Sunflower yield and root system development under water stress in tropical conditions

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ABSTRACT

Field experiments were carried out in Limeira, SP, in 2001, 2002 and 2003, to evaluate the sunflower cv. M 742 root system and yield under water stress conditions. A modified absence and presence method was used to evaluate the root system. The experimental design was a randomized block with four replications. The treatments were: (i) always irrigated, (ii) irrigated in critical periods, and (iii) rainfed. Sunflower plants developing under severe water stress showed higher root number, which also grew deeper than in plants under slight or no water stress. Rainfed sunflower showed two to four times more roots at 30 to 80 cm deep than the irrigated treatments. Sunflower cv. M 742 showed a grain yield reduction of about 30% under hard water stress. Under moderate water stress, with water supplementation at budding and grain filling, sunflower showed 17.2% grain yield reduction in relation to no water stress.

Key words: rainfed – root development – root system evaluation – seed yield.

INTRODUCTION

Temperature and water stress are the most important factors for the sunflower crop development and yield, although this plant adapts well to water stress periods (Choné, 1983). The plant is highly sensitive to soil acidity, mainly when a low pH occurs in subsurface levels; in those cases the taproot bends and there is less secondary root development which leads to smaller plants and less grain yield (Ungaro et al., 1985).

There are many studies about sunflower water stress under temperate and semi-arid conditions. Olalde et al. (2001), under sub-humid and semi-arid climate conditions, found different patterns of sunflower development, yield and yield components. These authors suggested that the greater soil humidity led to greater soil nutrient absorption, which resulted in greater grain and oil yield under warm sub-humid climate conditions. The data agreed with those obtained by Asri et al. (2000), who observed that the water supplementation during grain filling period increased the grain yield up to 1500 kg/ha and produced a greater oil content in the seeds. Singh and Singh (2000) found that water stress during flowering and grain filling period negatively influenced the final seed yield.

Bona et al. (2000) argue that sunflower is more tolerant to water stress than other plant species and that the deep root system is the main factor responsible for this trait. The root system is responsible for fixing, absorption, storage and nutrient and water translocation. The root density or volume usually shows a direct influence on the plant growth (Gomes, 1996). The sunflower roots develop fast at the beginning of the plant life cycle, when it is more important than the aerial part. At this time, the roots represent 20 to 25% of the total dry matter; but this proportion drops progressively to 15% at the end of the life cycle (Merrien and Milan, 1992).

Bona et al. (2000) report that sunflower is tolerant to water stress in comparison to other crops due to morphological and physiological characteristics, to its deep root system and also to some metabolic modifications that can be induced by less water availability in the soil. The transpiration index can be used as a metabolic sign which is strongly linked to the plant's physiological process. Under temperate conditions, these authors verified that one of the morphological effects of water stress was the leaf area reduction, which can cause a potential photosynthesis reduction. Foliar development reduction was observed before the transpiration decrease, which demonstrates that sunflower plant is able to tolerate the water stress by limiting foliar development without any transpiration reduction. Sunflower plant subjected to progressive water stress is able to adapt itself and be more efficient than a plant under late stress.

The aim of the study was to evaluate the sunflower grain yield and root development under different water stress regimes.

MATERIALS AND METHODS

Field experiments were carried out at Campo de Pesquisa Hidroagrícola do Pinhal, in 2001 and 2002, and at Horto Municipal Florestal, in 2003, both in Limeira, SP, using the sunflower cultivar M 742, in a winter sowing. Liming was performed only in the first year. The soil was fertilized with 300 kg/ha of 4-20-20 in 2001 and 2002; in 2003, 375 kg/ha of 4-14-8 was used. Twenty days after emergence 40 kg N/ha and 2 kg B/ha was applied, according to Quaggio and Ungaro (1996). Normal spraying irrigation was used. The experimental design was a randomized block with three treatments and four replications. The treatments were: (i) *Always irrigated*; (ii) *Irrigated in critical periods*; (iii) *Rainfed.*

One trench with 1.0 m depth and 1.0 m width was dug between plant rows to expose the sunflower root system in each replication and for the three years of observation. A thin layer of soil (1-2cm) was carefully removed from the wall along the whole trench. The root evaluation was made by the presence and absence methodology, according to Bohm (1979), modified by the authors.

A wire-wood frame with a grid of 0.2 x 0.2 m was pressed against the trench wall and the presence and absence of roots in each grid were recorded. As this method underestimates the root system because it does not consider the number and diameter of the roots, a method modification was tested, consisting of counting the number of roots in each grid.

For the evaluation of the total root number in each layer interval, the number of roots in each grid of a specific layer was summed and added to the results obtained in each replication of the same treatment for the three years. For the seed yield determinations, samples were taken at plant physiological maturation from an area of 10.8 m^{-2} in each replication during the three years and for all treatments.

Data of number of roots were transformed to log (x+1) before analysis of variance. Turkey test at the p=0.05 level was used for mean comparisons.

RESULTS AND DISCUSSION

Sunflower root distribution in the soil profile is dependent on soil conditions. According to Reichardt (1981), the main factors for little deep rooting in tropical soils are: the low pH, high exchangeable aluminum, compaction, inadequate aeration, and low retention and diffusion of water. In the present study, the soil texture in Campo de Pesquisa had less sand than Horto Florestal (Table 1) and, consequently, showed higher water retention in the 1-m profile. Soil pH was 5.2; 5.4; 5.8; 6.1 in Campo de Pesquisa, and 5.8; 5.9; 5.9 and 5.8 in Horto Florestal at 0-0.25 , 0.25-0.50 , 0.5-0.75 , 0.75-1.0 m depth, so both soils presented good conditions for normal sunflower development.

Table 1. Soil chemical and physical characterization

Hidroagrícola do Pinhal								
Soil depth	MO	P	K	Ca	V%	B	DS	Soil type
	g/dm^3	$mmol/dm^3$			%	mg/dm^3	g/cm^3	
0-25	28	6	2.8	41	59	0.22	1.34	Lime
25-50	17	2	1.7	26	56	0.20	1.29	Lime
50-75	11	1	0.8	27	63	0.07	1.16	Lime
75-100	8	1	0.6	24	62	0.06	1.22	Lime
Horto Florestal								
0-25	26	217	3.6	46	78	0.28	1.76	Lime
25-50	16	117	1.1	36	76	0.18	1.76	Lime
50-75	8	48	1.1	23	69	0.15	1.78	Clay to lime
75-100	8	22	1.1	20	69	0.15	1.78	Clay to lime

DS= Soil Density

Fig. 1 shows rain precipitation during 2001, 2002, and 2003 between June and October, 2003 being the dryest year. In 2001 and 2003 the rain occurred at the beginning of flowering and in the seed filling, which should have diminished the water stress symptoms in the *Rainfed* treatment. With the soil drying process, the upper layers are the first to dry. The plant exhibits a predominantly superficial root system under no water stress (Table 3), as shown in the *Always irrigated* treatment, and a larger number of roots in the *Rainfed* treatment in the deep layers in comparison to the irrigated treatments. The root growing towards humid soil of deeper layers can be considered as a sunflower defense against water stress.

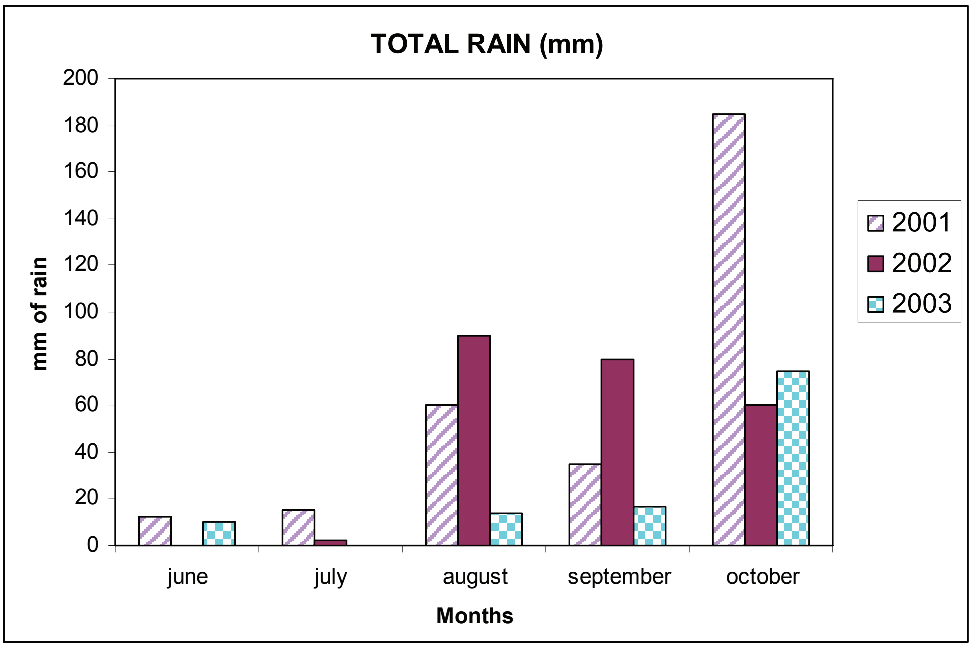

Fig. 1 Total month water precipitation for the years of 2001, 2002, and 2003.

Table 2 shows a significant difference between the average roots per grid of *Rainfed* treatment in relation to *Always irrigated and Irrigated in critical periods* by Turkey test at 5% significance. There was an increase in the number of roots per grid in the *Rainfed* treatment.

Table 2. Average number of roots/grid in the irrigation treatments, observed in the three years.

Treatments	Average roots/grid		
	2001	2002	2003
Always irrigated	7.54 b	13.70 b	6.39 b
Irrigated in critical phases	8.16 b	7.20 c	6.03 b
Rainfed	13.01 a	22.51 a	8.34 a
CV%	28.96	24.43	23.09

[1]Means followed by the same letter in column did not differ from Tukey at 5%.

According to Taiz and Zeiger (2004) moderate water deficits negatively influence the development of the root system. The ratio between root biomass and shoot apex seems to be governed by a functional balance between the root water absorption and shoot photosynthesis. This functional balance can be altered if the water supply decreases. The foliar expansion is affected by water shortage early on, but the photosynthesis activity is less affected. The inhibition of foliar expansion reduces carbon and energy consumption and a high proportion of vegetable assimilates can be distributed to the underground system to support the future growth of the roots. Those factors lead to a root growing priority to humid soils, as shown in the *Rainfed* treatment. With the increasing water shortage, the upper soil layers are the first to dry up.

Table 3 shows the total root number obtained by the sum of roots observed in each grid disposed in each layer of the treatments *Always irrigated*, *Irrigated in critical periods* and *Rainfed* using the adapted presence and absence methodology. Greatest total root number was observed in the *Rainfed* treatment. The total root number at each layer was affected by the water regime; *Rainfed* also showed between 2 to 4 times more roots in the deeper layers, between 30 and 80cm, than those of the irrigated treatments. In the *Irrigated in critical periods* and *Always irrigated* the roots were mainly in the more superficial layers.

Table 3 also shows a more superficial root system when the soil moisture is high, as verified in the treatment *Always irrigated*; when the upper layers dry, there is a root proliferation in the deeper layers in the *Rainfed* treatments. This root growing towards the humid soil according to Merrien and Milan (1992) and Connor and Hall (1997) can be considered a natural sunflower defense against water stress.

Table 3. Total root number found in each treatment in the different soil layers in the four replications.

Soil depth	***Always irrigated***	***Irrigated in critical phases***	***Rainfed***
00 – 10	6,763	7,201	6,814
10 – 20	2,267	1,947	2,148
20 – 30	415	215	382
30 – 40	154	36	250
40 – 50	39	46	157
50 – 60	43	76	114
60 – 70	66	18	65
70 – 80	6	3	22
80 – 90	5	0	3
90 –100	0	0	0
Total	9,542	9,758	9,955

Table 4 shows the grain yield obtained in each treatment and year. It is interesting to observe that the data shows the same yield level in the three years and in the two soil types, although 2003 was much drier with only 48mm of rain during the whole sunflower cycle, while 2001 and 2002 presented 90mm and 180 mm, respectively. The better soil characteristics of 2003 must have positively influenced the grain yield. The higher water stress in the *Rainfed* treatment resulted in a 30% yield reduction in relation to the treatment with no water stress. The moderate water stress presented by *Irrigated in critical phases* treatment reduced grain yield by about 17%.

Table 4. Results of the grain yield obtained in the three treatments, in 2001, 2002, and 2003, and the percentage of yield reduction in relation to *Always irrigated* treatment.

Treatment	2001	2002	2003	Average	%reduction
Always irrigated	1732 a	1604 a	1860 a	1732 a	0
Irrigated in critical phases	1483 b	1425 ab	1541 b	1483 b	17.2
Rainfed	1122 c	1112 b	1131 c	1121 c	29.8
Average	1446	1380	1511		

Means followed by the same letter in column did not differ from Turkey at 5%.

CONCLUSIONS

- The irrigation treatments showed no differences in relation to root number and distribution in the soil profile while *Rainfed* treatment developed two to four times more roots at 30 to 80cm deep;
- Under strong water stress the sunflower plant increases the number and the depth of the roots in order to minimize the lack of water;
- Sunflower cv. M 742, under hard water stress showed a grain yield reduction of about 30%;
- Under moderate water stress, with water supplementation at budding and grain filling, sunflower showed 17.2% grain yield reduction in relation to no water stress;

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