Relationship between nitrogen fertilization on crop rotation "Sunflower - Durum Wheat" and nitrogen cycle in Southern Italy

Ferri Donato, De Giorgio Donato, Rinaldi Michele [1]
Istituto Sperimentale Agronomico, v. C. Ulpiani, 5 - 70125 Bari (Italy)

Abstract

In order to obtain a better knowledge of the mechanisms which regulate the nutrients availability for the plants a 6-yr field study on "sunflower - durum wheat" rotation submitted to 4 N doses (0, 60, 120, 180 kg N ha^{-1}) cropped in a typic Southern Italy environment was carried out.

Durum wheat grain yield is poorly correlated with N fertilizer doses while the achenes yield of sunflower vs. N rates are fitted by a curvilinear relationship. The crop differences can be interpreted evaluating the ratio between N fertilization and N cycle and water supply.

To determine how nitrogen can be best utilized for each crop and the cropping sequence are evaluated: N uptake by the whole plant, residual soil N mineral at the autumn, soil N mineralized during the cropping cycle, and soil N mineral after the harvesting. Nitrogen balance was determined considering as inputs: N from fertilizer, soil residual N (autumn) and N mineralized; as output N uptake from whole biomass.

During the trial period soil N residual (from durum wheat) and N mineralized during the sunflower cycle were lower than corresponding durum wheat N cycle parameters. Also by "N-balance" approach differences between durum wheat and sunflower were significant: for the 1st crop N-balance is near to the parity supplying 120 - 180 kg N ha^{-1}, for the 2nd one (sunflower) N-balance equals zero at 85 - 114 kg N ha^{-1} of fertilizer added. These differences could be determined from the greater root development of sunflower which take up soil available N also from deeper soil layers.

Key words: *Helianthus annuus* L., nitrogen fertilization, rotation, *Triticum durum* Desf., N cycle parameters.

Introduction

The study of agrotechnical factors which influence the amount of N fertilizer required in sunflower production includes the determination of water balance because low and erratic rainfall is the most outstanding characteristic of arid and semi-arid regions. On the other hand to determine experimental conditions (i.e.: irrigation scheduling and N fertilizer doses) for an optimal sunflower management must be expand the knowledge on the N cycle that in natural ecosystem is governed by the balance between supply from mineralization of organic nitrogen, rain-borne N and fixation (both symbiotic and not-symbiotic) and losses through immobilization, leaching , volatilization and plants uptake.

Excessive application of N-containing fertilizers may result in high concentrations of soil nitrate which can be reduced with cropping systems that best utilize N. The management practices and crop rotations affect the reserve of mineralizable soil N, i.e.: fertilizer N retained in stalks, leaves and roots, augments soil organic N and provides a residual N source

[1] The three authors equally contributed in the preparation of the paper: Ferri for agrochemical, De Giorgio and Rinaldi for agronomical aspects respectively.

for subsequent crops (El-Haris *et al.*, 1983). In recent years the sunflower was used in some cropping systems in Southern Italy to interrupt durum wheat continuous cropping and different researches were carried out (Monotti, 1980; Pirani, 1981; De Giorgio *et al.*, 1988; Abbate *et al.*, 1992; Cosentino *et al.*, 1992; Rinaldi *et al.*, 1992; Di Bari *et al.*, 1993; Monica *et al.*, 1993; Campiglia and Caporali , 1994), but it is essential the understanding of factors limiting nitrogen utilization efficiency and nutrients dynamic in different experimental areas.

With this aim, an investigation on the effectiveness of "sunflower-durum wheat" cropping system in utilizing N was carried out to reduce potential pollution hazards and to improve crop performances (yield and quality of products) .

Materials and methods

The trial was carried out from 1983 to 1988 in Foggia (Southern Italy) on a "sunflower - durum wheat" rotation cropped on a Vertisol with 4 N rates (0, 60, 120, 180 kg N ha^{-1}). The soil is of alluvial origin (Typic Chromoxerert, fine, termic, by Soil Taxonomy USDA), silty-clay (o. m. = 2,1 %; total N = 0,122 %; $NaHCO_3$-extractable P = 41 ppm; NH_4OAc-extractable K_2O = 1598 ppm; pH (water) = 8,3).

The climate is "accentuated thermomediterranean" (FAO-Unesco classification) with temperatures which may fall below 0 °C in winter and rise 40 °C in summer. The rainfall is unevenly distributed throughout the year (570 mm), being mostly concentrated in winter months.

The field experiment has been laid out on completely randomized blocks, with three replications (elementary plot = 48 m^2). The first crop sowed in 1983 was sunflower (SF) and the last durum wheat (DW) in 1988, for three SF-DW 2-year cropping cycles. N supplying to sunflower was differentiated: 60 kg N ha^{-1} dose at sowing, 120, 180 kg N ha^{-1} in three times (sowing, 4th and 15th true leaf). On durum wheat N fertilization was splitted in two times: at the end of tillering and at elongation of stems.

At harvest achenes/grain yield and crop residues production were recorded. Total aboveground dry matter (DM), gross energy (GE) and yield index (YI) (assuming = 100 the overall mean of each crop) were calculated.

N uptake by the whole plants (N pl), residual soil mineral N in autumn (N res), soil N mineralized during the cropping cycle (N minz), and soil mineral N after harvest (N end) were evaluated for each crop and cropping sequence. N balance was determined considering as inputs: N from fertilizer, soil residual N (autumn) and mineralized N; as output: N uptake, considering negligeables other N losses in the trial environment.

Data analysis of grain/achenes yield and crop residues production was performed using the 3 year period ('83, '85 and '87 for SF and '84, '86 and '88 for DW) for each crop and then for DM, GE, YI and N cycle parameters globally the 6-year period. In the first case the orthogonal contrast technic among "N" doses was used to verify the kind of quantitative response. Least significative difference was calculated for treatment mean comparison.

N fertilizer effectiveness in the trial environment was also evaluated by the ratio DM yield/N uptake from the whole biomass (= N use efficiency, NUE) following and modifying the approach of Giardini (1989).

Results

Data analysis of each crop showed a significant "Year" and "N" effect for grain yield and for crop residues production (Tab. 1).

DW residues production response at increasing N doses was linear, but for grain yield a quadratic component resulted significant, probably for the drought spring of experimental site that reduced nutrients assimilation and translocation in the grain: this is confirmed also by a negative correlation between N doses and 1000 seed weight ($r=-0.47^{***}$). The unfertilized treatment yielded satisfactorily (4.6 t ha^{-1}) while the maximum N dose (180 kg ha^{-1}) showed a decrease, in comparison with 60 and 120 kg N ha^{-1}. Figure 1 shows an optimal dose for DW grain yield of about 70-80 kg of N ha^{-1}.

A yield variability very high among years was observed for SF, particularly low in the first year (1983) due to a low 1000 seed weight (69 g vs. 79 g in average in the other years), probably for the different characteristics of hybrids in following years. The N response was curvilinear for achenes yield and SF residues production, but with an optimal dose higher than durum wheat (about 100-120 kg of N ha^{-1}) (Fig. 1), probably because of a greater water availability due either to irrigation water (about 300-400 mm per growing season) and/or to deeper roots.

Analyses of six-year total dry matter, yield index and gross energy data, showed a significative interaction "years * N". The yield index showed the relative best performances of two crops in the 3rd cycle of rotations (1987 and 1988), expecially at higher nitrogen doses, for a cumulative nutritional effect (Tab. 2).

Significant differences for seed protein content and N uptake from grain and achenes (Tab. 2) were observed between SF and DW in the first two cycles of rotation while in the third one differences appear very small, probably since in 1987 N wasn't translocated from the lower to upper parts of plants, as results by evaluating N content of sunflower crop residues higher in comparison to previous cycles. Moreover in the 3rd cycle, N uptake (grain/achenes + crop residues) from the 2 crops is higher than corresponding N absorption in the previous cycles, because soil N availability was improved.

In the same table 2 we can observe that soil residual N (Nres) was significantly affected by the crops (years); soil Nres of SF were lower than soil Nres of DW.

N mineralized during the growing season (Nminz) depends from the precipitations during the experimental period because it is an estimated parameter; for this reason Nminz during DW growing seasons (winter crop) resulted higher than Nminz obtained through SF cropping cycle (spring-summer crop).

Soil residual N at the end of cropping cycle (Nend) increased from 1st to 3rd cycle with a maximum value for DW in the 2nd cycle. In fact in this year N uptake from whole DW biomass is very low because in the months of april and may the precipitations were negligeable.

Grain (or achenes) protein content augmented supplying N120 and N180 (respectively: + 1.85, + 2.76% in comparison with N0). N uptake from the grain (or achenes), crop residues and from the whole biomass increased considerably with N rates, but no significant differences were observed between N120 and N180. The poor effectiveness on the yields (SF and DW) of 180 kg N ha^{-1} was confirmed by soil analyses: soil Nres and Nend contents were higher in the plots fertilized with N180, because this N fertilizer dose exceeds N crops requirements and improves only the quality of products but not yield quantity. Furthermore soil and water pollution hazards may be in the experimental site following from N180 fertilization.

To complete the evaluation of N fertilizer effectiveness in the trial environment, the variations in the years of N use efficiency (DM yield/N uptake from the whole biomass=NUE) were recorded. Lowest NUE values were observed (Figure 2) for N120 and N180 (except in the 1985). Highest N doses supplied to DW were less efficient in comparison with sunflower responses: for the 1st crop NUE decreases if N rates > 120 kg ha^{-1}, on the contrary NUE is more constant for sunflower. It depends by water supply, more regular in SF (irrigated crop) and uneven (due to rainfall variability) in DW (rainfed crop).

Response curves to N fertilization for both the crops confirmed these findings. DW grain yield is poorly correlated with N fertilizer doses and decreases when soil Nres (autumn) increases; on the other hand grain protein content showed a linear relationship with N fertilizer doses proving that soil available N could be enough to obtain suitable DW grain yield and N supplied by fertilizer improves only the quality of durum wheat grain. DW takes advantage of soil N residual of sunflower as previous crop and N fertilizer applications in the spring can be reduced.

SF responses curves fit achenes yield vs. N rates by a curvilinear relationship (Figure 1) ; supplying N doses till 120 kg N ha^{-1}, achenes yield increases, but decreases if fertilizer N doses are higher. Since soil N residual from DW for the subsequent SF is lower than soil N residual from SF for DW, sunflower achenes yields appear correlated with N doses. The small differences observed between the two crops could be determined also from different root development: i.e., sunflower roots are ables to taken up soil available N also from deeper soil layers (Decau *et al.*, 1984).

In the Figure 3 were reported relationships (significative linear regressions of five years) between N balance and N rates. Coefficients of determination (R^2) ranged from 0.947 to 0.997 and mainly for DW varied through the years.

N-balance for DW is near to the parity supplying 120-180 kg N ha^{-1} depending on the years; for this crop, however, experimental results obtained in this and previous trial carried out in the same area, show N durum wheat requirements lower than N doses determined by "N-balance" approach. For SF, N-balance equals zero at 114 kg N ha^{-1} and at 85 kg N ha^{-1} of fertilizer added, respectively in 1985 and 1987, confirming our experimental results and of an other study on environmental adaptability of sunflower hybrids in the same site (De Giorgio *et al.*, 1988). N fertilizer requirement of SF in the 3rd cycle is lower than other two because the previous crops (SF-DW-SF-DW) improve soil N dynamics.

Conclusions

Drought spring in experimental site reduced yield performances of durum wheat because nutrients assimilation and translocation in the grain is difficult; on the other hand very high variability among years was observed for sunflower.

Durum wheat grain yield is poorly correlated with N fertilizer doses while sunflower responses curves fit achenes yield vs N rates by a curvilinear relationship. For the 1st crop "Nitrogen Use Efficiency" decreases if N rates> 120 kg ha^{-1}; on the contrary for sunflower NUE is more constant. The crop differences can be interpreted evaluating the ratio between N fertilization and N cycle and water supply (more regular in sunflower and uneven in durum wheat) . Both the parameters explain also the best performances of the two crops in the 3rd cycle of rotations: i.e. since soil N availability was improved, N uptake (grain/achenes + crop residues) increased. Other N cycle parameters confirmed this interpretation: as a matter of the fact, sunflower soil N residual (from durum wheat) and N mineralized were lower than durum wheat soil N residual (from sunflower) and N mineralized.

Also by "N-balance" approach differences between durum wheat and sunflower were significant : for the 1st crop, N-balance is near to the parity supplying 120 - 180 kg N ha^{-1}, for sunflower N-balance equals zero at 114 kg N ha^{-1} and at 85 kg N ha^{-1} of fertilizer added, respectively in 1985 and 1987. These differences could be determined from the greater root development of sunflower which take up soil available N also from deeper soil layers.

References

Abbate, V., Patanè, C., Santonoceto, C., 1992. Il ruolo del genotipo per una migliore valorizzazione di limitate risorse idriche nel girasole (*Helianthus annus* L.). Riv. di Agron., 26, 4 suppl., 791-779.

Campiglia, E., Caporali, F., 1994. Effetto del prato di erba medica (*Medicago sativa* L.,) e della concimazione minerale e organica sulle colture avvicendate di girasole (Helianthus annus L.,) e frumento tenero (*Triticum aestivum* L.,). Riv di Agron., 28, 2, 79-86.

Cosentino,. S., Sortino, O., Litrico, P. G., 1992. Risposta produttiva, temperatura radiativa della copertura vegetale e stato idrico della pianta nel girasole (*Helianthus annus* L.) in secondo raccolto con differenti regimi irrigui. Riv. di Agron., 26, 4 Suppl., 633-640.

Decau, J., Jamet, L., Merrien, A., Pujol, B., 1984. Influence du peuplement d'une culture de tournesol sur la dinamique ultèrieure de l'azote minéral du sol et sa disponibilité pour le blé suivant. C. R. Acad. Agr. de France, 70, 1133.

De Giorgio, D., Ferri, D., Maiorana, M., Rizzo, V., 1988. Prove di adattamento di tre ibridi di girasole sottoposti a dosi crescenti di azoto nell'ambiente meridionale: resa in acheni e olio, contenuto proteico e valore energetico. Proc. of Congress on "Stato attuale e prospettive delle colture oleaginose erbacee in Italia". Pisa, 24-26 febbraio, 369-378.

Di Bari, V., Castrignanò, A.M., Rizzo, V., 1993. Stima e analisi di "sensitivity" della resistenza colturale per il calcolo dei consumi idrici del girasole. Riv. di Agron., 27, 1, 17-22.

El-Haris, M. K., Cochran, V. L., Elliott, L. F., and Bezdicek, D. F., 1983. Effect of tillage, cropping and fertilizer management on soil nitrogen mineralization potential. Soil Sci. Soc. Am. J., 1157-1161.

Giardini, L., 1989. Aspetti agronomici e fisiologici della concimazione azotata in relazione con l'ambiente. Riv. di Agron., 23, 1, 3-22.

Monica, M., Molfetta, P., Vannozzi, G., Zerbi, G., 1993. Sapflow, gas exchange and water relations in *Helianthus annus* and *H. argophyllus* during drought cycles. Riv. di Agron., 27, 3, 191-197.

Monotti, M., 1980. Girasole: ambiente di coltivazione e scelta varietale. l'Inf. Agr., 17, 10352-10357.

Pirani, V., 1981. Il clima e le rese produttive del girasole nell'Italia centrale. Riv. di Agron., 15, 2, 107-114.

Rinaldi, M., Di Bari, V., De Giorgio, D., Maiorana, M., Rizzo, V., Carlone, G., 1992. Sunflower (*Helianthus annuus* L.) in two-year rotations with durum wheat, with or without catch soybean. Proc. of the 13th Int. Sunflower Conf., Pisa, 7th to 11th september, 1, 284-292.

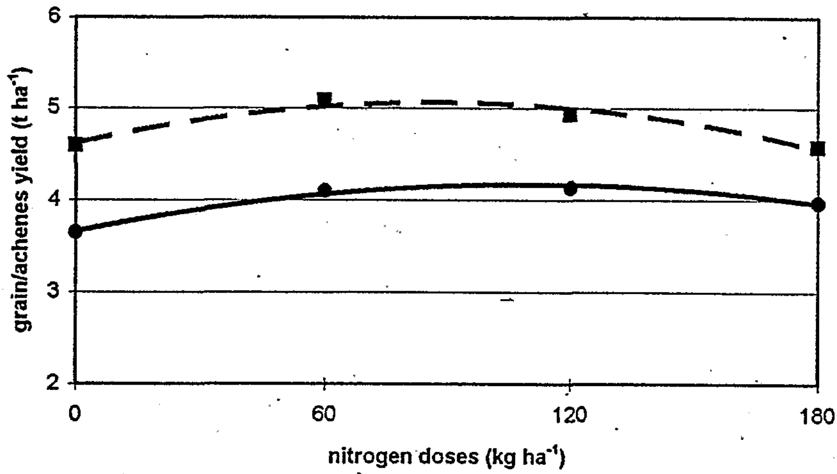

Fig. 1 - Quadratic relationship of durum wheat grain yield (square) and sunflower achenes yield (circle) and nitrogen doses applied (average values).

Table 1 - Main effects of sunflower and durum wheat yield and residues productions, in t ha^{-1}.

	Sunflower yield		Durum wheat yield	
	achenes	residues	grain	residues
Years				
1983	2.87	6.53	4.79	9.63
1984				
1985	4.56	5.11	4.08	7.64
1986				
1987	4.45	5.50	5.53	6.64
1988				
Nitrogen doses				
0	3.65	5.55	4.59	7.03
60	4.10	5.45	5.09	7.92
120	4.14	6.03	4.93	8.42
180	3.97	5.82	4.58	8.51
L.S.D. 0.05 P "Y"	0.29	0.57	0.33	0.38
L.S.D. 0.05 P "N"	0.34	n. s.	0.38	0.44

Table 2 - Effects of years (crops) and N-fertilizer rates on some agronomical and N cycle parameters.

Year (crop)	N doses (kg N ha^{-1})	Total dry matter (tha^{-1})	Yield Index	Gross Energy (GJ ha^{-1})	Protein content (%)	Nitrogen uptake by grain/ achenes	Nitrogen uptake by crop residues	Total nitrogen uptake	N residue	N minz	N end
						kg N / ha					
1983 (SF)	0	9.02	92.1	185.3	18.8	84.4	40.6	125.0			
	60	9.15	103.4	194.1	19.4	88.0	42.0	130.0			
	120	9.25	104.4	205.5	19.3	88.7	57.2	145.9			
	180	9.04	100.3	197.8	20.2	90.3	57.4	147.7			
1984 (DW)	0	13.97	110.8	252.3	15.8	124.0	38.9	162.9	9.96	57.89	14.91
	60	13.94	106.7	251.7	15.1	112.7	41.6	154.3	19.80	61.56	27.21
	120	13.61	95.4	245.7	16.9	115.6	74.1	189.7	25.70	59.04	26.85
	180	13.66	87.1	246.4	17.7	110.4	79.0	189.4	31.02	60.34	38.59
1985 (SF)	0	8.33	101.7	179.2	19.5	142.5	37.5	180.0	15.55	14.50	24.24
	60	9.25	125.6	202.7	19.9	188.5	61.1	249.6	19.45	15.42	25.67
	120	9.57	116.4	205.7	19.4	166.5	36.8	203.3	25.35	14.79	30.73
	180	9.73	117.3	208.8	19.8	155.0	44.9	199.9	33.74	15.11	37.74
1986 (DW)	0	10.41	86.6	188.2	11.3	72.1	25.9	96.0	17.74	53.39	39.59
	60	11.36	88.6	205.2	13.0	85.3	37.7	123.0	27.03	56.79	51.06
	120	11.48	84.3	207.3	16.0	99.2	44.6	143.8	28.76	54.45	63.01
	180	11.48	80.8	207.2	17.3	102.9	49.1	152.0	28.12	55.64	89.70
1987 (SF)	0	9.14	102.8	194.1	13.8	97.3	83.0	180.3	24.95	24.04	14.14
	60	9.00	111.9	194.3	15.2	114.1	72.0	186.1	29.44	25.57	17.42
	120	10.44	123.3	201.7	16.7	138.6	99.8	238.4	44.20	24.52	28.40
	180	9.42	111.7	223.4	17.2	128.7	76.9	205.6	62.75	25.06	59.50
1988 (DW)	0	8.71	90.3	157.7	13.0	85.0	21.8	106.8	9.56	56.23	28.72
	60	11.72	123.3	212.3	13.2	117.6	30.6	148.2	9.55	59.82	24.11
	120	13.04	129.0	236.0	15.0	140.0	48.8	188.8	8.93	57.35	33.33
	180	12.34	119.0	223.3	16.6	142.9	52.4	195.3	13.07	58.61	56.01
L. S. D.	"Year"	0.31	7.08	11.34	0.7	2.7	4.9	10.4	3.1	1.2	6.9
L. S. D.	"N"	0.25	5.78	9.26	0.6	7.8	4.4	9.7	2.8	1.1	6.2
L. S. D.	"Year * N"	1.82	17.7	n . s.	1.5	17.4	9.8	11.3	6.2	2.4	13.7

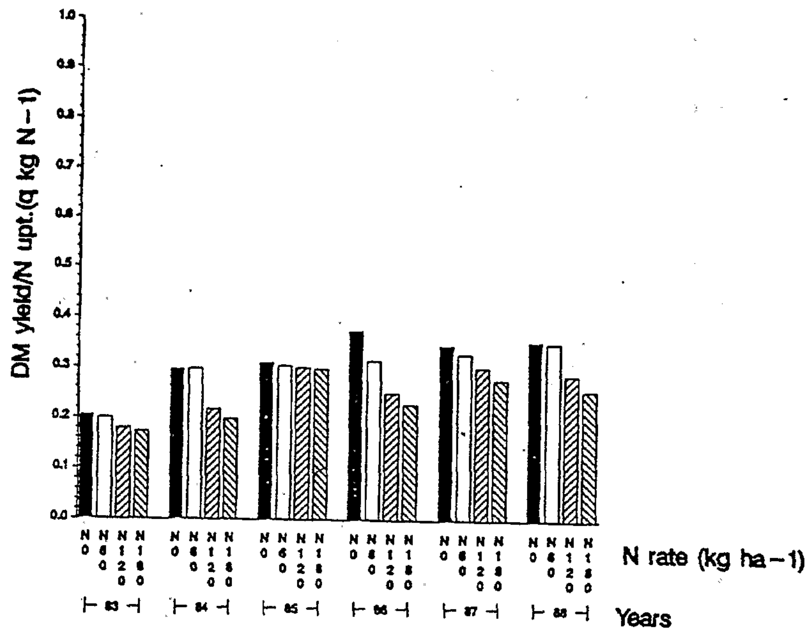

Fig. 2 - Nitrogen use efficiency (DM yield / N uptake) as affected by the years (crops) and N rates.

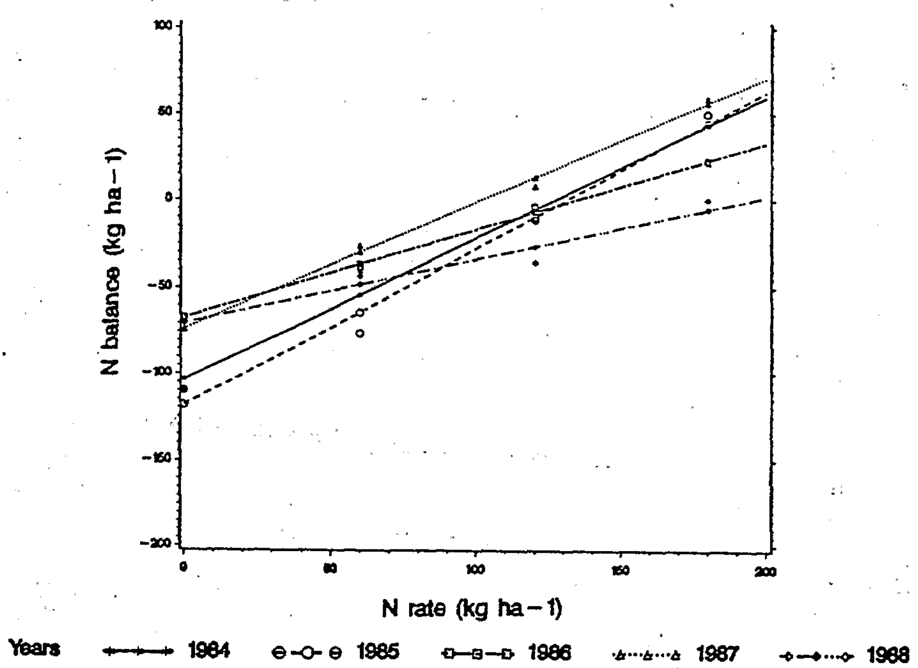

Fig. 3 - Linear relationships between N-balance and N rates in five years of experimental trial.