Nitrogen Use Efficiency and nitrate losses in sunflower and maize: a comparison.

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Abstract

An experiment was conducted during 1992 and 1993 growing seasons, in 32 drainage lysimeters of 0.88 m^2 surface 0.7 m deep, comparing two crops, sunflower and maize. The objective of the experiment was to establish how the level of N fertilisation and the timing of water withholding influence nitrogen use efficiency and yield.

The experimental units were fertilized with NH_4NO_3 at 0, 40, 80, 120, 160 and 240 kg ha^{-1} and irrigated with optimal water regime: on a group of lysimeters, fertilized with 120 and 240 kg ha^{-1} N, water was withheld during flowering and fruit set (S1), or during seed filling (S2).

Increasing levels of N fertilisation caused a higher biomass to be accumulated in both the crops. Water withholding hindered the obtaining of highest yield, more at high fertiliser level than at 120 kg ha^{-1} N, and depressed nitrogen use efficiency. The efficiency parameters calculated (Apparent Nitrogen Recovery ANR, Physiological Efficiency PE, and Agronomic Efficiency AE) pointed out distinct values among the two crops: sunflower lower PE, coupled to a decreased ANR at high fertiliser rate, were the principal responsible of the lower overall AE. Maize was more efficient in N uptake and allocation in the seeds at all N rates, included the highest.

After harvesting an abundant irrigation was performed, simulating the intense rainfall often occurring in the area at the end of the growing season. The drainage water was analysed to determine NO_3-N and NH_4-N content and to gain information on the potential risk of water table enrichment in these chemical components after fertilisation in shallow soils. No difference was found for NH_4-N content in the leaching water among the levels of fertilisation, but the average levels of NO_3-N were different for the two crops: 2.4 ppm for maize and 9.6 ppm for sunflower. In maize water shortage caused a moderate enrichment of NO_3-N concentration in the drainage water, never above 10 ppm, while in water-stressed sunflower leached water contained up to 22 ppm of NO_3-N.

Introduction

The efficiency with which nitrogen fertiliser is used by the different crops has become increasingly important both because of increased costs of manufacture and distribution of N fertiliser, and because residual N can be leached from the soil into groundwater besides being denitrified or lost in surface runoff (Legg and Meisinger, 1982). Potential risk connected to nitrate losses can be particularly serious in case of shallow soil profile (Ceccon et al. 1996) especially when rainfall often exceeds evapotranspiration during fall and winter months. In such conditions crops such as maize and sunflower can be regarded as alternatives for reducing costs and reliance upon fertiliser N. However for both crops proper N application timing and rates are crucial to meet plant needs an improve nitrogen use efficiency, together with an adequate water supply (Rawson and Turner, 1982, 1983). Management tecniques suitable to increase nitrogen use efficiency of fertiliser are often preferable to a mere reduction of the fertiliser rates applied (Dilz, 1988).

Nitrogen must be available during the early stages of crop growth (Steer and Hocking, 1984) for an appropriate leaf expansion (Radin and Boyer, 1992), to ensure a good flower initiation and an abundant fruit set (Steer and Hoching, 1984; Blanchet et al, 1987).

Maize is considered a crop with relatively high N demand and good nitrogen use efficiency (Craswell and Godwin, 1984), while sunflower is regarded as a poor utilizer of applied fertiliser (Merrien et al, 1988; Loubser and Human, 1992), and cannot take advantage of fertilisation when water supply is limited (Blanchet et al, 1987).

The purpose of this experiment was to determine how the level of N fertilisation and the water management may influence yield and the different aspects of nitrogen use efficiency in sunflower and maize.

Material and Methods:

The experiment was carried out in the Experimental Farm of the University of Udine (46° N) during 1992 and 1993. Sunflower cv. Euroflor and maize cv. Furia (class 600) were grown in 32 drainage lysimeters (0.83 m^2 surface 0.7 m deep). each housing 6 plants, covered by a rain shelter, to avoid rain to interfere with the water balance. A group of 6 experimental units was fertilized with NH_4NO_3 at 0, 40, 80, 120, 160 and 240 kg ha^{-1} N (split in 3 applications) and irrigated with optimal water supply (WW). On a group of lysimeters fertilized with 0, 120, 240 kg ha^{-1} N irrigation was withheld either during flowering and fruit set (S1), or during seed filling (S2), failing to restore a depleted water supply of 80 mm: soil moisture was then restored to field capacity at the end of the of the drought period. Watering volumes were calculated to prevent percolation. Plants were separately harvested. and plant material was dried and analysed for N content with Nitrogen Analyzer Carlo Erba NA 1500 applying the Dumas method. After harvesting an abundant irrigation was performed, simulating the intense rainfall often occurring in the area at the end of the season. Drainage water (approximately 40 mm) was collected and analysed to determine NO_3-N and NH_4-N content. During the growing season lysimeter soil was regularly sampled for nitrate content analysis. Data were statistically analysed by ANOVA. N use efficiency parameters were calculated according to Craswell et al (1984): 1) Apparent Nitrogen Recovery (A.N.R.), measures the increase of the above-ground N uptake (Nu) per unit of N fertiliser applied (Na), 2) Physiological Efficiency (P.E.), the increase in grain yield per unit of N uptaken, and 3) the product of P.E and A.N.R.. the Agronomic Efficiency (A.E.), that measures the increase in grain yield of the fertilized crop compared to the unfertilised crop per unit of N fertiliser applied.

Results and Discussion

The effect of N fertilisation on plant biomass and grain yield and is shown in figure 1. Both the crops reacted to N fertilisation increasing total biomass and yield, and the regression interpolates only the well watered treatments. Sunflower grain yield was heavily penalised by water shortage, at both stage S1 and S2. Yield reduction was however more severe at high fertiliser level (respectively -31.6% and -39.7% for S1 and S2) than at intermediate fertiliser level (-16.3 and -30.5%). As regard maize, no difference was detected among watering treatments at 120 N, while a significant effect of water regime was observed at 240 N.

Figure 2 reports the N amount recovered at harvest in the plant. While for sunflower unfertilised treatments recovered approximately 60 Kg of N, fertilized plants took up nearly 200 kg if well watered, 20% less when water shortage occurred. Maize, on the other hand, recovered approximately 80 kg in unfertilised plots and 280 at the highest N rate. The slope represents the average rate of N recovery for the crop in well watered conditions, and the significantly different value for the two crops (0.057 for sunflower and 0.084 for maize) is a quantitative measure of the different physiological ability of the plants to utilise the available N (both naturally available and supplied).

More in details. figure 3 reports the distinct aspects of N use efficiency. Agronomic Efficiency (AE) shows different values in the two species: around 12-17 (kg of grain per Kg of N applied) for sunflower and 35-40 for maize. In both crops and at either intermediate or high fertilisation rate, a water shortage was effective in decreasing the overall efficiency with which applied N is used. These distinct values may arise from any of the two components: Apparent Nitrogen Recovery actually shows different values not in terms of range (between 60 and 80 for both crops). but in terms of trend: decreasing recovery values in sunflower. but not in maize, even at high rates. Remarkable reductions of efficiency with water stress were observed in sunflower, at both 120 and 240 N, less severe in maize, where only at 240N and S2 a significative reduction was detected. These values are rather high as compared to those reported in litterature because of the particular growing conditions: controlled lysimeters of limited size, where percolation was prevented. The second component of AE, Physiological Efficiency, shows distinct values among the two crops, around 20 for sunflower, with not much variation, and decreasing between 60 and 40 for maize. This parameter, that represents the efficiency with which the plant utilises recovered N for the synthesis of grain reflects the different physiology of the two crops, in terms of length of the crop cycle, photosynthetic efficiency, ability of the plant to store protein in the seeds.

The amount of NO_3-N measured in the soil is reported in fig 4. Both the crops started out with a comparable amount of NO_3-N in the soil at the beginning that gradually exhausted throughout the cycle, even when fertilised with 240N. Soil NO_3-N was removed more rapidly in sunflower, at all fertiliser rates. Maize, on the other hand, with a longer cycle, was able to better exploit the soil N resources, from mineralization and fertilisation, till approximately day 250. At harvest well watered maize plants showed a soil NO_3-N content of 5 ppm if unfertilised or moderately fertilised, around 10 ppm with high N fertilisation; the stressed treatments and 240 N displayed higher soil NO_3-N content. In sunflower the lowest value of soil NO_3-N content was reached earlier in the season, and the values of NO_3-N at harvest were moderately higher than in maize (7 ppm for unfertilised and around 12 for 240 N). The early senescence caused by water shortage caused a lower NO_3-N uptake from the soil . and a consequent higher concentration in the lysimeter soil.

Figure 5 reports the concentration of NH_4-N and NO_3-N recovered in the leaching water consequent to the over-watering after harvest. No differences were found for NH_4-N content in the leached water between the crops and among the treatments. Conversely NO_3-N average concentration was significantly lower for maize (ranging between 1 and 4 ppm) than for sunflower ranging between 8 and 12 ppm). NO_3-N content in the percolating water increased with the N application rate in both the crops, and was most abundant in the leachates of water stressed treatments. In particular for sunflower crop water shortage was effective in enhancing NO_3-N content in the leachates, for both the stressing period S1 and S2, and at both 120 and 240 N.

Conclusions

Maize was more efficient in recovering N supplied, and its ANR did not decrease, even at high rates of fertiliser, suggesting that under these conditions N losses could be limited, even in stressful conditions. Rates up to 240 N or even higher are frequently applied in normal practice, and are very likely to be still in the range of increasing productivity on the response curve. Sunflower displayed high recovery with N rates up to 120 N in well watered treatments, but the efficiency of N use decreased above this value; it was also penalised by stress conditions, particularly when occurring late in the season. This behaviour could explain the high NO_3-N concentration found in the percolate and confirm the potential risk represented by intense autumn rainfall leaching the unexploited N fertility of the soil.

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Fig. 1 - Grain yield and above-ground plant biomass as related to N fertilization for the two crops.

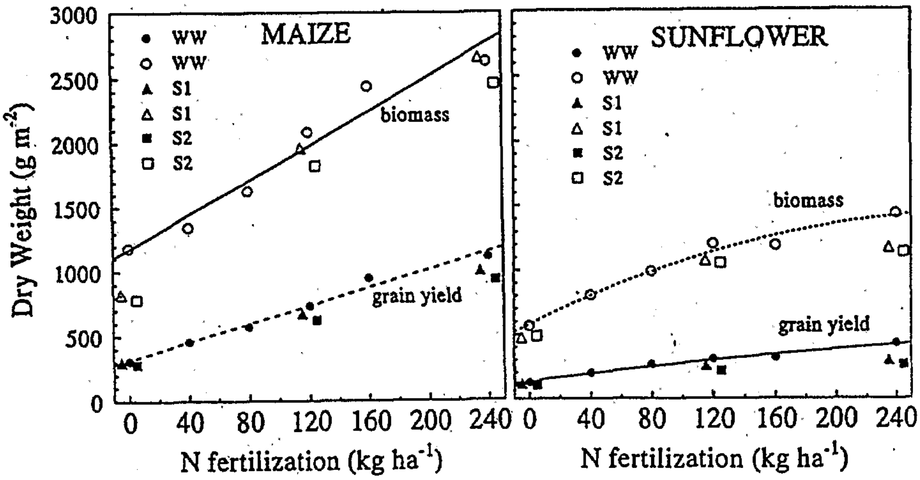

Fig. 2 - N removed from the soil by grain yield and above-ground plant biomass as related to N fertilization for the two crops.

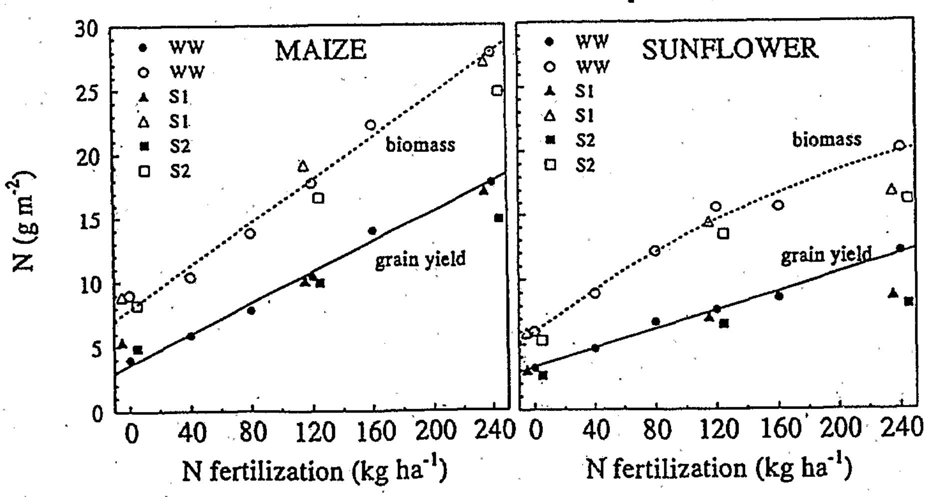

Fig. 3 - Nitrogen Use Efficiency parameters: respectively Apparent Nitrogen Recovery, Physiological Efficiency and Agronomic Efficiency in response to N fertilization for the two crops.

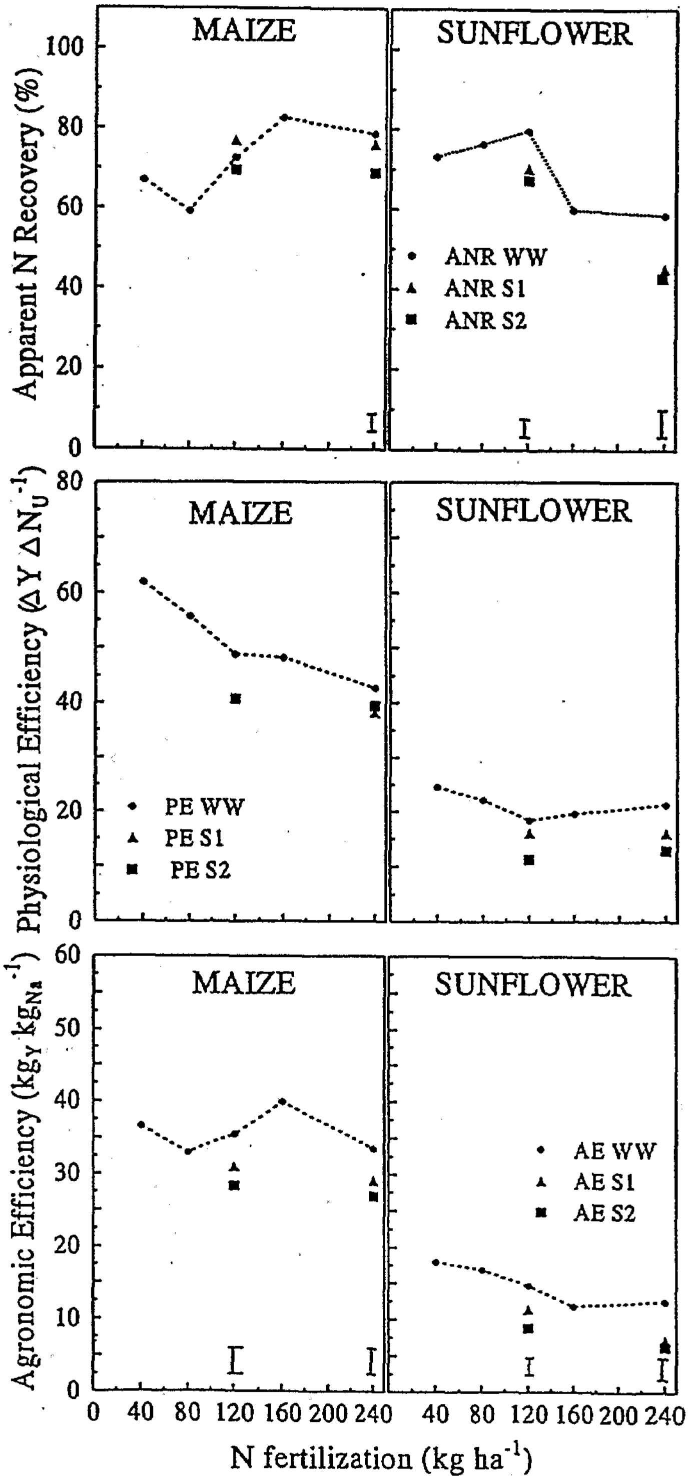

Fig. 4 - NO_3-N content in the soil during the growing season for the two crops.

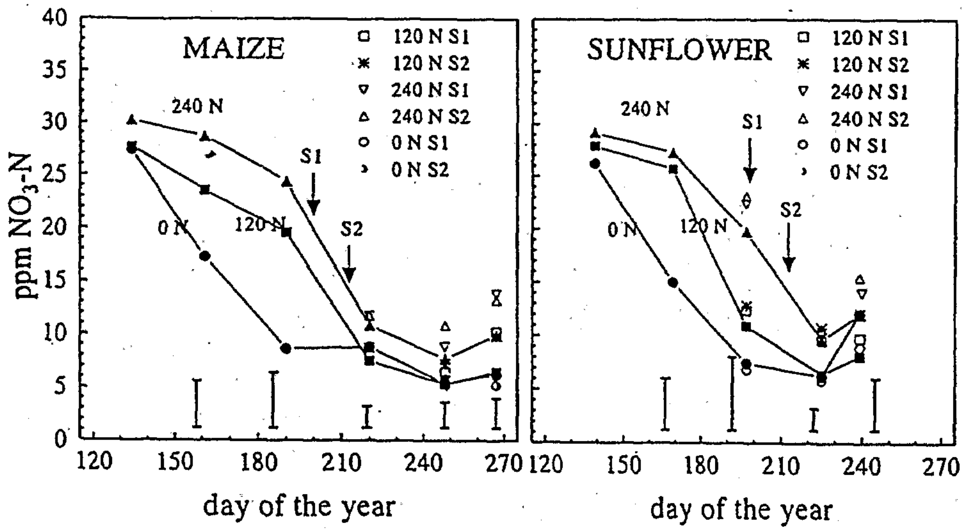

Fig. 5 - NH_4-N and NO_3-N content in leaching water consequent to overwatering after harvest for the two crops.