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University of Buenos Aires, Faculty of Agriculture, Buenos Aires, Argentina

Effect of Phosphorus and Nitrogen Fertilization on Sunflower (*Helianthus annus* L.) Nitrogen Uptake and Yield

M. M. Zubillaga, J. P. Aristi and R. S. Lavado

Authors' address: Drs M. M. Zubillaga (corresponding author; e-mail: mzubilla@agro.uba.ar), J. P. Aristi and R. S. Lavado, Cátedra de Fertilidad y Fertilizantes, Facultad de Agronomía, Universidad de Buenos Aires, Avenida San Martín 4453 (C1417DSQ), Buenos Aires, Argentina

With 3 figures and 7 tables

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Abstract

Little is known about the effect of combined phosphorus and nitrogen (P-N) fertilization on the N requirement of sunflower (*Helianthus annus* L.). This study was carried out to evaluate the effects of varying levels of P and N, as well as the interaction P $\times$N, on the N uptake, yield and N apparent utilization efficiency under field conditions. Split-plot design experiments were conducted in the mid-western Pampas in Argentina. Four levels of N (0, 46, 92 and 138 kg N ha^{-1}) and three levels of P (0, 12 and 40 kg P ha^{-1}) were applied to two Typic Hapludolls over two growing seasons (1997–98 and 1998–99). N uptake and soil N-NO_3 contents were determined at the V_7, R_5 and R_9 growth stages. The sunflower yield ranged from 2.5 to 5.0 Mg ha^{-1}. The total N requirement was around 45 kg N Mg^{-1} grain, and this result suggests that it is not necessary to use different N requirements (parameter b) for fertilized crops when a yield response is expected. To achieve a 100 % yield maximum a N supply (soil plus fertilizer) of 181 kg N ha^{-1} at P_{40} was needed. However, at P_0, the highest yield was about 80 % of the maximum yield with a N supply (soil plus fertilizer) of 164 kg N ha^{-1}. P application increased the apparent use efficiency of the supplied N.

Key words: grain yield — N uptake — P-N fertilization — soil nitrates — sunflower

Introduction

Fertilization needs to be used rationally in order to avoid a negative ecological impact and undesirable effects on the sustainability of agricultural production systems. Excessive application of fertilizers also affects the farmer's economy. In order to calculate the amount of fertilizer to be applied to crops, it is necessary to develop recommendation programmes that adjust fertilizer rates to crop requirements. The nutrient demand for achieving a given yield is a variable need to be taken into account. Sunflower (*Helianthus annuus* L.) is a warm-season crop with an intermediate water requirement that can add diversity to dry land crop rotations. Sunflower is characterized by high plasticity under different nutrient availabilities (Connors and Hall 1997, Sadras and Trapani 1999).

Because nitrogen (N) application increases crop growth and yields, this nutrient is one of the most frequently studied. In some regions, phosphorus (P) deficiencies can also limit the accumulation of crop biomass. This is attributable to (i) a reduction in the partitioning of assimilates to the formation of leaf area, or (ii) a decrease of the efficiency with which the intercepted radiation is used for the production of above-ground biomass (Colomb et al. 1995). Rodriguez et al. (1998) observed that under P deficiencies sunflower showed a reduction in the rate of leaf expansion and in photosynthetic rate per unit of leaf area.

Argentina is the main sunflower producer in the Americas, and one of its main sunflower production zones is the western part of the Pampas. The predominant soils in that region are coarse textured (Typic and Entic Hapludolls). For years, agricultural activity took place in the Argentinian Pampas without nutrient replacement. This unsustainable production system produced significant decreases in soil P contents as well as in organic matter (Michelena et al. 1989) and the N availability (Urricariet and Lavado 1999). Soil nutrient depletion was more evident after the introduction of genetic material of high production potential. This material increased yields significantly, and so crop nutritional requirements also rose. Several fertilization experiments carried out in this zone have

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determined responses to N fertilization in sunflowers (Diaz-Zorita and Grosso 2000, Zubillaga et al. 2000). There is general agreement on the nature of the responses of sunflower to variations in N supply, but little emphasis has been placed on documenting the relationship between N requirement and P supply. The crop N requirement per unit of yield may vary depending on combined phosphorus and nitrogen (P-N) fertilization, if the P addition affects grain N concentration or N partitioning between grain and straw (Loubser and Human 1993, Makowski et al. 1999).

This study was carried out to evaluate the effects of varying levels of P and N, as well as the interaction P × N, on N uptake, yield and apparent N use efficiency under western Pampas field conditions.

Materials and Methods

Field experiments were conducted during the 1997–98 and 1998–99 growing seasons in the Casares-Bragado area in the mid-western Pampas, Argentina (35°27′–35°40′S, 60°53′–61°30′W; 76 m above sea level, 960 mm mean annual rainfall; 16 °C mean annual temperature), on two Typic Hapludolls. Some characteristics of the soil surface horizons at the beginning of the experiments are shown in Table 1. Analytical determinations were carried out for pH (1 : 2.5 soil : water ratio), total N (Kjeldahl) and extractable P (Bray and Kurtz 1) (Sparks 1996).

Seeds of a single-cross sunflower hybrid, Paraíso 6 from Nidera, Argentina, S.A., were sown on 23 and 7 October in 1997 and 1998, respectively. The distance between crop rows was 0.7 m and the final plant population was 51 000 plants ha^{-1} for the first experiment (1997–98) and 49 000 plants ha^{-1} for the second experiment (1998–99). Plots were 10 m long and 7 rows wide at both sites. The crops were kept free of weeds and insects. Treatments were arranged in a split-plot design with P fertilization treatments as the main plot and N fertilization treatments as the subplot. The main plots were arranged in a randomized complete block design with three replications. In the first experiment, in which we explored the effects of a high N fertilization rate, the main plots were two levels of soil P fertilization: 12 (P_{12}) and 40 (P_{40}) kg P ha^{-1}. Subplots were three N rates: 46, 92 and 138 kg N ha^{-1} (N_{46}, N_{92} and N_{138}, respectively). In the second experiment, we also explored the effects of no P addition, so the main plots were 0, 12 and 40 kg P ha^{-1} (P_0, P_{12} and P_{40}) and the three subplots were N rates of 0, 46 and 92 kg N ha^{-1} (N_0, N_{46} and N_{92}). P (triple superphosphate, 0-46-0) was banded 5 cm below the seeds. N (urea, 46-0-0) was applied as surface broadcast and incorporated at 20 and 10 days after planting (DAP) for both years.

Table 1: Soil characteristics at planting of sunflower

Year	Layer (cm)	NO_3-N (mg kg^{-1})	P (mg kg^{-1})	pH	Total N (g kg^{-1})
1997	0–20	60	13	6.2	0.178
	20–40	40			
	40–60	15			
1998	0–20	44	9	6.0	0.121
	20–40	48			
	40–60	26			

Soil sampling was monitored at planting and at the V_7, R_5 and R_9 stages (Schneiter and Miller 1981) by randomly collecting five 2-cm-diameter cores between rows per experimental unit from depths of 0–20, 20–40 and 40–60 cm. Cores of each depth were combined for analysis. Inorganic N content was extracted from wet samples with KCl and NO_3-N content was determined by microdistillation (Keeney and Nelson 1982).

Total above-ground plant dry weight and its partitioning into grain and straw were determined at physiological maturity, by harvesting 10 plants of sunflower per experimental unit. In 1997–98, sampling was performed at 43 DAP (V_7), 85 DAP (R_5) and 126 DAP (R_9). In 1998–99 samples were taken at 82 and 147 DAP (R_5 and R_9, respectively). Plants were cut at ground level, oven-dried, weighed and milled (1 mm mesh) and N concentration was determined (Nelson and Sommers 1973). Total N accumulated in each fraction was calculated as the product of its N concentration (dry weight basis) and dry weight. Two hundred and fifty grains were randomly selected to quantify grain biomass and grain number per plant. These samples were also used to determine the oil content of the grain by means of nuclear magnetic resonance analysis (Robertson and Morrison 1979). Measurements of grain yield were corrected by oil content, using the conversion method where each gram of oil is multiplied by 2.407 to calculate its mass in terms equivalent to other plant biomass components.

The relationship between grain relative yield (RY) and N supply (soil + fertilizer) was adjusted using an optimization model (Eqns 1a and 1b) that fitted the experimental data iteratively by means of curve-fitting software (GENSTAT 3.1, Genstat 5 Committee 1987):

$$RY = a + b_x x \quad \text{if } x < x_{\max}; \tag{1a}$$

$$RY = a + b_x x_{\max} \quad \text{if } x > x_{\max}, \tag{1b}$$

where RY is the relative yield (%), a the y-axis intercept, x the N supply (soil + fertilizer), with the N supply from soil being the N-NO_3 content from 0 to 60 cm at planting, and $x_{\max}$ the N supply (soil + fertilizer) at maximum relative yield. In both experiments, the yield obtained from each treatment was divided by the average yield of the treatment with the highest yield for each year, to determine the relative yield (RY).

The statistical analysis for yield and its components, N uptake, N requirement and soil N was performed using ANOVA with the mixed model procedures of the Statistical Analysis System (SAS Institute 1997). Means separation was evaluated using a Tukey test. The effect of growing season was evaluated for grain yield when the treatments were repeated in both years (P_0N_0, $P_{12}N_{46}$, $P_{12}N_{92}$, $P_{40}N_{46}$ and $P_{40}N_{92}$). In this case, the grain yield was analysed using the mixed model procedures, with growing season the random factor and fertilization treatment (N-P) the fixed factor (SAS Institute 1997).

Results and Discussion

Rainfall during the growing season, October to February, was 188 mm greater than the long-term average of 590 mm for the area in 1997–98 but 114 mm less than the long-term average in 1998–99 (Table 2). In general, in the first experiment there were more days with low radiation and low temperature. The most critical periods for sunflower yield determination are anthesis and grain filling (Chimenti and Hall 1992). Shading during grain filling can reduce grain yield per plant by 40 % (Andrade 1995). So, sunflower grain yields in 1998–99 for P_0N_0, $P_{12}N_{46}$, $P_{12}N_{92}$, $P_{40}N_{46}$ and $P_{40}N_{92}$ were significantly higher than in 1997–98 as a result of better growing conditions (Table 3). In 1997–98, the P × N interaction ($P = 0.017$) indicated a greater response to N fertilization for the P_{40} application. Thus, it was found that sunflower responded only to the highest N dose of 138 kg N ha^{-1} when the P dose was also high (40 kg P ha^{-1}) (Fig. 1). Similar results were reported by Blamey and Chapman (1981). In 1998–99, there was no P × N interaction but there was a response to N application ($P = 0.001$) and P application ($P = 0.0009$). This difference could be attributed to lower availability of P at sowing in the second growing season.

Table 3: Effect of growing season on grain yield

	Least mean squares estimate		
Treatment	1997–98	1998–99	P > |t|
P_0N_0	2443.30	2570.48	< 0.0001
$P_{12}N_{46}$	3191.94	4577.86	< 0.0001
$P_{12}N_{92}$	3253.75	4786.40	< 0.0001
$P_{40}N_{46}$	3127.56	3923.57	< 0.0001
$P_{40}N_{92}$	3447.91	5236.67	< 0.0001

The harvest index (DM_{grain}/DM_{total}) was on average 0.31 for both growing seasons. There were no effects of P-N fertilization on the biomass partitioning to grains at both sites. Bange et al. 1997) found that the harvest index was similar among different genotypes, N levels and radiation treatments, but this index increased at very low temperatures during grain filling, possibly as a result of limitations in biomass accumulation and translocation. At anthesis the crops accumulated an important proportion of the total dry matter, around 90 and 70 % for 1997–98 and 1998–99, respectively. The occurrence of *Sclerotinia sclerotiorum* favoured by high levels of N could have

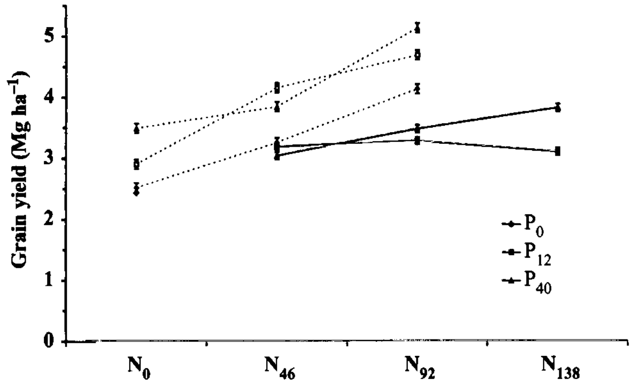

Fig. 1: Grain yield expressed as dry matter for the different P-N fertilization levels applied during the (a) 1997/98 (dashed lines) and (b) 1998/99 (continuous lines) growing seasons. Bars are standard errors for the difference of the means

Table 2: Monthly mean maximum and minimum temperatures and accumulated rainfall during the 2 years of the experiments

	1997–98			1998–99		
	Temperature (°C)			Temperature (°C)		
Month	Maximum	Minimum	Rainfall (mm)	Maximum	Minimum	Rainfall (mm)
October	22.0	11.3	139	24.0	11.1	138
November	23.7	12.5	140	25.9	12.2	88
December	25.8	14.2	243	28.6	14.1	93
January	27.7	15.1	110	28.8	14.6	71
February	24.9	13.7	155	28.6	15.9	84
Total			778			475

affected the accumulation of dry matter in 1997–98, a year with heavy rains.

Higher grain yields for high N treatments were associated with an increase in grain number. The number of grains per head was the main yield component determining the effects of fertilization (Table 4). This finding agrees with previous reports for sunflower (Blamey and Chapman 1981, Hocking and Steer 1989). Grain number is established around anthesis and is partially a response to the supply of assimilates (Andrade 1995). Yield was reduced in shaded treatments as a result of smaller grain size (Bange et al. 1997). In general, grain size in 1997–98 was smaller than in 1998–99, which could be attributed to more cloudy days during the grain-filling period in the first year.

Blamey and Chapman (1981) found that N fertilization tended to decrease the oil concentration in the seed, while P had the opposite effect. In this study, P fertilization did not affect the oil content in either year, but the rate of N application significantly affected oil concentrations only in 1997/98 (Table 4). In this growing season, the highest oil concentration was found in the N_{46} treatment. However, in 1998/99 N application did not affect the oil concentration. This may have been a result of better yield responses to N fertilization. There were significant negative correlations between the protein and oil concentrations in the seed in each season, as reported by other authors (Blanchet and Merrien 1982). Increases in the rates of N and P application significantly increased the oil yield (kg ha^{-1}). There was no P x N interaction but oil production responded to P application in both years. N application augmented the oil yield in 1998/99. In 1997/98, although oil concentration decreased, the oil yield was not affected. High levels of N availability, particularly after anthesis or during grain filling, may reduce seed oil concentration, although absolute amounts of oil per plant can increase (Steer and Hocking 1983).

As a result of the effect of P-N fertilization on oil concentration, grain yield for each treatment was affected by the oil content. At both sites, there were highly significant adjusted yield responses (glucose equivalents) to N and P application. The response to P-N fertilization of adjusted grain yield was similar to that of grain yield (Table 4).

Recent local studies have shown a good correlation between sunflower grain yield and surface soil NO_3-N content for crops at the V_6–V_8 stage (Diaz-Zorita and Grosso 2000, Gonzalez Montaner and Di Napoli 2000). Table 5 shows NO_3-N contents in both soils at the V_7, R_5 and R_9 stages. In 1997–98, the highest soil NO_3-N levels were found at the V_7 stage. Soil NO_3-N increased as N fertilizer rates rose. However, soil NO_3-N content was not

Table 4: Effect of P and N fertilization on grain number, thousand-grain weight and oil content for the 1997–98 and 1998–99 growing seasons

Treatment effects	Grain number (grains m^{-2})		Grain weight [g (1000 grains)$^{-1}$]		Oil (%)		Oil yield (kg ha^{-1})		Adjusted yield (kg glucose ha^{-1})	
	1997–98	1998–99	1997–98	1998–99	1997–98	1998–99	1997–98	1998–99	1997–98	1998–99
Nitrogen										
N_0	–	6452b	–	46.06c	53.70	–	1634c	–	5309c	
N_{46}	5515	7275a	39.06	53.56b	50.38a	53.10	1616	2120b	5234	6883b
N_{92}	5742	7958a	39.24	58.51a	48.76b	53.46	1656	2537a	5354	8241a
N_{138}	5984	–	39.79	–	49.34ab	–	1710	–	5531	–
Standard error	255	–	0.74	–	0.41	0.28	42	–	136	–
Phosphorus										
P_0		–	6590	–	50.52	53.01	–	1815b	–	5896b
P_{12}	5520b	7316	39.33	53.70	49.53	53.24	1602b	2164a	5181a	7029a
P_{40}	5974a	7780	39.40	53.90	49.46	54.00	1720a	2310a	5566b	7508a
Standard error		210	0.60	1.17	0.34	0.28	–	–	–	–
Probabilities										
P	0.037	0.004	ns	ns	ns	ns	0.036	0.001	0.034	0.001
N	ns	0.001	ns	0.000	0.042	ns	ns	0.001	ns	0.001
P ×N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

The means of P and N levels followed by different letters differ significantly at $P < 0.05$.

modified by P fertilization. Even during anthesis, there were significant differences in soil NO_3-N between N treatments. The greater soil NO_3-N content at the V_7 stage would allow the crop to continue N accumulation during the grain-filling period. In general, in 1997–98 the soil presented lower NO_3-N than in 1998–99 for similar N doses applied. This difference could be attributed to some leaching resulting from rainfall previous to anthesis (80 mm in 3 days before soil sampling) and lower temperatures, which affect N mineralization.

The increase in residual mineral N begins with the smallest N dose that maximizes yield (Makowski et al. 1999). At R_9, NO_3-N contents were 50 % higher for the 138 kg N ha^{-1} dose than for the other treatments.

The effect of P-N fertilization on N uptake over time is presented in Table 6. N uptake was lowest where no N fertilizer was applied, while the combination of high N and P levels gave the highest N uptake. There was significant P × N interaction only at the V_7 stage. This interaction ($P = 0.025$) indicated that, at low N doses, N uptake was higher for P_{40}. Fertilizer application did not affect total biomass accumulation but the leaf area (data not shown) was modified. Higher leaf area means higher crop cover, which reduces the competition of weeds for water, light and nutrients (Steer and Hocking 1983, Hocking and Steer 1989, Bange et al. 1997). Also, the level of leaf N affects leaf photosynthesis in sunflower (Connor et al. 1993). However, at V_7 the N concentration was not affected by P or N fertilization, being on average around 32.4 g kg^{-1}.

N uptake showed significant differences at anthesis according to the level of applied N at both sites. P application allowed accumulation of N after anthesis mainly in 1998–99. Root systems remain capable of N uptake during grain filling (Goswami and Srivastava 1988). N could be utilized by the crop at a late stage, even when the fertilizer was applied late in the season (Mathers and Stewart 1982, Loubser and Human 1993).

Nutrient utilization efficiency is the ratio of grain yield to actual N uptake from above-ground plant parts (Fig. 2). The parameter b, which represents N uptake per unit of yield, is used in the balance sheet method. Total N required per unit of grain yield was around 45 kg N Mg^{-1} grain. Similar values were found in the literature (Blamey and Chapman 1981, Andrade 1995). Crop N requirement increased when N was applied ($P < 0.05$), but there were no effects of P on this parameter (Table 7). When N was not applied, the requirement was around 36.7 kg N Mg^{-1} grain. These results suggest that it is not necessary to use

Table 5: Effect of P and N fertilization on soil NO_3-N content at V_7, R_5 and R_9 for the 1997–98 and 1998–99 growing seasons

	Soil NO_3-N content (kg N ha^{-1})				
	1997–98			1998–99	
Treatment factor	V_7	R_5	R_9	R_5	R_9
Phosphorus					
P_0	–	–	–	36.56	23.93
P_{12}	62.33	17.85	28.67a	35.12	27.11
P_{40}	71.81	20.77	18.76b	35.69	26.48
Standard error	5.22	2.81	–	1.95	3.50
Nitrogen					
N_0	–	–	–	29.50c	25.03
N_{46}	42.96b	11.87b	19.00b	35.79b	26.10
N_{92}	70.07ab	17.35b	20.22b	42.07a	26.39
N_{138}	88.19a	28.72a	31.95a	–	–
Standard error	–	–	–	–	1.24
Probabilities					
P	ns	ns	0.004	ns	ns
N	0.017	0.004	0.004	0.001	ns
P × N	ns	ns	ns	ns	ns

The means of P and N levels followed by different letters differ significantly at $P < 0.05$.

Table 6: Effect of P and N fertilization on N uptake for V_7, R_5, and R_9 in the 1997–98 and 1998–99 growing seasons

Treatment		N uptake (kg N ha^{-1})				
		1997–98			1998–99	
P	N	V_7	R_5	R_9	R_5	R_9
0	0	20.49	84.36	87.29	82.90	98.20
0	46	–	–	–	120.23	161.25
0	92	–	–	–	166.37	188.60
12	0	–	–	–	71.51	107.82
12	46	28.03	115.03	125.31	151.67	192.97
12	92	30.45	138.36	172.05	111.25	227.71
12	138	36.15	146.46	155.67	–	–
40	0	–	–	–	94.31	130.26
40	46	35.44	131.21	135.38	119.00	170.75
40	92	33.57	127.44	154.70	175.59	253.04
40	138	30.39	152.51	184.76	–	–
Standard error		2.84	9.20	8.07	16.49	11.92
Probabilities						
P			ns		ns	0.046
N			0.043		0.001	0.001
P × N		0.042	ns	0.036	ns	ns

different N requirements (parameter b) for fertilized crops when a yield response is expected.

Since yields were associated with annual weather variation, data for each cropping year were expressed relative to the maximum yield of each year, i.e. all yields were expressed as a percentage of that for the N treatment with the highest yield in a given year. The relative yield for sunflower as a function of N supply (soil plus fertilizer) at P_0 and P_{40} is shown in Fig. 3. Thus, an N supply (soil plus fertilizer) of 181 kg N ha^{-1} at P_{40} was needed to achieve a 100 % yield maximum for sunflower under the conditions of this study. However, at P_0 the highest yield was about 80 % of the maximum yield with an N supply (soil plus fertilizer) of 164 kg N ha^{-1}. The P application increased the supplied N use efficiency. A similar P × N interaction was found for rice yield by De Wit (1992). In that case, the positive effect of P was attributable to its effect on the uptake of N, so that fertilization with P could be considered disguised fertilization with N. This may be explained by the favourable

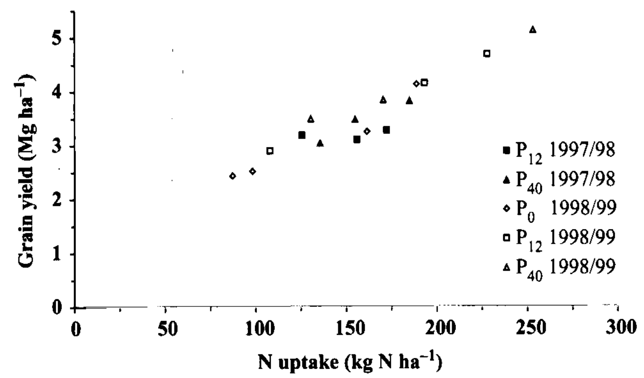

Fig. 2: Grain yield as a function of N uptake in both growing seasons

Table 7: Effect of P and N fertilization on N requirement (coefficient b) in the 1997–98 and 1998–99 growing seasons

Treatment effects	N requirement (kg N Mg^{-1} grain) 1997–98	1998–99
Phosphorus		
P_0	–	44.62
P_{12}	47.52	43.93
P_{40}	45.71	43.6
Standard error	1.45	1.21
Nitrogen		
N_0	–	37.82a
N_{46}	41.21a	46.75b
N_{92}	49.02b	47.71b
N_{138}	49.64b	–
Probabilities		
P	ns	ns
N	0.027	0.001
P × N	ns	ns

The requirement for P_0N_0 in 1997–98 was 35.6 kg N Mg^{-1} grain. The means of P and N levels followed by different letters differ significantly at $P < 0.05$.

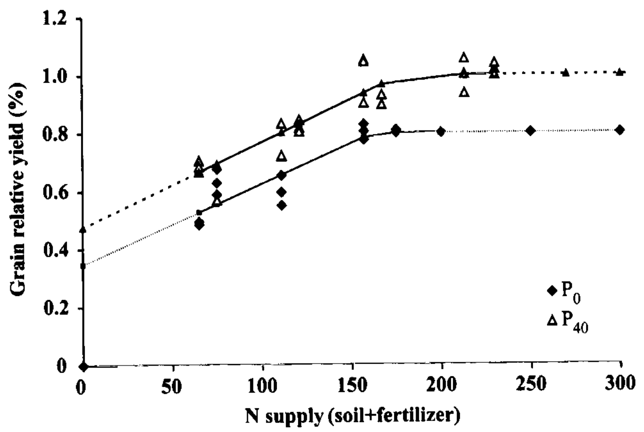

Fig. 3: Observed (symbols) and fitted (lines) values of relative grain yield (RY) as a function of N supplied from soil NO_3-N content at planting plus N fertilizer [N supply (soil + fertilizer)]

effect of P on root development in the early stages of growth when the N supply is still at a reasonable level (De Wit 1992). P application also increased the photosynthetic rate and the radiation use efficiency in sunflower (Colomb et al. 1995, Rodriguez et al. 1998). Thus, P fertilization increases the N supply (soil + fertilizer) use efficiency in sunflower.

In conclusion, under the conditions of this study, the crop N requirement was around 20 % higher when fertilization include P. N application increased soil mineral N at anthesis and allowed accumulation of plant N during grain filling mainly when P was applied. Therefore, P application produced greater and more consistent effects on crop performance as P fertilization allowed more efficient use of supplied N. This finding will be of interest from both the economical and ecological points of view.

Zusammenfassung

Der Einfluß von N-und-P-Düngung auf N-Aufnahme bei der Sonnenblume

Über die Wirkung einer P-N-Düngung auf den N-Bedarf der Sonnenblume ist nur wenig bekannt. Die vorliegende Studie dient daher dem Zweck, die Wirkung unterschiedliche N- und P-Gaben sowie deren Interaktion auf die N-Aufnahme, den Ertrag und die N-Nutzungseffizienz unter Feldbedingungen aufzuzeigen. Verwendet wurde eine Split-Plot-Anlage im mittleren Westen der Pampas (Argentinien). Vier verschiedene N-Düngungsstufen (0, 46, 92 und 138 kg N ha^{-1}) und drei P-Stufen (0, 12 und 40 kg P ha^{-1}) wurden in zwei Jahren (1997/98 und 1998/99) auf zwei Bodentypen (Typic Hapludolls) verglichen. Die N-Aufnahme sowie der Nitratsickstoff des Bodens wurden zu den Entwicklungsstadien V_7, R_5 und R_9 ermittelt. Die Sonnenblumenerträge lagen im Bereich von 2,5 bi 5,0 t ha^{-1}. Die Pflanzenart reagierte auf die höchste N-und P-Stufe und zeigte eine P × N-Interaktion (P = 0017). Der Gesamtstickstoffbedarf betrug etwa 45 kg N t^{-1} Körner. Eine Verwendung unterschiedlicher N-Bedarfswerte (Parameter b) ist nicht erforderlich, wenn eine Ertragsreaktion erwartet wird. Um einen maximalen Ertrag zu erzielen, ist eine N-Versorgung (Bodenmineralisierung und Düngung) von 181 kg N ha^{-1} bei P_{40} erforderlich. Bei P_0 betrug der Ertrag jedoch höchstens 80 % des Maximalertrages bei einer N-Versorgung (Boden und Düngung) von 164 kg N ha^{-1}. Eine P-Versorgung gestattete die Steigerung der Nutzungseffizienz der N-Gabe.

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