SUNFLOWER PRODUCTION RESPONSE IN RELATION TO WATER AVAILABILITY

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Summary

Research was carried out in the years 1987, 1988 and 1989 at the experimental farm of the Grosseto centre of the Tuscan Regional Body for agricultural and forestal development, situated at "Barbaruta".

In each of these years, in an experimental scheme using a split-plot design, with three replications, three hybrids characterized by a different length of biological cycle ("Romsun HS 90", "Gloriasol" and "Stromboli") and six irrigated theses were compared. The theses consisted of : one control irrigated only at seeding (0/0) to guarantee uniformity in emergence; one thesis fully irrigated according to its requirements throughout the cycle (I), ensuring 100% reintegration of maximum evapo-transpiration minus rainfall above 10 mm ; another four theses (0/1, 1/1, 0/2 and 1/2) to which 1 - 3 waterings were administered in specific phases of the biological cycle susceptible to water stress, restoring the soil to field capacity down to a depth of 70 cm.

The natural water supply in the area where the experimental farm is situated ensures that spring-sown sunflower normally does not require watering until inflorescence appears. Subsequently, however, water availability is crucial for production.

The criterion adopted of watering in specific phenological plant stages sensitive to water deficit led to satisfactory results. In particular, applying irrigation at the beginning of anthesis together with further irrigation roughly half-way through maturation (15 d after flowering) proved to be the most effective means of obtaining a significant increase in number and weight of achenes and also in their oil percentage. These two waterings (thesis 0/2) also presented greatest water efficiency and lowest evaporation coefficient values. Mean production increase over the three-year period for thesis 0/2 was over 26% (compared to the control irrigated only at seeding), with total irrigation rates of 267 mm. As regards the hybrids, "Gloriasol", characterized by a biological cycle of medium length, provided the most satisfactory production results.

Introduction

In Italy sunflower cultivation takes place predominantly in environments where the water available for irrigation is, generally speaking, very limited. This is mainly because the oil crop manages, thanks to its adaptability and hardiness, to provide considerable yields even in hilly areas and those characterized by scant rainfall during the spring-summer period (Salera and Detti, 1990), where the more common intertilled crops, such as sugar beet and maize, are unlikely to be grown. This is because the plant not only has an excellent extractive capacity for soil water (Berengena and Henderson, 1980) but also succeeds in using the water reserves present at deep levels in the soil (Boyer, 1976; Quaglietta Chiarandà et al., 1990).

In the principal areas of cultivation, spring-sown sunflower crops usually manage to complete the vegetative phase without running into problems of water deficit thanks to the water reserves accumulated in the soil during the winter and the spring rainfalls. Subsequently the lack of rainfall, the higher mean temperatures and the water consumption of the plants, which reaches its peak in the critical period between the appearance of the flower bud and grain filling (Blanchet and Merrien, 1982; Dubbelde et al., 1985; Merrien, 1986; Merrien, 1988; Bonari et al., 1989; Rizzo et al., 1989), are the principal factors limiting production.

In these environments of limited water availability during the spring-summer period, where irrigation is a possibility, the criterion of watering only in the above-mentioned phases of the biological cycle of the plant, when its sensitivity to shortages is greatest, could result in considerable water savings without causing yield reductions. With this aim and within the "Oil Plants" Project of the Ministry of Agriculture and Forests, Subproject "Sunflower", a research project covering a period of several years was carried out in various locations in Italy typical for sunflower cultivation, of which the results presented in this paper are a part.

Materials and methods

The present research was carried out in the three-year period 1987-89 on the experimental farm at the Grosseto Centre of the Tuscan Regional Body for agricultural and forestal development, situated at "Barbaruta". In every case the trials took place on flat land, located on the middle Tyrrhenian coastal strip; the physico-chemical and hydrological characteristics of these soils are indicated in Table 1.

Every year, in an experimental scheme using a split-plot design with three replications, comparisons were made between three *sunflower* hybrids each with a biological cycle of different length, "Romsun HS 90", "Gloriasol"and "Stromboli" (respectively, early, medium and late), and the following six irrigated theses:

- thesis 0/0, control irrigated only at seeding;
- thesis 0/1, one watering at the beginning of anthesis (Schneiter and Miller's stage R5) (Schneiter and Miller, 1981);
- thesis 1/1, two waterings, the first of which at the flower bud stage (Schneiter and Miller's stage R2) and the second at the beginning of anthesis;
- thesis 0/2, two waterings, one at the beginning of anthesis and the next 15 days after the beginning of anthesis;
- thesis 1/2, three waterings of which one at the flower bud stage and two as in thesis 0/2;
- thesis I, fully irrigated according to the requirements *throughout the biological cycle of the sunflower crop.*

In addition to irrigation at seeding, all the theses included irrigation rates such as to restore the field capacity of the soil from 0 to 50 centimetres depth.

The fully irrigated thesis (I) ensured 100% reintegration of maximum evapo-transpiration minus effective rainfall (that is, over 10 mm in 24 hours). The latter was estimated on the basis of the evaporate from a class "A" pan (Eo"A"), corrected with the following crop coefficients (Kc):

Kc 0.4 - up to the tenth true leaf (Schneiter and Miller's V10 stage);
Kc 0.7 - up to flower bud;
Kc 1.0 - up to 15 days after the beginning of anthesis;
Kc 0.8 - up to 30 days after the beginning of anthesis;
Kc 0.5 - up to physiological maturity (Schneiter and Miller's R9 stage).

Due to the differing precocity of the experimental hybrids, *for the definition of the Kc's the phenological phases* were observed on the earliest of the hybrids, "Romsun HS 90", for the increasing Kc's (0.4, 0.7 and 1.0) and on the latest of the hybrids, "Stromboli", for the decreasing Kc's (0.8 and 0.5). The change of Kc was made in every case when the phenological phase under consideration was present in 50% of the plants. The calculation of the maximum evapo-transpiration was taken as starting as from the date of the irrigation carried out after seeding and was common to all the theses.

The irrigation rate, kept constant throughout the irrigation period, was calculated on the basis of the hydrological and physical characteristics of the soil, so as to restore 2/3 of the water available to the plant for a soil depth of 50 centimetres. Irrigation was carried out when the crop had used all the water supplied by the previous irrigation, as a result of which the irrigation timetable varied according to the estimated consumption.

On the other hand in the theses which provided irrigation in the phenological phases in which the crop is presumably more susceptible to water stress, the irrigation rate was calculated for each watering operation (based on the humidity profile from 0 to 75 cm recorded in the plots of every thesis before irrigation) so as to restore the soil to field capacity down to a depth of 70 centimetres. In every case irrigation took place when 50% of the plants were in the particular phenological phase and, given the differing precocity of the trial cultivars, in different periods for each of these.

The irrigation system adopted always used a highly efficient distribution method (localized system), with the exception of irrigation at seeding which was carried out simultaneously for all the theses by sprinkling; every experimental hybrid and, within the area of each of them, every irrigated thesis was watered separately.

The ground for the trials was always ploughed the previous summer, to a depth of 40-50 cm, worked with a grubber during the winter and prepared finally for sowing a few days beforehand.

Basal dressing consisted of 100 kg/ha of phosphorus and 80 kg/ha of potassium, while nitrogen was applied at the rate of 150 kg/ha while the seed bed was being prepared.

Sowing took place, using a parcel sowing machine, on the 6th April 1987, the 15th April 1988, and the 19th April 1989. Each plot, consisting of six rows of plants 60 cm apart, had an area of 25.2 m2 (7.0 m x 3.6 m); both the first order plots (hybrids for comparison) and the second order ones (irrigated theses) were suitably separated from one another by sowing another three rows of sunflower so as to prevent the effects of irrigation being felt also in the adjacent plots. The same density of 5 plants/m2 was used for all the theses and all the hybrids.

Weed control was carried out by the application, in crop pre-emergence, of a herbicide mixture consisting of Metobromuron + Prometrina (500 + 1000 g/ha).

On the crop were recorded values concerning the date of attainment of the principal phenological phases, expressed in days from emergence and referring to the moment in which 75% of the plants were seen to be in one of the above-mentioned phases.

At maturity observations were carried out on the height of the plant, the head diameter and the sterile part area sometimes present at the centre of the latter, while at harvest achene humidity and yield expressed in t.ha-1 at 0% humidity were determined. The 1000-achene weight and the percentage content of oil in the achenes (by NMR method) were also determined. Finally for every irrigated thesis the water efficiency (g d.m. achenes/l) and the evaporation coefficient (l/kg d.m. achenes) were calculated. For the observations concerning the yield characters, the test area was limited in every plot to the four central rows, and furthermore eliminating from the latter the last three plants at each end.

The thermopluviometric trend, recorded during the three-year trial period, is shown in Figures 1, 2 and 3.

With the aim of obtaining one factorial experiment only (years x hybrids x irrigated theses), the trials were sown every year on soils with similar characteristics and always in rotation with hard wheat.

All the data recorded underwent analyses of variance according to the arrangement in the field of the split plots.

Results and discussion

Year effect. All the characters examined, with the exception of the 1000-achene weight, were seen to be influenced by the climatic trend (Tabs. 2 and 3). In particular, the higher temperatures which occurred in the second trial year (Fig. 2) caused a shortening of the phenological phases in question (Tab. 4) which on the other hand achieved their greatest extent in 1987 due also to a certain anticipation in the sowing date. The biometric and yield characters were also significantly greater in the latter year (Tab. 4 and 5).

Hybrid effect. The behaviour shown by the cultivars under comparison, confirmed the differences in their biological cycle (Tab. 4). The "Stromboli" variety, as one might have expected from its phenological characteristics, was seen to be the latest, showing the longest duration for all the three periods in question. It is also of interest to note that the cultivar "Gloriasol" showed the period beginning of anthesis - physiological maturity similar in duration to that of the late hybrid, which allowed it, notwithstanding a shorter biological cycle, to complete the delicate and important phases of seed setting and grain filling under optimal conditions.

Analysing the biometric characters, statistical processing has shown how on average in the three-year experimental period the greatest plant height (Tab. 4) was displayed by the hybrid "Stromboli", which also showed the smallest head diameter and the greatest value for the sterile part area present in the latter. Concerning the yield characters (Tab. 5), "Gloriasol" was seen in every case, with the exception of the 1000-achene weight, to be the best.

Irrigation treatment effect. The length of the phenological periods, in particular those of beginning of anthesis-physiological maturity and emergence-physiological maturity (Tab. 4), was seen to be closely related to the number of waterings and the quantity of water distributed. In fact passing from thesis 0/0 to those following, a significative increase in the length of the above-mentioned periods occurred which became maximum (for $P \leq 0.05$) in thesis I.

Generally speaking, the different irrigation treatments also significantly influenced the value both for plant height and head diameter (Tab. 4). Both characters in fact showed the greatest values, statistically similar among themselves, in the theses I and 1/2, whereas the plant and the head of significantly least dimensions were obtained with the non-irrigated thesis. Even the sterile part area of the head felt the effect of the various irrigation treatments. In fact the greatest sterility was found in the theses 0/0 and 0/1, whereas in those where more waterings occurred decidedly lower values were recorded which were statistically similar among themselves.

Moving on to consider the yield characters, in general the statistically greater results were given by the most copiously irrigated theses. In particular, concerning the number of achenes/m2, we note in fact how the greatest values were obtained by theses 1/2 and I (Tab. 5). Even in the case of the 1000-achene weight, thesis I displayed the significantly highest value, while 0/0 and 0/1 the lowest. Theses 1/1, 02 and 1/2, on the other hand, showed intermediate values, statistically similar among themselves. The character "achene yield" was seen to be *influenced significantly by the various* irrigation treatments. The maximum yield was in fact given by the plants on which total reintegration of evapo-transpiration took place, while the non-irrigated control and the thesis 0/1 gave the lowest yields. For the other irrigation treatments, intermediate yields were recorded and in the case of 0/2 and 1/2 there was no significant difference between them.

The oil in the achenes (expressed as percentage of dry matter) was also seen to be directly influenced by the irrigation treatments. In fact a water shortage already present at the flower bud stage, provoking a slowing down in the growth *of the leaf apparatus* (Muriel and Downes, 1974), reduces the assimilation activity, the translocation of assimilates towards the head (Turner, 1986) and consequently the subsequent synthesis of fatty acids. Water stress at the seed setting - physiological maturity stage has repercussions on grain filling and on oil synthesis (Amaducci,1984; Dubbelde et al., 1985), causing, given that in this period its accumulation is very rapid, a lower content of oil in the achenes (Gurr et al., 1972; Appelquist,1975; Blanchet and Merrien, 1982; Blanchet et al., 1988; Merrien, 1988). From the analysis in Table 5 it is obvious that the oil percentage was significantly greater in theses I, 1/2 and 0/2, while the statistically smallest percentage values (for $P \leq 0.01$) were obtained, other than in the dry control, by irrigating only at the beginning of anthesis (0/1) and also when this was preceded by an irrigation in the flower bud phase (1/1). The oil yield, similarly to the achene yield by which it was more directly influenced, was seen to be higher in thesis I; after the latter the best values, statistically similar among themselves, were shown by theses 1/2 and 0/2.

<u>Interaction effect</u>. Statistical processing has shown how, generally speaking, only the interactions years x hybrids, for almost all the characters considered, and, only for some of these characters, years x irrigation treatments were significant (Tabs. 2 and 3). For both interactions an examination of the achene yield seems appropriate. Looking at Figure 4, the first point to note is the lower yield given by the hybrids in 1988; and precisely with regards to the negative result given in this year, "Romsun HS 90", in spite of having

given the statistically greater yields in the other two years, on average showed values similar to those of "Gloriasol", although the latter resulted better concerning the percentage content of oil. The interaction years x irrigation treatments (Fig. 5) has highlighted the fact that in general the yield of the various theses was influenced by the different seasonal trends. In fact in the second trial year all the theses gave lower returns. The significantly greatest yields were achieved in 1987 and 1989 with the thesis which allowed the total reintegration of evapo-transpiration; high yields were also shown by thesis 1/2, in particular in 1989 when it produced the statistically greatest value (for $P \leq 0.05$).

Water efficiency. The relation between the achene dry matter produced and the EET measured, allows an attempt at an evaluation of the efficiency of the water consumed by the crop and the determination of the evaporation coefficient values. Examining these two factors (Tab. 6) it is evident that on average the irrigated theses which showed the greatest water efficiency and the lowest evaporation coefficient values were 0/2 and 1/2. If we observe the average values of the total irrigation rates during the three-year period, we note moreover that 267 mm were supplied to thesis 0/2 in contrast to 283 mm to thesis 1/2.

Conclusions

The criterion adopted of watering at precise phenological phases of the sunflower, in which it is particularly sensitive to water deficit, has, generally speaking, given satisfactory results. In particular, irrigating at the beginning of anthesis together with further irrigation 15 days after the latter (thesis 0/2) proved to be the most effective way of obtaining a significant increase in the number and weight of achenes, as well as in their percentage of oil. Theses 0/2 and 1/2, which in addition to the two above-mentioned waterings received a third at the flower bud stage, displayed the greatest water efficiency and the lowest evaporation coefficient values. On average in the three-year period the thesis 0/2 gave an achene and oil return statistically analogous to that of thesis 1/2 with a lower mean value of the total irrigation rates supplied (267 mm compared to 283 mm), thus stressing the fact that in the environment of the research centre it is possible to do without irrigation at the flower bud stage. The yield increase achieved with thesis 0/2, compared to the control irrigated only at sowing, was over 26%.

As regards the choice of hybrid, "Gloriasol" which is characterized by a medium length biological cycle, gave on average over the three-year period the best yield results, due amongst other to its high oil percentage.

Tab. 1 - Physical, chemical and hydrological characteristics of the trial soils.

Soil characteristics		Values		
		1987	1988	1989
Sand (%)		24	16	19
Silt (%)		43	47	45
Clay (%)		33	37	36
pH (in water)		7.67	7.56	7.75
Total lime (De Astis) (%)		13.3	13.8	13.5
Total nitrogen (Kjeldahl) (‰)		1.7	1.6	1.7
Assimilable phosphorus (Olsen) (ppm)	P	5.6	5.9	5.8
" " " "	P_2O_5	12.82	13.51	13.28
Assimilable potassium (ppm)	K_2O	410	426	417
Organic matter (Lotti) (%)		1.9	1.8	1.9
Soil dry bulk density ($t \cdot m^{-3}$)	0-20 cm	1.25	1.26	1.26
	20-40 cm	1.23	1.26	1.26
	40-60 cm	1.23	1.25	1.25
Field capacity "in situ" (w/w)	0-20 cm	31.9	32.4	32.0
	20-40 cm	31.7	32.2	32.0
Relationship between tension (bar) - soil moisture (w/w)	- 0.3 bar	44.2	42.4	43.1
	- 0.5 bar	36.4	35.3	35.7
	- 1.5 bar	28.9	28.2	28.5
	- 3.0 bar	23.8	23.1	23.6
	- 8.0 bar	17.8	17.6	17.7
	-15.0 bar	16.7	16.4	16.4

Tab. 2 - Significance of variance for some phenologic and biometric characters. (*) Significant at the 0.05 probability level; (**) significant at the 0.01 probability level; (n s) not significant at the 0.05 probability level.

Sources of variation	Period em.-b.a.	Period b.a.-p.m.	Period em.-p.m.	Plant height	Head diameter	Head's sterile part area
Years	* *	* *	* *	* *	* *	* *
Hybrids	* *	* *	* *	* *	*	* *
Irrigation treatments	*	* *	* *	* *	* *	* *
Years x hybrids	* *	* *	* *	* *	n s	* *
Years x irr. treat.	n s	n s	n s	* *	* *	n s
Hybrids x irr. treat.	n s	n s	n s	n s	n s	n s
Yea. x hyb. x irr. tr.	n s	n s	n s	n s	n s	n s

Tab. 3 - Significance of variance for some yield characters. (*) Significant at the 0.05 probability level; (**) significant at the 0.01 probability level; (n s) not significant at the 0.05 probability level.

Sources of variation	No achenes·m-2	1000 grain weight	Yield of achenes	Oil in achenes	Yield of oil
Years	* *	n s	* *	*	* *
Hybrids	* *	* *	* *	* *	* *
Irrigation treatments	* *	* *	* *	* *	* *
Years x hybrids	* *	* *	* *	* *	* *
Years x irr. treat.	* *	n s	* *	n s	* *
Hybrids x irr. treat.	n s	n s	n s	n s	n s
Yea. x hyb. x irr. tr.	n s	n s	n s	n s	n s

Tab. 4 - Average effect of year, hybrid and irrigation treatment on phenologic and biometric characters.

Treatments		Period em.-b.a. (days)	Period b.a.-p.m. (days)	Period em.-p.m. (days)	Plant height (cm)	Head diameter (mm)	Head's sterile part area (%)
Year							
	1987	72.1 aA	40.6 aA	112.7 aA	160 aA	203 aA	3.1 aA
	1988	67.8 cC	38.5 bB	106.3 cC	112 cC	142 bB	0.1 bB
	1989	70.2 bB	39.2 bB	109.4 bB	127 bB	196 aA	0.0 bB
Hybrid							
Romsun HS 90		68.2 cC	37.8 bB	106.1 cC	116 cC	183 a	0.5 bB
Gloriasol		68.9 bB	40.0 aA	108.9 bB	132 bB	181 ab	0.3 cB
Stromboli		73.0 aA	40.4 aA	113.4 aA	152 aA	177 b	1.1 aA
Irrigation treatment	0/0	69.7 c	37.7 cC	107.4 fE	123 eD	168 dD	1.5 aA
	0/1	70.0 ac	38.2 cC	108.2 eD	126 dD	174 cC	1.0 aAB
	1/1	69.8 bc	39.7 bB	109.5 dC	137 bB	182 bB	0.5 bBC
	0/2	70.1 ac	40.0 bAB	110.1 cB	132 cC	183 bB	0.4 bC
	1/2	70.4 a	40.1 bAB	110.5 bAB	140 aAB	186 abAB	0.4 bC
	I	70.2 ab	40.7 aA	111.9 aA	142 aA	189 aA	0.3 bC

Means followed by the same letter do not differ significantly at the 5% level (small letters) and the 1% level (capital letters) according to Duncan's multiple range test.

Tab. 5 - Average effect of year, hybrid and irrigation treatment on yield characters.

Treatments		Number of achenes (no·m-2)	1000 grain weight (g)	Yield of achenes (t·ha-1 0% humid.)	Oil in achenes (% of d.m.)	Yield of oil (t·ha-1)
Year						
	1987	5272 aA	56.8	2.94 aA	51.6 ab	1.52 aA
	1988	4114 bB	57.1	2.28 bB	52.2 a	1.19 bB
	1989	5091 aA	57.5	2.93 aA	50.1 b	1.63 aA
Hybrid						
Romsun HS 90		4017 cC	68.3 aA	2.75 aA	50.3 cB	1.43 bB
Gloriasol		5484 aA	50.3 cC	2.77 aA	52.4 aA	1.51 aA
Stromboli		4976 bB	52.9 bB	2.64 bB	51.1 bAB	1.40 bB
Irrigation treatment	0/0	4357 dD	52.5 cC	2.24 eD	49.9 dC	1.16 eE
	0/1	4571 cCD	53.5 cC	2.40 dD	50.7 cdBC	1.26 dD
	1/1	4693 cC	57.5 bB	2.65 cC	50.9 bcBC	1.40 cC
	0/2	4947 bB	58.4 bB	2.83 bB	52.1 aA	1.53 bB
	1/2	5102 abAB	58.6 bB	2.95 bB	51.6 abAB	1.58 bB
	I	5283 aA	62.3 aA	3.23 aA	52.4 aA	1.75 aA

Means followed by the same letter do not differ significantly at the 5% level (small letters) and the 1% level (capital letters) according to Duncan's multiple range test.

Tab. 6 - Hydrological balance components, water efficiency and evaporation coefficent. Three-year mean values.

Irrigation treatments	Total irrig. rates (mm)	Rainfall (mm)	Water storage of the soil utiliz. (mm)	Effective evapotrasp. (mm)	Water efficiency (g d.m. ach./l)	Evaporation coefficent (l/kg d.m. ach.)
0/0	74	135	90	300	0,75	1337
0/1	189	135	58	383	0.63	1592
1/1	204	135	62	402	0,66	1515
0/2	267	135	- 3	400	0.71	1412
1/2	283	135	- 3	416	0.71	1412
I	421	135	-95	461	0,70	1429

Fig. 1 - Temperature, rainfall and evaporation patterns at 10-day intervals throughout the growing season (march-october 1987).

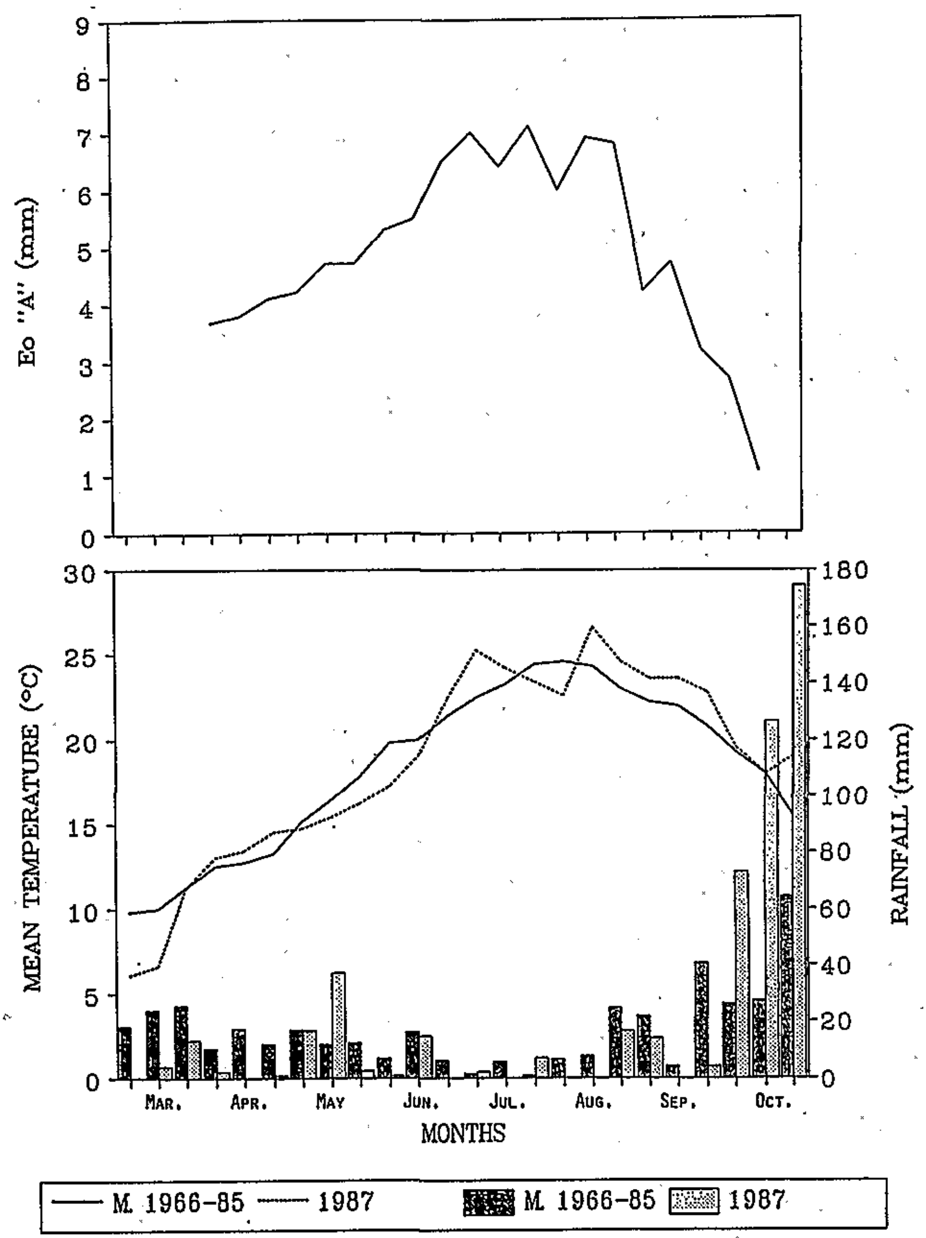


Fig. 2 - Temperature, rainfall and evaporation patterns at 10-day intervals throughout the growing season. (march-october 1988).

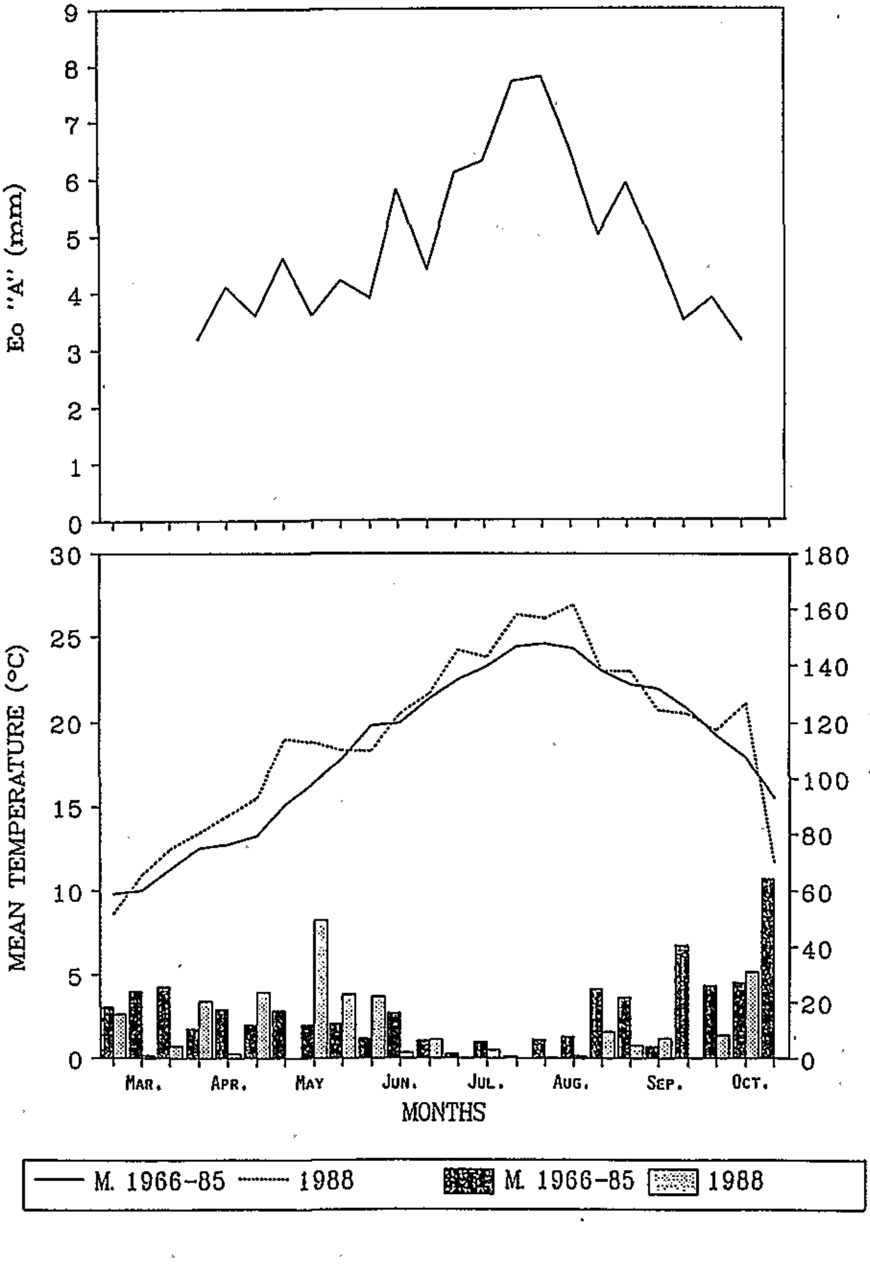


Fig. 3 - Temperature, rainfall and evaporation patterns at 10-day intervals throughout the growing season (march-october 1989).

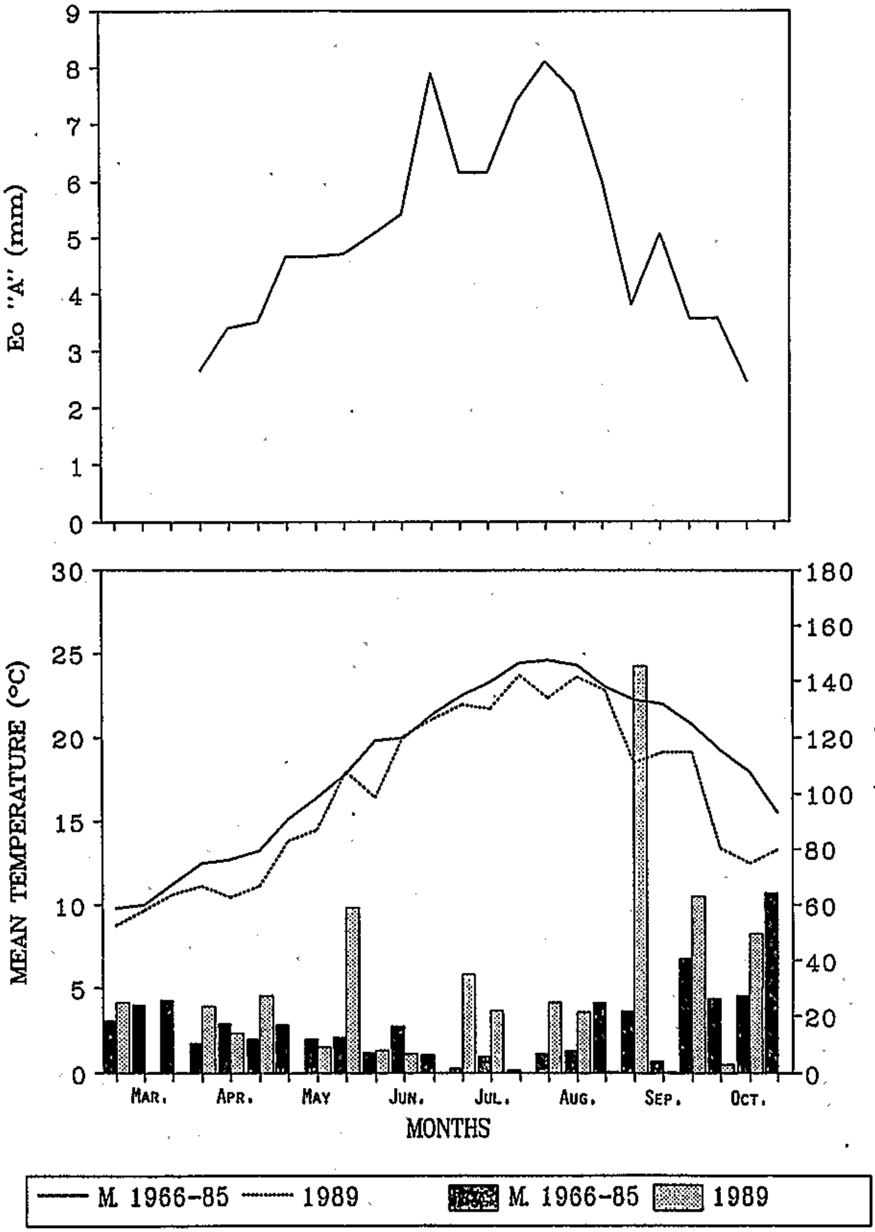


Fig. 4 - Interaction years x hybrids.

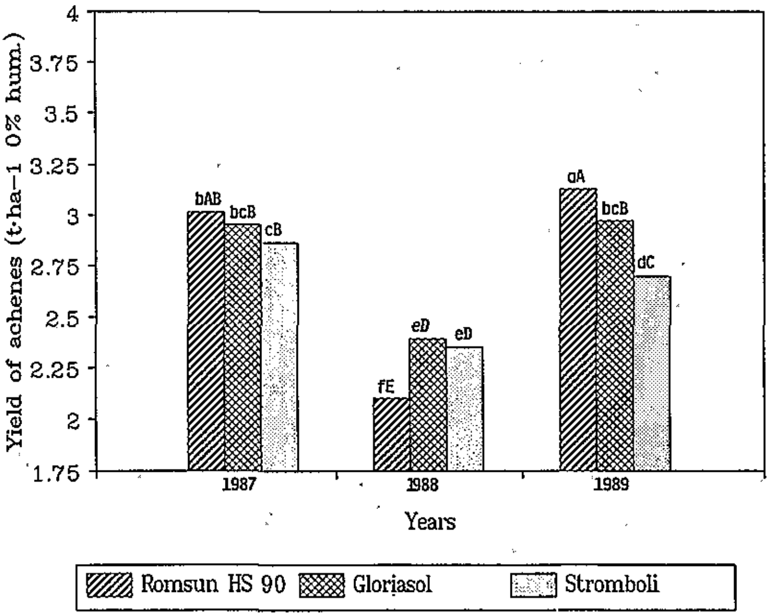
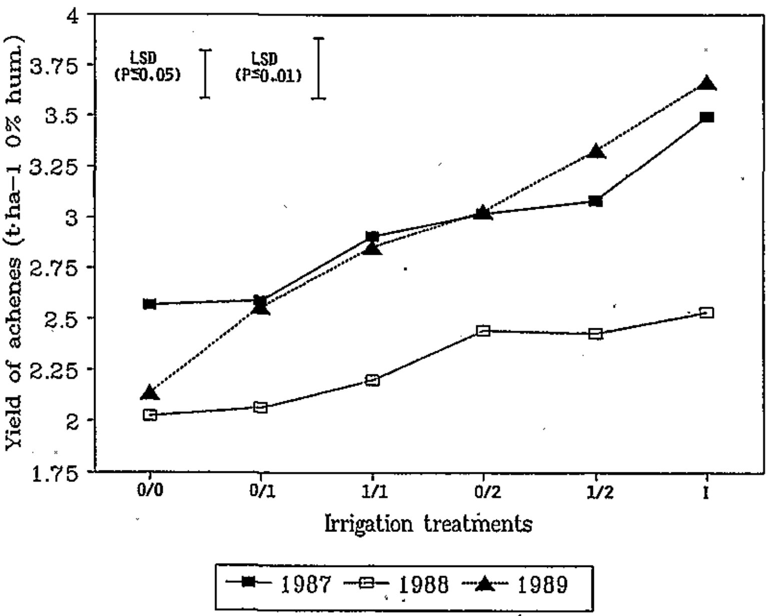


Fig. 5 - Interaction years x irrigation treatments.



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