INFLUENCE OF CLIMATIC CONDITIONS ON YIELDS, N UPTAKE AND EFFICIENCY IN SUNFLOWER INFLUENZA DELLE CONDIZIONI CLIMATICHE SULLA PRODUZIONE, L'AZOTO ASPORTATO E L'EFFICIENZA DI UTILIZZ...

5 authors, including:

Francesco Montemurro
Council for Agricultural Research and Agricultural Economy Analysis

Donato De Giorgio
Council for Agricultural Research and Agricultural Economy Analysis

Francesco Fornaro
Council for Agricultural Research and Agricultural Economy Analysis

Emanuele Scalcione
ALSIA Agenzia Lucana di Sviluppo e di Innovazione in Agricoltura

INFLUENCE OF CLIMATIC CONDITIONS ON YIELDS, N UPTAKE AND EFFICIENCY IN SUNFLOWER

INFLUENZA DELLE CONDIZIONI CLIMATICHE SULLA PRODUZIONE, L'AZOTO ASPORTATO E L'EFFICIENZA DI UTILIZZAZIONE DELL'AZOTO NEL GIRASOLE

Francesco Montemurro[1]*, Donato De Giorgio[1], Francesco Fornaro[1], Emanuele Scalcione[2], Carolina Vitti[1].

[1]:*C.R.A. – Istituto Sperimentale Agronomico, Via C. Ulpiani, 5 – 70125 Bari, Italia.*
[2]:*ALSIA – Agenzia Lucana di Sviluppo e di Innovazione in Agricoltura, Viale Carlo Levi sn – 75100 Matera, Italia.*
**Corresponding author,Tel.:+39 080 5475011; fax: + 39 080 5475023. E-mail address: francesco.montemurro@entecra.it*

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Abstract
The Mediterranean area is often characterised by variable and unpredictable climatic conditions that strongly influence plant development and yield. In this matter, the right choice of the genotypes and of the agronomic practices could be important features to obtain high crops performance. Therefore, the aim of this work was to study the effects of air temperatures, annual and seasonal rainfall on yield, oil production, N uptake and N utilisation efficiency of sunflower genotypes grown in a semiarid conditions. To accomplish this goal, a four-year field experiment was carried out at Foggia (Southern Italy) on five different genotypes cropped with three N fertilisation levels. The research was conducted in a "accentuated thermomediterranean" environment, as classified by UNESCO-FAO, and on a soil defined by Soil Taxonomy-USDA as "fine mesic, Typic Chromoxerert". During the field experiment, the minimum and the maximum air temperatures and the rains were daily recorded, whereas at the end of the each cropping year, yields, quality, plant dry weight, N content of the different parts of plant were determined, allowing the calculation of oil production, N uptake and N efficiency parameters. The results of this work indicated, trough the trial years, high rainfall variations during the first vegetative phases of sunflower. This amount of rain was correlated with sunflower performance, confirming that environmental conditions clearly affected both yields and N uptake. In particular, in the year characterised by the lowest total rain the oil production decreased of the 33.9% in respect to the year with the highest oil yield. The same behaviour was also observed for total N uptake (31.5% of reduction). A significant difference among N fertilisers was found throughout the field experiment in yield and N uptake, indicating that the weather conditions strongly also influenced this important agronomic parameters. The highest N fertilisation treatment reached both the greatest value (1.74 t ha^{-1}) and one of the lowest (1.14 t ha^{-1}) values of oil production during the trial period. Finally, the N utilisation parameters showed low absolute values, reflecting a poor crop use of N fertiliser by sunflower, especially when the climatic conditions were adverse.

Keywords: *Helianthus annuus* L., Mediterranean condition, oil production, N uptake.

Riassunto
Gli areali Mediterranei sono spesso caratterizzati da andamenti climatici irregolari ed imprevedibili che influenzano fortemente la produzione e lo sviluppo della pianta. In un simile contesto, la giusta scelta del genotipo e delle pratiche agronomiche potrebbe essere importante per ottenere risposte produttive di rilievo. Lo scopo di questo studio, quindi, è stato studiare gli effetti delle temperature, della piovosità annuale e stagionale sulle produzioni, le rese d'olio, l'azoto asportato e l'efficienza di utilizzazione dell'azoto dei genotipi di girasole coltivati in condizioni di semi aridità. Per raggiungere questo scopo, è stato condotto un esperimento di campo quadriennale a Foggia (Sud Italia) su cinque diversi genotipi coltivati a tre differenti livelli di concimazione azotata. La ricerca è stata condotta in un ambiente classificato dall'UNESCO-FAO come " accentuato termomediterraneo" e su un suolo limo-argilloso, ("fine, mesic, Typic Chromoxerert" Soil Taxonomy-USDA). Durante l'esperimento in campo sono state registrate giornalmente, le temperature massime e minime e la pioggia, mentre alla fine di ogni anno sono state determinate alla raccolta la produzione, il peso secco e il contenuto di azoto delle differenti parti di pianta per calcolare l'azoto asportato e l'efficienza di utilizzazione dell'azoto. I risultati ottenuti confermano che le variazioni della piovosità durante l'ultima importante fase del girasole, influenzano sia la produzione che l'azoto asportato. In particolare, l'anno caratterizzato dalla piovosità più bassa ha fatto registrare una diminuzione della produzione in olio del 33.9% rispetto all'anno con produzione di olio più alta. Lo stesso comportamento è stato osservato per l'azoto asportato totale (riduzione del 31.5%). Sempre a causa dei decorsi climatici è stata rilevata, inoltre, una differenza significativa tra i diversi livelli di fertilizzazione sulla produzione e l'azoto asportato. La concimazione azotata più alta ha, infatti, prodotto sia il valore più alto (1.74 t ha^{-1}) che uno dei più bassi (1.14 t ha^{-1}) della produzione di olio nelle diverse annate. Infine, i parametri dell'efficienza di utilizzazione dell'azoto hanno mostrato i valori assoluti più bassi, evidenziando uno scarso utilizzo di azoto da parte del girasole.

Parole chiave: Helianthus annus *L., condizioni mediterranee, produzione di olio, azoto asportato.*

Introduction

Nitrogen (N) is one of the most important nutrients for plants and when it is applied through fertilisation it increases the total biomass production, the yields and the yield components. Nevertheless, it can also increase the economic cost and the environmental risks, especially when N fertiliser management is inaccurate (Sylvester-Bradley, 1993; Janzen *et al.*, 2003) and climatic conditions are unfavourable. Due to the sunflower (*Helianthus annuus* L.) needs high N requirements, one of the new research aims for this crop could be to choose the both appropriate genotypes and N fertilisation management to maintain high yielding level and decrease potential groundwater pollution. In fact, sunflower cultivation is one of the most important oil crops and it has been expanding in Mediterranean conditions (Lòpez-Bellido *et al.*, 2003), as a consequence of its high polyunsaturated fatty acid content (an important source in edible vegetable oils) and of favourable European agricultural policies. The selection of genotypes with high performance and well adapted to the specific environmental conditions, could be an important goal, especially when low input is adopted (Leto *et al.*, 1997; Montemurro *et al.*, 2005).

In semi-arid areas, characterised by a high variability of both rainfall and air temperature, the main factors limiting growth and production are water and N supplies. In fact, the same amount of N fertiliser applied on sunflower crops could result in a depletion or accumulation of soil mineral N, depending on rainfall, temperature during the cycles, plant growth and genotype utilised. In this matter, the right choice of genotypes and of agronomic practices could be important features to obtain high performance. In particular, among agronomic practices, the effects of N supply on sunflower yield have been studied in several researches (Steer *et al.*, 1985; Hocking and Steer, 1995; Maiorana *et al.*, 2005), aimed to schedule N application in sunflower cultivation. However, there is still a lack of knowledge about the effects of different N fertilisation rates on sunflower yield and N uptake in different genotypes, grown in Mediterranean conditions, especially when sustainable management is adopted. Consequently, the effects of N fertiliser level on N uptake and, because of the high correlation with yields, also on crop performance (Montemurro and De Giorgio, 2005), are important features for the farmers.

Therefore, the objective of this work was to study the effects of the climatic pattern parameters (temperatures, annual and seasonal rainfall) on yield, oil production, quality, N uptake and N utilisation efficiency of sunflower genotypes grown in a semiarid condition. The evaluation of N uptake and yield reductions and their interactions with different genotypes under N constraints were further investigated. To accomplish these aims, a four-year field experiment was conducted at Foggia, on five different sunflower genotypes grown at three N fertilisation levels.

Materials and methods

Site

The research was carried out at the "Istituto Sperimentale Agronomico" experimental farm of Foggia (Southern Italy, 41° 27' lat., 3° 04' long., 90 m above sea level). The climate is "accentuated thermomediterranean" (UESCO-FAO classification) with temperatures that can fall below 0 °C in the winter and rise above 40 °C in the summer, with rainfall unevenly distributed during the year, being concentrated mainly in the winter season. The soil is a clay-loam textural class, classified by Soil Taxonomy-USDA as fine, mesic, Typic Chromoxerert. The mean main starting physical and chemical soil characteristics, determined on samples taken from each elementary plot in the 0-50 cm layer, air dried, ground to pass a 2-mm sieve, were as follows: total N = 1.22 g kg^{-1}, determined by the Kjeldhal digestion and distillation method; available P = 27 mg kg^{-1}, by Olsen and Sommers method; exchangeable K = 1018 mg kg^{-1}, by Thomas method; organic matter = 20.7 g kg^{-1} by Springer-Klee method; pH = 8.13, on 1 : 2.5 soil water suspension; sand = 29.2%, clay = 37.5% and silt = 33.3%, determined by hydrometer method.

Experimental design and measurements

The research was conducted in the trial years 1996, 1997, 1998 and 1999 on four sunflower hybrids (Isoleic, Sanbro, Akiles, Select) and one selected genotype (Prointa AGD), which was included in the experiment since 1997. The hybrids are the most cropped in Southern Italy, and, together with Prointa AGD, were selected for their ability to grown in drought conditions. Three N fertilisation levels (0, 50 and 100 kg N ha^{-1}, indicated as N0, N50 and N100, respectively) were also compared in this study. The experimental design was a split-plot with three replications. The main plot was assigned to the nitrogen level and the sub-plot to the sunflower genotype. The elementary plot consisted of 45 m^2 with 7 plant m^{-2}. Subdividing the total N amount of N50 and N100 treatments in two equal parts (25 and 50 kg ha^{-1}, respectively); ammonium nitrate fertiliser was applied in each year at 3-4 and 11-12 sunflower leaves and broadcasted before tillage. Therefore, the two N fertiliser treatments were applied at the same time, but using different rates of N application. The P fertiliser (50 kg P_2O_5 ha^{-1}) was spread before sowing, whereas no K fertilisation was made in both years, due to its high initial soil level.

The irrigation was applied only once (80 mm) at the sunflower early flowering stage.

At maturity, a sample of sunflower plants was collected from each elementary 10 m^2 plot and then separated by leaves, stems and heads. Total dry weight biomass (48 h at 70 °C) and N content of the different plant parts (CHN elemental analyser Fison EA 1108) were determined, allowing the calculation of N uptake (N content per dry weight). The following parameters were also determined: seed yield (at 10% of humidity) and protein and oil content (extraction with diethyleter in Soxlhet for 36h).

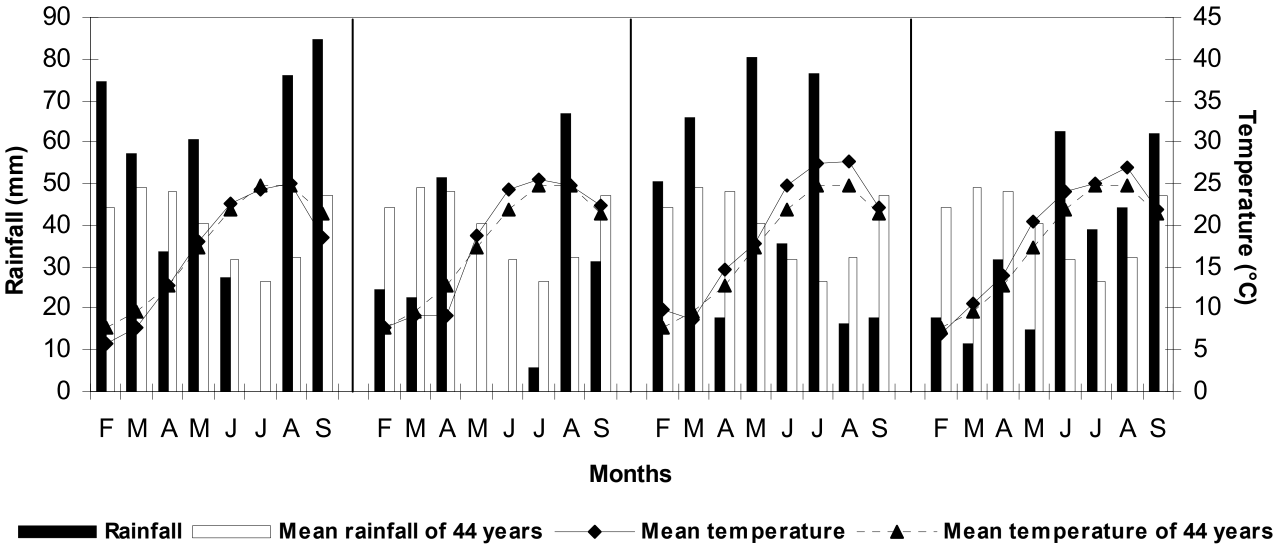


Fig. 1 - Monthly average of air temperature and rainfall during the four-year trial period.
Fig. 1 - *Temperature e piogge medie mensili registrate durante i quattro anni di sperimentazione.*

To better understand the yield performance of the treatments, the oil production (yield per oil content) was calculated. Based on these measurements, the N utilisation efficiency "NUE" (ratio of grain weight to N uptake, in kg kg^{-1}) and the N harvest index "NHI" (ratio of N uptake by the seeds to N uptake by the plants, in %) were also determined, according with the terminology of Montemurro *et al.* (2002).
Statistical analysis was made using the SAS software package (SAS Institute, 1990), considering the years as random and both the genotypes and N fertilisation levels as fixed effects. Differences among treatments were evaluated by means of the Duncan Range Multiple Test (DMRT). For most of the parameters measured the full analysis of variance, which involved all first order variables and interactions, was significant for the 4-year field trial, year x N fertilisation and year x genotype interactions. Hence, the data presentation is divided following these sub-categories.

Results and discussion

Weather conditions

Fig. 1 shows the monthly average of air temperature and rainfall during the four-year field experiment compared with the long-term averages (1952-1995). Great difference was found throughout the trial years in spring and summer, which are the most important seasons for the sunflower growth (Tab. 1). In particular, the sum of rains fallen in these two seasons were 282.6, 155.8, 244.7, 254.4 mm for 1996, 1997, 1998, 1999, respectively, vs. the 225.6 mm of the long-term period. These values point out that in the 1997 the rainfall was lower than the other trial years and that the reduction was larger in spring (- 57% in comparison with the 44 long-term value) than in summer. Consequently, although the sunflower received an irrigation at the early flowering time (about 80 mm), this trend strongly influenced the

Tab. 1 - Average rainfall and temperature of the spring-summer period in the four-year trial experiment.
Tab. 1 *- Piogge e temperature medie registrate durante i periodi primavera- estate nei quattro anni di sperimentazione.*

	Rainfall (mm)		**Mean temperature (°C)**	
Years	Spring	Summer	Spring	Summer
1996	122.0	160.6	17.8	22.6
1997	51.8	104.0	17.3	24.2
1998	133.4	111.3	19.1	25.7
1999	109.4	145.0	19.5	24.7
44 -years mean	120.4	105.2	17.3	23.7

Tab. 2 - Mean values of genotype (column) and year (row) and genotype-year interaction for oil production (t ha^{-1}).
Tab. 2 *- Valori medi del genotipo (colonna) e dell'anno (riga) ed interazione genotipo-anno per la produzione di olio (t ha^{-1}).*

Genotype	**Year**				
	1996	1997	1998	1999	Mean
Isoleic	1.03g	1.10fg	1.46cd	1.57bd	1.29b
Sanbro	1.51cd	1.08fg	1.57bd	1.99a	1.54a
Akiles	1.42ed	1.27ef	1.55bd	1.64bc	1.47a
Select	1.49cd	1.18fg	1.57bd	1.58bd	1.46a
Prointa AGD	-	1.04g	1.65bc	1.75b	1.48a
Mean	1.36c	1.13d	1.56b	1.71a	

The values of the means of both genotype (column) and year (row) and of the interaction genotype-year which present any common letter are significantly different according to DMRT at P≤0.05.

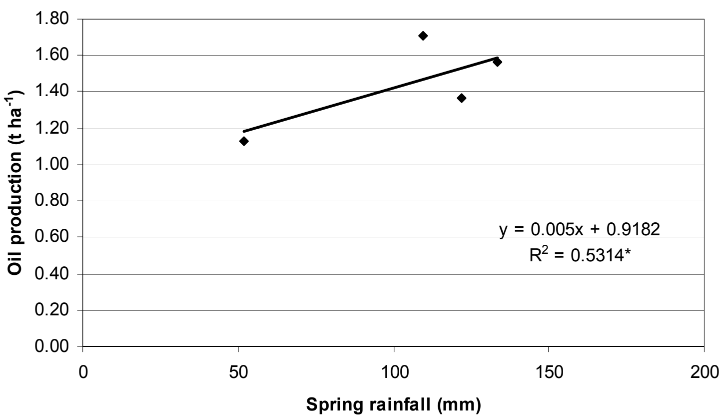
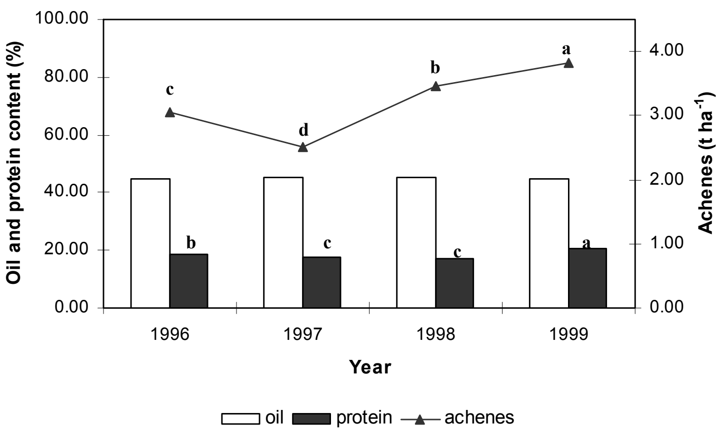


Fig. 2 - Relationship between oil production and spring rainfall for a four-year experiment.
Fig. 2 *- Correlazione tra la produzione di olio e la pioggia registrata nel periodo primaverile nei quattro anni di sperimentazione.*

sunflower response to N fertilisers. In fact, different authors (Lòpez-Bellido *et al.* 2003; Montemurro and De Giorgio, 2005) reported that N uptake, and consequently yield performance, increased if there is an adequate soil watering during the sunflower growth.
The mean temperatures of spring in 1998 and 1999 (19.1 and 19.5 °C, respectively) were higher than those of 1996, 1997 and long-term period (17.8, 17.3 and 17.3 °C), while in the summer only slight difference was recorded (22.6, 24.2, 25.7, 24.7 °C and 23.7 °C for 1996, 1997, 1998, 1999 and long-term period, respectively) (Fig. and Tab.1). On the whole, the last two experimental years presented better climate conditions during the vegetative sunflower phases in comparison with the first two trial years.

Effects of years on sunflower yield and quality
The variation of climatic conditions significantly influenced the mean oil productions (1.36, 1.13, 1.56 and 1.71 t ha^{-1} for 1996, 1997, 1998, 1999, respectively) (Tab. 2). The year characterized by lowest rainfall during the vegetative sunflower phases (1997) showed a decrease of oil production of the 33.9% compared to 1999 experimental year. Also the 1998 year presented significantly higher oil production than the first two field trials, confirming the importance of good climatic conditions (temperature and rainfall) in sunflower yield. The low amount of rainfall observed in summer 1997 (104 mm) (Tab. 1) determined a reduction of water available for grain filling, thus increasing the detrimental effects of water stress on the formation of achenes and, consequently, reducing the sunflower yield, in agreement with the findings of Botella Miralles *et al.* (1997).
The linear regression analysis between the sunflower oil production and the rainfall during the whole growing season of the four-year experiment was significant (Oil production = 0.003rainfall + 0.7335; R^2 = 0.4387*). However, the goodness of fit was improved and the value increased when only the amount of the rainfall of the spring period (vegetative phases) was considered (Fig. 2), even it the slopes were similar in any cases. Conversely, the regression of the sunflower oil production with the rainfall during summer period was not significant, (oil production = 0.0034rainfall + 1.0011; R^2 = 0.1336) in agreement with the results of Pinthus (1963) which found that adverse both rainfall and temperature during ripening interfere with the accumulation of oil in achenes, thus reducing their oil production. Therefore, these findings, although with a relative small number of observations, indicated that the first phases of sunflower growth are the most important (occurred in springs), since those strongly affect the final yields. The availability of additional water accumulated by fallow under the semiarid conditions, fell in spring period, could be considered a key to sunflower productivity. Similar results were found in other crops by Lòpez-Bellido *et al.* (1996) and in sunflower by Magrin *et al.* (2004), which suggested that a high rainfall in spring period contributed to increase yields, especially in semiarid areas. Furthermore, Pinthus (1963) indicated that a favourable climate during vegetative period increase the total number of achenes, while rainfall and nutrient deficiencies reduce their number, increasing the infertile parts of the sunflower head.
With reference to the genotype-year interaction for oil production (Tab. 2), significant differences were found among the genotypes (1.29, 1.54, 1.47, 1.46 and 1.48 t ha^{-1} for Isoleic, Sanbro, Akiles, Select and Prointa AGD,



Within years and parameters (achenes production, oil and protein content) the means followed by different letters are significantly different according to DMRT at P≤0.05.

Fig. 3 - Sunflower achenes production, oil and protein content in the four-year experiment.
Fig. 3 *- Resa, contenuto di olio e proteina nei quattro anni di sperimentazione.*

respectively). In particular, the highest absolute performance was observed for Sanbro in 1999 (1.99 t ha^{-1}), which presented good yield throughout the whole experimental period, while the Isoleic hybrid showed a lower yield, even in the most favourable climatic conditions of 1999. High variability in oil production was found for Prointa AGD, ranged from 1.04 t ha^{-1} of 1997 and 1.75 t ha^{-1} of 1999, thus showing that, although this genotype was selected for drought characteristics, it presented low adaptability in arid climates. This finding pointed out that the selection of genotypes well adapted to the specific environmental conditions is very important for obtaining good results (Leto *et al.*, 1997).
Tab. 3 shows the N fertilisation-year interaction for oil production. As mean of field trials, a significant difference was found among the N fertilisation treatments and, in particular, N100 showed the highest oil production compared to N0 and N50 (1.50, 1.42 and 1.41 t ha^{-1}, respectively). As a consequence, our results seem to justify the high N application rates used by farmers. However, Lòpez-Bellido *et al.* (2003) indicated that the application of N fertilisers in sunflower, cropped in semiarid conditions, is a controversial practice, since N availability is governed by rainfall patterns. The results obtained in our study confirmed this finding, because N100 reached the highest value (1.74 t ha^{-1} in 1999) but also one of the lowest (1.14 t ha^{-1} in the driest 1997). In addition, the oil production of sunflower grown without any fertilisers (N0) presented no substantial difference with N100 in all experimental years, except in 1996, confirming again that the weather conditions strongly influenced the sunflowers performance in Mediterranean environment (Botella Miralles *et al.*, 1997). Therefore, this four-year experiment suggested that the annual rate of N fertiliser could be 100 kg ha^{-1}, according to the weather conditions during the vegetative phases.
No significant difference among years was found in oil content, indicating that this parameter is more influenced by genetic background than climatic conditions (Maiorana *et al.*, 2005; Montemurro and De Giorgio, 2005) (Fig. 3). Furthermore, Scheiner *et al.*, (2002) pointed out that the reduction of oil content due to agronomical practices is relatively small. A significant higher protein content value was obtained in 1999 (20.4%) in respect to 1997 and 1998 years (17.6 and 17.3%, respectively). Conversely, the seed yield in 1998 and 1999 presented higher values than the other two field trials, as found for oil production.

Effects of years on sunflower N uptake and efficiency

Significantly higher mean value of N uptake was found in 1999 compared to the other trial years (Tab. 4); in particular, the level of this important parameter was extremely low in 1997 (78.44 kg ha^{-1}), confirming that N uptake is limited by drought conditions. As a consequence, sunflower oil production was reduced, because of the high correlation between these two parameters, as suggested by Corbeels *et al.* (1998) and Montemurro *et al.* (2005). Among the genotypes, Akiles and Select showed the highest mean values of total N uptake (103.41 and 106.84 kg ha^{-1}, respectively) throughout the trial years. Therefore, the genotypes reached different values of total N uptake, indicating that sunflower crop is particularly susceptible to different agronomic management and climatic conditions (Murillo *et al.*, 1998).
Tab. 5 shows the N fertilisation level-year interaction for total N uptake. A significant difference was found in N uptake as mean values (95.50, 98.57 and 106.04 kg ha^{-1} for N0, N50 and N100, respectively). As found in oil production, the N100 treatment reached the highest value of N uptake (119.49 kg ha^{-1} in 1999) and one of the lowest values (79.60 kg ha^{-1} in 1997), indicating that a higher N supply cannot overcome the limits imposed by environmental conditions. Therefore, in Mediterranean areas the potential N uptake of sunflowers is more limited by soil water level than N supply and the additional N application could have a negative effect on the productions.

Tab. 3 - Mean values of N fertilisation level (column) and year (row) and N fertilisation level-year interaction of the oil production (t ha^{-1}).
Tab. 3 - *Valori medi del livello di fertilizzazione azotata (colonna) e dell'anno (riga) ed interazione livello di fertilizzazione azotata-anno per la produzione di olio (t ha^{-1}).*

N fertilisation	Year 1996	1997	1998	1999	Mean
N0	1.25cd	1.14d	1.55b	1.73a	1.42b
N50	1.32c	1.11d	1.54b	1.65ab	1.41b
N100	1.52b	1.14d	1.60ab	1.74a	1.50a
Mean	1.36c	1.13d	1.56b	1.71a	

The value of the means of both N fertilisation level (column) and year (row) and of the interaction of N fertilisation level-year which present any common letters are significantly different according to DMRT at P≤0.05.

Tab. 4 - Mean values of genotype (column) and year (row) and genotype-year interaction for total N uptake (kg ha^{-1}).
Tab. 4 - *Valori medi del genotipo (colonna) e dell'anno (riga) ed interazione genotipo-anno per l'azoto asportato (kg ha^{-1}).*

Genotype	Year 1996	1997	1998	1999	Mean
Isoleic	85.66f	67.13fg	107.51bd	117.77ac	94.52c
Sanbro	119.48ac	80.74fg	87.27ef	101.05ed	97.13bc
Akiles	105.29bd	82.41f	104.50cd	121.46ab	103.41ab
Select	109.02ad	83.02f	110.85ad	124.48a	106.84 a
Prointa AGD	-	78.92fg	101.43ed	107.89bd	96.08cb
Mean	104.86b	78.44c	102.31b	114.53a	

The value of the means of both genotype (column) and year (row) and of the interaction of the genotype-year which present any common letters are significantly different according to DMRT at P≤0.05.

Tab. 5 - Mean values of the N fertilisation level (column) and year (row) and N fertilisation level-year interaction for total N uptake (kg ha^{-1}).
Tab. 5 *- Valori medi del livello di ferilizzazione azotata (colonna) e dell'anno (riga) ed interazione livello di fertilizzazione azotata-anno per l'azoto asportato (kg ha^{-1}).*

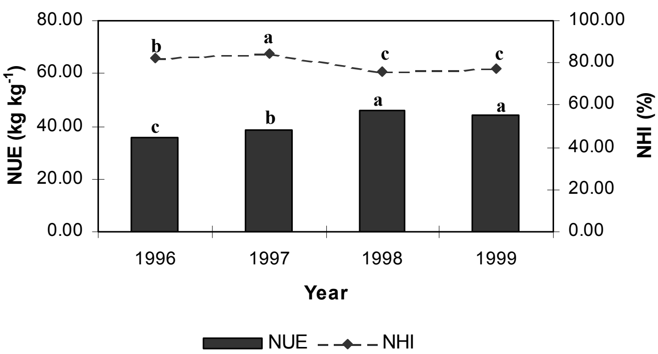
N fertilisation	Year				
	1996	1997	1998	1999	Mean
N0	97.25cd	77.49e	95.69d	111.57ab	95.50b
N50	100.68bd	78.24e	102.83bd	112.52ab	98.57b
N100	116.66a	79.60e	108.42ac	119.49a	106.04a
Mean	104.86b	78.44c	102.31b	114.53a	

The value of the means of both year and N fertilisation level (column) and year (row) and of the interaction N-fertilisation level-year which present any common letters are significantly different according to DMRT at P≤0.05.

Significant difference was found in NUE values among years (Fig. 4), indicating that climatic conditions also influenced the sunflower capability to translate N uptake in the yielding components of plants. The mean value of NUE recorded in this study was low (41.10 kg kg^{-1}), pointing out that sunflower requires a higher N rate to optimise yields. These results could be due to high values of N supplied by the soil to the sunflower through the mineralisation of organic nitrogen accumulated during the previous years. Our finding suggested that it is extremely difficult for this plant grown in Mediterranean conditions to match higher yield performance and a better agroecosystems expectation.
The NHI values showed a better translocation ability of N uptake in sunflower plants grown in 1996 and 1997 in respect to 1998 and 1999. Once more, the results indicated a significant influence of weather conditions on sunflower performance and N utilisation ability.
On the whole, as mean value, the N100 treatment showed the highest performance in oil production (Tab. 3), N uptake (Tab. 5), and protein content, while there was no reduction in oil content (data not showed), confirming the results of other researches (Ujjanaiah *et al.*, 1995; Dalla Costa and Giovanardi, 1996), which suggested 100 kg N ha^{-1} as the optimal N fertilisation level. However, our results highlighted that this N amount should be distributed according to the climatic conditions and, in particular, to the rainfall of vegetative period. As a consequence, considering that sunflower plants can both absorb a high amount of residual N from the soil (Leto *et al.*, 1997) and produce yield with low N input (Sinsawat and Steer, 1993), the mineral N fertiliser could be applied only annually and according to the total N uptake.

Conclusions

The results obtained in this four-year experiment allow us to draw a practical conclusion on the best N fertilising strategy of sunflower, as a function of the annual weather conditions. The rainfall below 100 mm during the sunflower growth period (1997 experimental year) did not allow to have a response about the sunflower N application rates. The amount of 50 kg N ha^{-1} could be used during the first sunflower stages and the additional N fertiliser can be applied as a top dressing according to the amount of rainfall fallen during the spring season, the residual N present in the soil and, as a consequence, the N uptake.
The weather conditions strongly influenced sunflower responses and, in particular, the oil production; in fact, in 1997 it showed a reduction of 33.9% in respect to 1999 years, which was characterised by the best rainfall distribution. The same behaviour was also found for N uptake (31.5% of reduction). The genotypes and the N fertilisation treatments showed different values of N uptake and oil production throughout the trial years. Furthermore, considering that the same amount of N fertiliser reached both the highest and one of the lowest values of oil production and N uptake in the experimental years, the N supply could be applied on annual basis, according to rainfall and air temperatures.
Finally, the low mean value of NUE recorded in this research (35.50 kg kg^{-1}) indicated that sunflower plants require high N supply for optimising N uptake and oil production. Therefore, in order to reduce the negative environmental impact of cultivation (high N supply usually causes great groundwater nitrate contamination), it is necessary to select recommended sunflower genotype and adjust fertiliser rates to crop requirements.



Within years and parameters (NUE and NHI) the means followed by different letters are significantly different according to DMRT at P≤0.05.

Fig. 4 - Sunflower NUE and NHI values in the four-year experiment.
Fig. 4 *- NUE e NHI nei quattro anni di sperimentazione.*

References

Botella Miralles, O., De Juan Valero, J.A., De Santa Olalla, M., 1997. Growth, development and yield of five sunflower hybrids. Eur. J. of Agron., 6, 47-59.

Corbeels, M., Hofman, G., Van Cleemput, O., 1998. Residual of nitrogen fertilisation in a wheat-sunflower cropping sequence on a Vertisol under semi-arid Mediterranean conditions. Eur. J. of Agron., 9, 109-116.

Dalla Costa, L., Giovanardi, R., 1996. Nitrogen use efficiency and nitrate losses in sunflower and maize: a comparison. Atti del "Proceeding of the 14th International sunflower conference", Shenyang China, 12-20 June 1996, 284-289.

Hocking, P.J., Steer, B.T., 1995. Effects of timing and supply of nitrogen on nitrogen remobilization from vegetative organs and redistribution to developing seeds of sunflower. Plant and Soil, 170, 359-370.

Janzen, H.H., Beauchemin, K.A., Bruinsma, Y., Campbell, C.A., Desjardins, R.L., Ellert, B.H., Smith, E.G., 2003. The fate of nitrogen in agroecosystems: an illustration using Canadian estimates. Nutrient Cycling in Agroecosystems, 67, 85-102.

Leto, C., Montemurro, F., Losavio, N., Bottazzi, P., Giordano, I., Marras, G., Palazzo, D., Sunseri, F., 1997. Effetti della riduzione degli input di coltivazione sul girasole (Helianthus annuus L.) coltivato in diversi ambienti mediterranei. Riv. di Agron., 31 (4), 984-992.

Lòpez-Bellido, L., Fuentes, M., Castillo, J.E., Lòpez-Garrido, F.J., Fernàndez, E.J., 1996. Long-term tillage, crop rotation, and nitrogen fertilizer effects on wheat yield under rainfed Mediterranean conditions. Agron. J., 88, 783-791.

Lòpez-Bellido, R.J., Lòpez-Bellido, L., Castillo, J.E., Lòpez-Bellido, F.J., 2003. Nitrogen uptake by sunflower as affected by tillage and soil residual nitrogen in a wheat-sunflower rotation under rainfed Mediterranean conditions. Soil & Tillage Research, 72, 43-51.

Magrin, G.O., Travasso, M.I., Rodriguez, G.R., 2004. Changes in climate and crop production during the 20th century in Argentina. Climatic change, 72, 229-249.

*Maiorana, M., Charfeddine, M., Montemurro, F., Vonnella, A.V., 2005. Reduction of agronomic inputs in sunflower (*Helianthus annuus *L.). Helia, 28, 133-146.*

Montemurro, F., De Giorgio, D., 2005. Quality and nitrogen use efficiency of sunflower grown at different nitrogen levels under Mediterranean conditions. Journal of Plant Nutrition, 28 (2), 335-350.

Montemurro, F., Convertini, G., Maiorana, M., Ferri, D., 2002. N-use efficiency, yield and quality in maize-winter barley rotation. Agrochimica, 46 (3-4), 146-154.

Montemurro, F., Maiorana, M., Convertini, G., Fornaro, F., 2005. Improvement of soil properties and nitrogen utilisation of sunflower by amending municipal solid waste compost. Agronomy Sustainable Development, 25, 369-375.

Murillo, J.M., Moreno, F., Pelegrín, F., Fernanández, J.E., 1998. Responses of sunflower to traditional and conservation tillage under rainfed conditions in southern Spain. Soil & Tillage Research, 49, 233-241.

Pinthus, M.J., 1963. Some environmental effects on the oil yield components of sunflower seeds. Plant foods for human nutrition, 9, 328-336.

SAS Institute - 1990 - SAS/STAT Software. SAS Institute Inc. Cary, NC.

Scheiner, J.D., Gutiérrez-Boem, F.H., Lavado, R.S., 2002. Sunflower nitrogen requirement and 15N fertilizer recovery in Western Pampas, Argentina. Eur. J. of Agron., 17, 73-79.

*Sinsawat, V., Steer, B.T., 1993. Growth of florets of sunflower (*Helianthus annuus *L.) in relation to their position in the capitulum, shading and nitrogen supply. Field Crops Res., 34, 83-100.*

*Steer, B.T., Hocking, P.J., Low, A., 1985. Nitrogen nutrition of sunflower (*Helianthus annuus *L.): concentrations, partitioning between organs and redistribution of N in seven genotypes in response to N supply. Field Crops Res., 12, 17-32.*

Sylvester-Bradley, R., 1993. Scope for more efficient use of fertiliser nitrogen. Soil Use and Management, 9, 112-117.

Ujjanaiah, U.S., Thimmegowda, S., Sridhara, S., Prasad, T.G., 1995. Effect of moisture, plant population and fertilizer regimen on yield of sunflower. Helia, 22, 77-82.