in Site 2. Site 1 had a larger soil organic matter content and a shorter cropping cycle than Site 2 (Table 1). This difference could be related to the lack of response on Site 1. Contrary to what was reported by other authors working in the same region (Diaz-Zorita and Duarte, 1996), there was no effect of other nutrients addition. Scheiner and Lavado (1999) observed, also in this area, that fertilization with nutrients other than N increased leaf area, but not seed yield.

Nitrogen fertilization increased lodging only in one hybrid. There was no effect of N addition on Paraíso 4, while lodging of Paraíso 6 plants significantly increased with the highest N level (N300 treatment). Control and N150 plants showed a lodging of 7.4 and 7.9%, respectively, while 16.2% of the plants were lodged at the N300 treatment. Addition of other nutrients had no effect on lodging.

Seed oil content decreased when N was added, regardless of fertilizer rates (Tables 2 and 3). These reductions of oil content were relatively small (5 and 2% at Site 1 and 2, respectively). Lower oil content was related to higher protein content of seed, which agrees with previous reports for sunflower (Merrién and Milan, 1992; Sosa et al., 1999). Steer and Seiler (1990) observed that N fertilization increased the amount of oil produced per hectare even though seed oil content was lowered, which agrees with our results at the responsive site. There was no effect of the addition of other nutrients on seed oil content. Conversely, Blamey and Chapman (1981) reported that contrary to nitrogen, phosphorus addition tended to increased seed oil content. Their results were obtained on soils with P availability levels much lower than ours.

Table 4 shows the nitrogen absorption per unit of seed yield (*b*-value). Nitrogen fertilization (regardless of N rate) increased the *b*-value only at Site 1, where there was not yield response. Addition of other nutrients including P and K had a

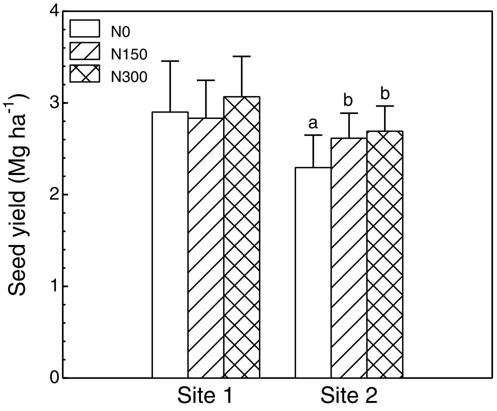

Fig. 1. Effects of Nitrogen fertilization on sunflower seed yield. Different letters denote significant differences between N treatments within a site (LSD, $P < 0.05$).

Table 3
Effects of Nitrogen and other nutrients addition, and hybrid used on grain oil and protein contents

	Oil content (mg g^{-1})		Protein content (mg g^{-1})	
	Site 1	Site 2	Site 1	Site 2
Nitrogen levels				
N0	465 ± 19.3 a	484 ± 7.9 a	202 ± 14.2 a	194 ± 7.8 a
N150	443 ± 14.0 b	476 ± 6.5 b	227 ± 13.5 b	200 ± 6.9 b
N300	438 ± 14.7 b	474 ± 11.7 b	236 ± 12.3 c	202 ± 10.9 b
Other nutrients				
Added	447 ± 20.6	477 ± 8.4	224 ± 20.8 a	199 ± 8.1
Not added	451 ± 19.2	478 ± 11.3	219 ± 18.0 b	198 ± 10.3
Hybrid				
Paraíso 4	455 ± 22.4 a	483 ± 7.2 a	215 ± 20.0 a	192 ± 5.9 a
Paraíso 6	443 ± 15.2 b	473 ± 9.9 b	228 ± 17.0 b	205 ± 7.6 b

Mean ± S.D. for each main factor level. Different letters denote significant differences (LSD, $P < 0.05$).

small effect on *b*-value, raising it by 1.2%. This result suggests that other nutrients had no relevant effects on Nitrogen use efficiency. This is consistent with the lack of yield response to the addition of other nutrients, as no effect on N use efficiency is expected if none of the other nutrients is deficient. The two hybrids presented a different *b*-value. Paraíso 6 had a slightly higher *b*-value (+2.5%) than Paraíso 4. The values of nitrogen absorbed per unit of yield (*b*-value) observed in this study were within the range of values previously reported for sunflower by other authors (Andrade, 1995; Blamey et al., 1997).

The rise in *b*-value was related to the increase of seed protein content. Nitrogen fertilization increased seed protein content at both sites, but this increase was larger at Site 1 (+14.5%) than at Site 2 (+3.7%) (Tables 2 and 3). These results suggest that N addition increases grain protein and the *b*-value only where there was no yield response. In an experiment in the southeastern Pampas, *b*-value increased from 29.2 to 40.3 kg Mg^{-1} due to the addition of 100 kg ha^{-1} of N, while seed yield did not vary (average seed yield, 2.98 Mg ha^{-1}) (Ruffo et al., 1998).

At the ^{15}N recovery experiment, the % ^{15}N atom excess in plant tissue averaged 0.23 with no differences between treatments. Fertilizer ^{15}N recovery was 51% regardless of other nutrients addition (Table 5). Similar N fertilizer recoveries have been reported for other crops in temperate humid regions (Strong, 1995). In general, low recovery values (< 20%) were associated to extreme situations of water availability, like drought or excessive rainfall or irrigation (Strong, 1995). As mentioned, the rainfall during the experiment at Site 1 was adequate to meet crop requirement.

The pre-sowing soil NO_3–N showed a relatively homogenous vertical distribution within the first 60 cm (Table 1). Soil NO_3–N at the 0–20 cm layer represented a 36% of the NO_3–N at the 0–60 cm layer. Alvarez et al. (2001) observed a different vertical distribution of soil NO_3 working with a dataset of 77 soils from the Pampean region that included several soils from the same area that our experimental sites. NO_3–N content steadily decreased with depth and NO_3–N content at the 0–20 cm layer represented about 54% of the NO_3–N at the 0–60 cm layer. They proposed a simple linear model to estimate the NO_3–N at the 0–60 cm layer using the NO_3–N content at the 0–20 cm layer, simplifying sampling and lab work. In our case, the use of this model would have led to an underestimation of soil NO_3–N of about 31%. Our results stress the relevance of measuring NO_3–N up to 60 cm deep whenever it is possible.

4. Conclusions

Crop nitrogen requirement per unit seed yield (*b*-value) increased due to nitrogen fertilization only at the site where there was not a positive yield response. These results suggest that it is not necessary to use different *b*-values for non-fertilized crops than for fertilized ones if a yield response is expected. Decreasing of grain oil content due to N addition was relatively small, and was overcompensated by the seed yield increase at the responsive site. Addition of nutrients other than N, including P and K, did not affect the *b*-value or fertilizer N recovery. Recovery of fertilizer N was of 51%, and this uptake efficiency should be taken into account when a fertilizer recommendation is done based on crop requirements. It is justified to measured soil NO_3–N up to 60 cm deep, as most NO_3–N was below 20 cm and it is not possible to accurately estimate it from the 0–20 cm content. Susceptibility to lodging due to N addition depended on the hybrid.

Table 4
Effects of Nitrogen and other nutrients addition, and hybrid used on Nitrogen absorption per unit of yield (*b*-value)

	b-value (kg N Mg^{-1} seed)
Nitrogen levels	
Site 1	
N0	37.4 ± 2.54 a
N150	42.6 ± 2.61 b
N300	43.2 ± 2.25 b
Site 2	
N0	37.4 ± 0.94 a
N150	38.3 ± 0.70 a
N300	38.0 ± 1.05 a
Other nutrients	
Added	39.4 ± 3.17
Not added	38.9 ± 2.51
Hybrid	
Paraíso 4	38.7 ± 2.92
Paraíso 6	39.7 ± 2.76
ANOVA	
Main effects	
Site	**
Nitrogen	**
Other nutrients	**
Hybrid	**
Interactions	
Site × nitrogen	**

**, Significant effect at the 0.01 probability level. All other interaction terms were not significant ($P > 0.05$). Mean ± S.D. Different letters denote significant differences (LSD, $P < 0.05$).

Table 5
^{15}N atom excess in plant material and ^{15}N fertilizer recovery

	^{15}N a. excess (%)	Fertilizer recovery (%)
Treatments		
N150	0.246 ± 0.0319	53.1 ± 6.86
N150 + other nutrients	0.227 ± 0.0343	49.0 ± 7.39
Mean	0.237 ± 0.0314	51.0 ± 6.75
ANOVA		
Treatment effect	ns	ns

Mean ± S.D.; ns, non significant.

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