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PHENOLOGY, YIELD AND WATER USE EFFICIENCY OF SUNFLOWER IN FUNCTION OF ENVIRONMENT AND NITROGEN

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SUMMARY

During the rainy season of 1998, a field experiment was established in Cocula, Guerrero (hot subhumid climate, Awo) and in Montecillo, México (semiarid climate, BS_1), to evaluate the effect of nitrogen (0, 10 and 20 g m^{-2}) and environment on phenology, yield and its components, water use efficiency (WUE), and crop evapotranspiration (ETc) and heat units (HU) accumulated during the growth cycle of sunflower (*Helianthus annuus* L.) cv. Victoria. The crop was planted on June 1 at a density of 7.5 pl m^{-2} in both climates. In Cocula, maximum and minimum temperatures were more extreme and rainfall was more intense, while soil was poor in total nitrogen, compared with Montecillo. Crop growth, yield and its components, and water use efficiency were affected significantly by the environment, nitrogen and the interaction environment * nitrogen. The crop cycle in the hot environment was 36 days shorter, with a greater accumulation of HU and ETc. Yield and its components and water use efficiency were significantly higher in Cocula. Nitrogen positively affected the evaluated variables. The interactive effect of environment * nitrogen was observed clearly, since in Cocula there was response to the application of nitrogen in most of the variables evaluated, while in Montecillo there was not.

Key words: heat units, evapotranspiration, yield components

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is cultivated predominantly as source of oil and vegetable protein (Blamey and Chapman, 1981), and it is furthermore considered one of the oil crops of major importance in the world because of its moderate production requirements, high-quality oil, protein content and utilization of all the

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parts of the plant (Škorić, 1992). This crop is cultivated in several countries; in Mexico, it is produced in several states, although recent records indicate major production only in Sonora and Tamaulipas with more than 90% of the national production (SAGAR, 1997). However, because this production does not satisfy the requirements of the population, Mexico has had to import large quantities of seed for its processing industries (INEGI, 1997). The growing need for oilseed in Mexico has led to a search for technological alternatives to increase production in different environments. Most of the investigations have been conducted in semi-arid and arid temperate climates with low production potential.

Economic crop production is the conversion by the plant community of three natural sources (light, water and nutrients) into products useful for man, and the efficiency with which they are used is determined, in part, by crop management (Zaffaroni and Schneiter, 1989). Environment (Bange *et al.*, 1997) and crop management through nitrogen fertilization (Sarmah *et al.*, 1994; Escalante, 1995) are factors that can impact potential sunflower yield. Škorić (1992) indicates that oil concentration in the seed depends on the daily mean temperature in addition to the availability on water during the seed-filling period. Harris *et al.* (1978) found that oil concentration decreased with increases in temperature, while Unger and Thompson (1982) found that it increased.

Studies conducted with sunflower in different environments show that increasing applications of nitrogen increases seed yield (Sarmah *et al.*, 1994; Vivek *et al.*, 1994; Sharma, 1994), biomass production and seeds per m^2 (Vega, 1999), weight of 100 seeds (Sarmah *et al.*, 1994), and head size (Vivek *et al.*, 1994). It has also been observed that a low nitrogen supply resulted in reductions in seeds per plant, seed dry weight and, consequently, a reduction of 85% in oil yield (Hocking and Steer, 1989). In a semi-arid temperate environment in Mexico, Escalante (1995) found that applications of nitrogen in sunflower cv Victoria cultivated under rainfed conditions increased biomass production, seed and oil yields and water use efficiency. Greater biomass production and seed yield were obtained with 100 kg N ha^{-1}. Under the same climate conditions, Vega (1999) found similar trends with application of nitrogen fertilizer. The objective of the present study was to evaluate phenology, yield and water use efficiency of sunflower in function of environment and nitrogen.

MATERIALS AND METHODS

The experiment was conducted during the summer rainy season of 1998 under rainfed conditions at the experiment stations of the Colegio Superior Agropecuario del Estado de Guerrero near Cocula, Guerrero, (18° 19' N and 99° 39' W and 640 msnm, Awo climate, hot subhumid) and the Colegio de Postgraduados in Montecillo, State of Mexico, (19° 21' N and 98° 54' W, 2250 msnm, BS_1 climate, the least dry of the arid climates) (García, 1988).

The effect of the two environments (Cocula and Montecillo) and three nitrogen levels (0, 10 and 20 g m^{-2}) on phenology, heat units, evapotranspiration, water use efficiency and yield and its components of sunflower cv. Victoria were evaluated using an experimental design of complete random blocks in both environments.

Planting was done in the two sites on 1 June 1998 at a density of 7.5 pl m^{-2}. During planting, the crop was fertilized in bands, using ammonium sulfate (20.5% N) and 100 kg P_2O_5 ha^{-1} with triple calcium superphosphate (46% P_2O_5) as the source of nitrogen for the entire experiment.

Through the experiment, the following weather data were recorded: maximum (Tmax, °C) and minimum temperature (Tmin, °C), evaporation (Ev, mm) and daily rainfall (P, mm). The phenological stages registered were days to initial emergence (Ve), days to initial flowering (R_1) and anthesis ($R_{5.1}$) and days to physiological maturity (R_9) (Schneiter and Miller, 1981). Also, heat units accumulated by the crop (HU, °C) were determined for each phenological stage using the residual method (Flores *et al.*, 1985), which is expressed by the following equation: HU=Tmax+Tmin/2-TB, where: Tmax=daily maximum temperature (°C), Tmin=daily minimal temperature (°C) and TB=base temperature, considered as 6°C (Merrien, 1986). Crop evapotranspiration (ETc) was estimated for the entire experiment as the evaporation (Ev) from tank type "A", using the coefficients 0.6 and 0.8 of the evaporimeter (Ke) for Cocula and Montecillo, respectively, and the crop coefficient Kc for different developmental stages, as in the following equation: ETc=Ev*Ke*Kc (Doorembos and Pruitt, 1986). Crop measurements were total biomass (TB, g m^{-2}), harvest index (HI = SY/TB, %), seed yield (SY, weight of seed with 10% moisture, g m^{-2}), weight of 100 seeds (W100S, g), number of seeds per m^2 (NSM), head area (HA, cm^2), seed oil content (OC, %), and oil yield (OY, g m^{-2}). Water use efficiency for total biomass, seed and oil yields (g m^{-2} mm $^{-1}$) were calculated considering the relationship WUE=TB, SY or OY/ETc. Oil content was measured in the laboratory by nuclear magnetic resonance and oil yield was obtained by multiplying seed yield by percent of oil.

Statistical analyses consisted of a combined analysis of variance [environment (E), nitrogen (N) and environment * nitrogen (E*N)] for all the variables, and for those with significant statistics a Tukey test at 5% of probability was done for the principal effects and an orthogonal polynomial test for the interactions.

RESULTS AND DISCUSSION

Soil and weather

The soil of Cocula is characterized by its clayey texture, average bulk density of 1.30 g cm^{-3}, moderately alkaline pH, negligible effects of salinity on the crop, deficiency of organic matter and total nitrogen, and medium to high phosphorus content (Table 1). In Montecillo, the soil is similar in texture, salinity and bulk density to the previous location, but it has a moderately alkaline pH and high organic matter and total extractable nitrogen and phosphorus contents. The soils of the two sites are different in organic matter content and total nitrogen, which can influence sunflower response to increasing applications of nitrogen.

Table 1: Physical and chemical characteristics of experiment soil

Environment	Depth	Texture	Dap	pH	E.C.	O.M.	N	P
Cocula	0-30	Clay	1.20	7.1	0.248	1.30	0.065	6.0
	30-60	Clay	1.40	7.1	0.217	2.08	0.104	22.0
Average		Clay	1.30	7.1	0.232	1.69	0.08	14.0
Montecillo	0-30	Clay	1.26	7.5	0.632	6.50	0.325	20.0
	30-60	Clay	1.28	7.1	0.812	7.54	0.377	72.0
Average		Clay	1.27	7.3	0.722	7.02	0.351	46.0

Dap = bulk density (g cm^{-3})
pH = potential hydrogen
E.C. = electric conductivity (dS m^{-1})
O.M. = organic matter (%)
N = nitrogen (%)
P = phosphorus (ppm)
Depth = sampling depth (cm)

Weather data collected in Cocula showed that the average maximum and minimum temperatures during crop growth were 35.5 and 21.5° C, respectively. Temperatures were high during the period of sowing (S) and emergence (Ve) tending to decrease as the crop matured (R_9) (Figure 1).

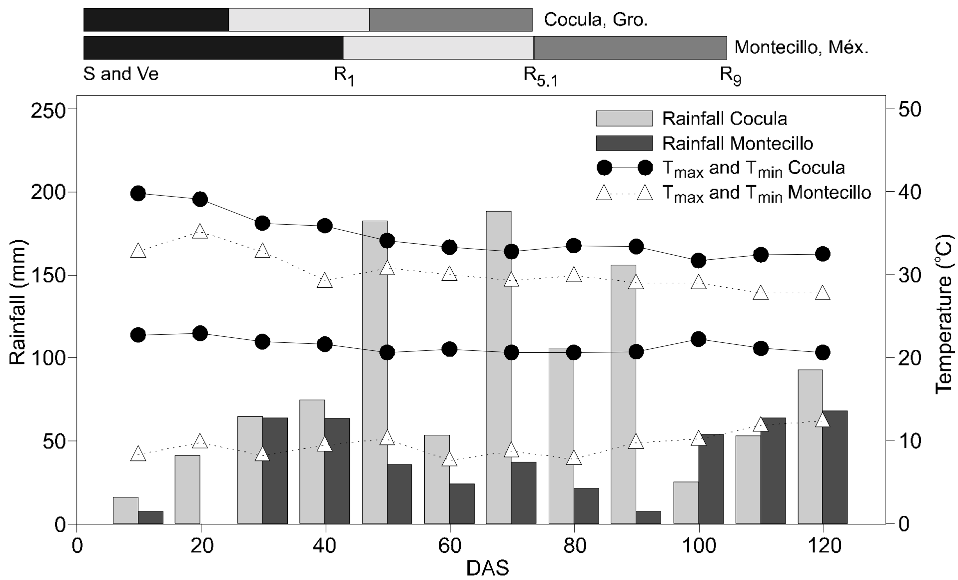

Figure 1: Distribution of rainfall (sum decenal), maximum and minimum temperatures (mean decenal) during the development of sunflower cv. Victoria in contrasting environments. S = sowing, Ve = beginning of emergency, R_1 = beginning of flowering, $R_{5.1}$ = beginning of anthesis, R_9 = physiological maturity, DAS = days after sowing

The rainfall accumulated from sowing to physiological maturity was 725 mm, with greater incidence during the period between initial flowering (R_1) and initial anthesis ($R_{5.1}$). In Montecillo, the maximum and minimum temperatures were lower than in Cocula during the entire crop cycle, with the averages of 30.3°C and 9.5°C, respectively. Maximum temperatures in Cocula also tended to decrease, while minimum temperatures increased slightly. The total accumulated rainfall in Montecillo was 382 mm, decreasing in amount during the period R_1-$R_{5.1}$ (Figure 1). On average, the maximum and minimum temperatures and rainfall during the crop cycle were higher in Cocula, by 5.2°C, 12°C and 343 mm, respectively. Also, the distribution of rain was more favorable there since the greater proportion of rainfall occurred during flowering (R_1-$R_{5.1}$) and seed-filling ($R_{5.1}$-R_9), contrasting to what occurred in Montecillo. These marked differences in elements of weather between the two environments can be determinant in crop performance.

Table 2: Phenology of sunflower cv Victoria in function of environment and nitrogen

Source	Ve	R_1	$R_{5.1}$	R_9
Environment(E)	**	**	**	**
Nitrogen (N)	NS	NS	NS	NS
A*N	NS	NS	NS	NS

*,** P£0.01 and 0.05, respectively
NS = not significant
Ve = emergence
R_1 = initial flowering
$R_{5.1}$ = initial anthesis
R_9 = physiological maturity

Phenology

Crop development was affected significantly by environment, but not by nitrogen fertilization or the interaction environment * nitrogen (Table 2). The sunflower cycle in Cocula lasted 77 days, while in Montecillo it lasted 113 days (Table 3).

Table 3: Phenology of sunflower cv Victoria in function of environment and nitrogen

Factor	Level	Ve	R_1	$R_{5.1}$	R_9
A	Cocula	4.00b	33.22b	53.58b	77.00b
	Montecillo	9.00a	50.78a	79.22a	113.00a
N	N_0	6.50a	42.25a	66.58a	96.00a
	N_{10}	6.50a	42.25a	65.83a	96.00a
	N_{20}	6.50a	41.50a	66.79a	96.00a
DSH $_{0.05}$ §	Environment	0.001	1.414	1.617	0.001
	Nitrogen	0.001	2.121	2.425	0.001

¶ Values with the same letter are not statistically different, $\alpha = 0.05$
§ Honest meaningful difference, 5% probability
Ve = emergence
R_1 = initial flowering
$R_{5.1}$ = initial anthesis
R_9 = physiological maturity
N_0, N_{10} and N_{20} = 0, 10 and 20 g m^{-2} nitrogen

Nitrogen did not affect sunflower phenology. Identical trends were found by Escalante (1995), who evaluated the phenology of the cv. Victoria under dryland farming conditions in a temperate climate (Cw). The flowering stage (R_5) occurred 45 days after sowing and physiological maturity at 110 days.

In Cocula, days to emergence (Ve, 4.0 days), initial flowering (R_1, 33.0 days), initial anthesis ($R_{5.1}$, 54 days) and physiological maturity (R_9, 77.0 days) were 5, 18, 26 and 36 days shorter than in Montecillo, where days to Ve, R_1, $R_{5.1}$ and R_9 were 9.0, 51.0, 79.0 and 113, respectively (Table 3). Likewise, the phenological stages S-Ve, Ve-R_1, R_1-$R_{5.1}$ and $R_{5.1}$-R_9 were 5, 13, 8 and 11 days shorter, respectively. These differences in crop phenology between the environments can be attributed to differences in the environmental temperature. In this regard, Goyne and Hammer (1982) indicate that temperature has a marked influence on sunflower phenology, mainly in the number of days to initial anthesis and in the visible state of head growth.

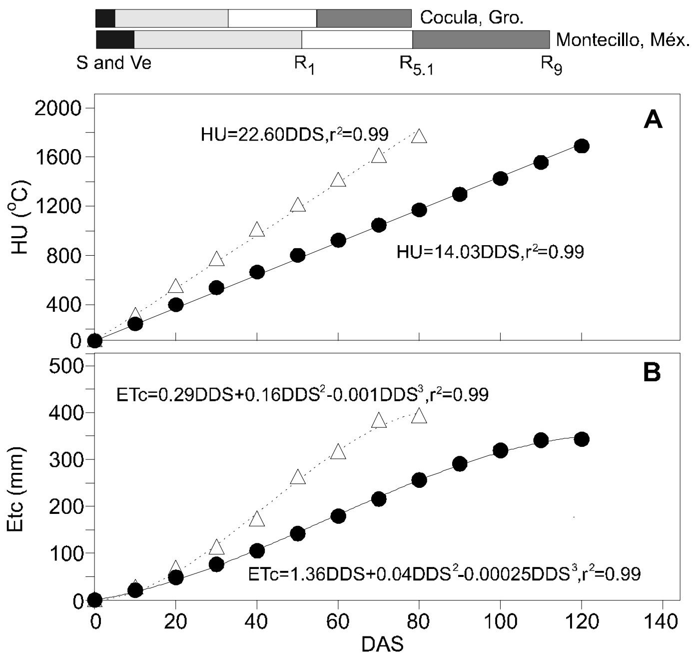

Figure 2: Accumulate heat units (A) and evapotranspiration (B) during the development of the sunflower cv. Victoria in contrasting environments. S = sowing, Ve = beginning of emergency, R_1 = beginning of flowering, $R_{5.1}$ = beginning of anthesis, R_9 = physiological maturity, DAS = days after sowing

Heat units and crop evapotranspiration

The heat units (HU) accumulated in Cocula during the vegetative stage (VE), reproductive stage (RE) and in the total cycle (TC) were 746, 994 and 1740°C, respectively (Figure 2A). In contrast, in Montecillo, despite the longer crop cycle, the accumulation of HU in the different phenological stages was inferior to that in Cocula (716, 869 and 1585° C for the EV, ER and TC, respectively). In Cocula, 30, 125 and 155 °C more HU were accumulated for EV, ER and TC, respectively.

More HU accumulated in Cocula (1740°C) in a shorter crop cycle than in Montecillo (1585°C). This can be associated with the high temperatures that occur in this region (35.5 and 21.5°C in Cocula, and 30.3 and 9.5°C in Montecillo). Similar results were obtained by Salera and Baldini (1998) who found a range of 1612 to 2036°C in growth degree-days (GDD) from sowing to physiological maturity in the genotypes evaluated. They also indicated that the differences among sunflower hybrids in the GDD accumulated were due to the lengthening of their biological cycle because of the climate.

Accumulated ETc in Cocula (Figure 2B) was 138, 255 and 393 mm for VE, RE and TC, respectively. In contrast, in Montecillo, ETc was lower than in Cocula during RE and TC (193 and 341 mm, respectively) but higher during the VE (148 mm). A similar seasonal ETc (371 mm) was reported by Escalante (1995) in sunflower cv. Victoria cultivated under dryland conditions in a Cw climate, but with a longer cycle (33 days more). In Cocula, in a shorter crop cycle, accumulated ETc was inferior only in the VE by 10 mm, but in the other phenological crop stages it was 62 and 52 mm higher for ER and ET, respectively.

The higher ETc in Cocula during these stages can be associated with the higher rainfalls and incident temperatures in this region. In this regard, Škorić (1992) reported that sunflower uses a great deal of water during the period of growth because of the large amount of dry matter produced and a high coefficient of transpiration.

With respect to the dynamics of the ETc during the crop cycle, in Figure 2B it can be observed that in Cocula, in the initial development stages, the rate of increase in ETc is high (0.29 and 0.16 mm day^{-1}) and tends to decrease by -0.001 mm day^{-1} with physiological maturity. In Montecillo, ETc behavior was similar, but with different rates (1.36, 0.04 and -0.00025 mm day^{-1}). The greater rates of evapotranspiration at the beginning of the crop cycle can be explained by the scant plant cover which does not prevent water from evaporating from the soil surface; as the crop grows the canopy reduces evaporation from the soil surface and crop transpiration is increased.

Biomass (TB) and harvest index (HI)

The biomass (TB) was affected by the environment (E), nitrogen (N) and the interaction environment * nitrogen (E*N), while HI varied only by the different values of E and E*N (Table 4).

In Cocula, HI (0.29) was higher (Table 5), while in Montecillo a higher accumulation of TB was obtained (1428 g m^{-2}). The greater response in TB in the latter environment is apparently associated with the greater accumulation of photoassimilates in stems, leaves and receptacles, but with scarce translocation to seeds, reflected in a smaller HI.

Table 4: Water use efficiency, yield and its components of sunflower cv. Victoria in function of environment and nitrogen

Source	NSM	W100S	HA	HI	OC	TB	SY	OY	WUE_{TB}	WUE_{RS}	WUE_{RA}
Environment (E)	**	**	NS	**	*	**	**	**	**	**	**
Nitrogen (N)	**	**	**	NS	**	**	**	**	**	**	**
A*N	*	**	**	*	NS	*	**	**	*	**	**

*,** P£0.01 and 0.05, respectively
NS = not significant
NSM = seeds number per m^2
W100S = weight of 100 seeds (g)
HA = head area (cm^2)
HI = harvest index (%)
OC = oil content (%)
SY = seed yield at 10% moisture ($g\ m^{-2}$)
OY = oil yield ($g\ m^{-2}$)
WUE_{TB}, WUE_{SY} and WUE_{OY} = Water use efficiency for total biomass, seed and oil yield, respectively ($g\ m^{-2}\ mm^{-1}$)

Table 5: Yield components of sunflower cv. Victoria in function of environment and nitrogen

Factor	Level	NSM	W100S	HA	HI	OC
A	Cocula	6387a¶	5.31a	210a	0.29a	52.54a
	Montecillo	4933b	4.44b	193a	0.15b	42.30b
N	N_0	4818b	4.47b	181b	0.21a	48.24a
	N_{10}	6260a	4.99a	208a	0.23a	………
	N_{20}	5902a	5.16a	216a	0.23a	46.61b
$DSH_{0.05}$§	Environment	717	0.22	16.83	0.03	1.51
	Nitrogen	1075	0.33	25.25	0.04	1.51

¶ Values with the same letter do not differ (α = 0.05)
§ Least meaningful difference, 5% probability
NSM = seeds number by m^2
W100S = weight of 100 seeds (g)
HA = head area (cm^2)
HI = harvest index (%)
OC = oil content (%)
N_0, N_{10} and N_{20} = 0, 10 and 20 $g\ N\ m^{-2}$

Averaging the two environments, the application of 10 $g\ N\ m^{-2}$ increased TB by 289 $g\ m^{-2}$ (Table 6), while the HI did not vary (average of 0.22).

Table 6: Total biomass, seed and oil yield and water use efficiency of sunflower cv. Victoria in function of environment and nitrogen

Factor	Level	TB	SY	OY*	WUE_{TB}	WUE_{SY}	WUE_{OY}*
A	Cocula	1155b¶	343a	163.23a	2.95b	0.88a	0.42a
	Montecillo	1428a	220b	87.76b	4.16a	0.61b	0.26b
N	N_0	1091b	216b	100.62b	3.03b	0.59b	0.27b
	N_{10}	1380a	316a	………	3.78a	0.85a	………
	N_{20}	1404a	313a	150.38a	3.85a	0.79a	0.40a
$DSH_{0.05}$§	Environment	136.8	35.0	26.38	0.365	0.097	0.08
	Nitrogen	205.1	52.4	26.38	0.548	0.146	0.08

¶Values with the same letter do not differ (α = 0.05)
§ Least meaningful difference, 5% probability
TB = total biomass ($g\ m^{-2}$)
SY = seed yield ($g\ m^{-2}$)
OY = oil yield ($g\ m^{-2}$)
N_0, N_{10} y N_{20} = 0, 10 and 20 $g\ m^{-2}$ of nitrogen
* = evaluated for N_0 and N_{20}
WUE_{TB}, WUE_{SY}, WUE_{OY} = water use efficiency of total biomass, seed and oil yield, respectively ($g\ m^{-2}\ mm^{-1}$)

Other authors have also observed that nitrogen increases biomass production in sunflower (Rousseaux *et al.*, 1999), maize and sorghum (Muchow and Davis, 1988), as well as HI in beans (Escalante, 1999) and in maize and sorghum (Muchow and Davis, 1988).

Table 7: Orthogonal polynomial test of the interaction E*N of water use efficiency, yield and its components of sunflower cv. Victoria

Variable	Trend	Cocula	Montecillo
NSM	Linear	**	NS
	Quadratic	NS	NS
W100S	Linear	**	NS
	Quadratic	**	NS
HI	Linear	**	NS
	Quadratic	NS	NS
TB	Linear	**	NS
	Quadratico	*	NS
SY	Linear	**	NS
	Quadratic	**	NS
OY	Linear	**	NS
WUE_{TB}	Linear	**	NS
	Quadratic	*	NS
WUE_{SY}	Linear	**	NS
	Quadratic	*	NS
WUE_{OY}	Linear	**	NS

A*N=environment*nitrogen interaction; TB=total biomass (g m^{-2})
NSM=seeds m^{-2}; SY=seed yield (g m^{-2})
W100S=weight of 100 seeds (g); OY=oil yield (g m^{-2})
HI=harvest index (%)
WUE_{TB}, WUE_{SY} and WUE_{OY}=water use efficiency for total biomass, seed and oil yield, respectively (g m^{-2} mm^{-1})

Table 8: Regression equations of interaction E*N of water use efficiency, yield and its components of sunflower cv. Victoria

Variable	Cocula		Montecillo
SY	$Y_i=208.67+26.06n_i-0.75n_i^2$	$r^2=0.56$	....
OY	$Y_i=112.32+5.09n_i$	$r^2=0.62$	....
TB	$Y_i=817+76.60n_i-2.57n_i^2$	$r^2=0.44$	....
NSM	$Y_i=4842+333.37n_i-10.73n_i^2$	$r^2=0.31$	....
W100S	$Y_i=4.31+0.81n_i-0.005n_i^2$	$r^2=0.57$	....
HI	$Y_i=0.26+0.003n_i$	$r^2=0.36$	....
WUE_{BT}	$Y_i=2.08+0.20n_i-0.007n_i^2$	$r^2=0.44$	....
WUE_{SY}	$Y_i=0.53+0.07n_i-0.002n_i^2$	$r^2=0.56$	....
WUE_{OY}	$Y_i=0.29+0.01n_i$	$r^2=0.61$	....

SY=seed yield (g m^{-2}); NSM=seed m^{-2}
OY=oil yield (g m^{-2}, ; W100S=weight of 100 seeds (g)
TB=total biomass (g m^{-2}); HI=harvest index (%)
WUE_{TB}, WUE_{SY}, WUE_{OY}=water use efficiency for total biomass, seed and oil yield, respectively (g m^{-2} mm^{-1})

Regarding the interaction E*N (Figures 3C and 3D) show a response to N in both environments. The orthogonal polynomial test and the regression equations are shown in Tables 7 and 8.

The TB in Cocula increased with increasing applications of N, with a maximum of 1388 g m^{-2} with the application of 14.9 g N m^{-2}. After reaching the maximum, TB decreased at a rate of 2.57 g m^{-2} per g N m^{-2} applied; thus after applying 20 g N m^{-2}, total biomass decreased by 1322 g m^{-2} (Figure 3C). In the temperate climate (Montecillo), TB was higher, however, no significant increases were observed as a result of N application; the average was 1428 g m^{-2}, with minimal increases in biomass of 40 g m^{-2} relative to those obtained in the hot climate.

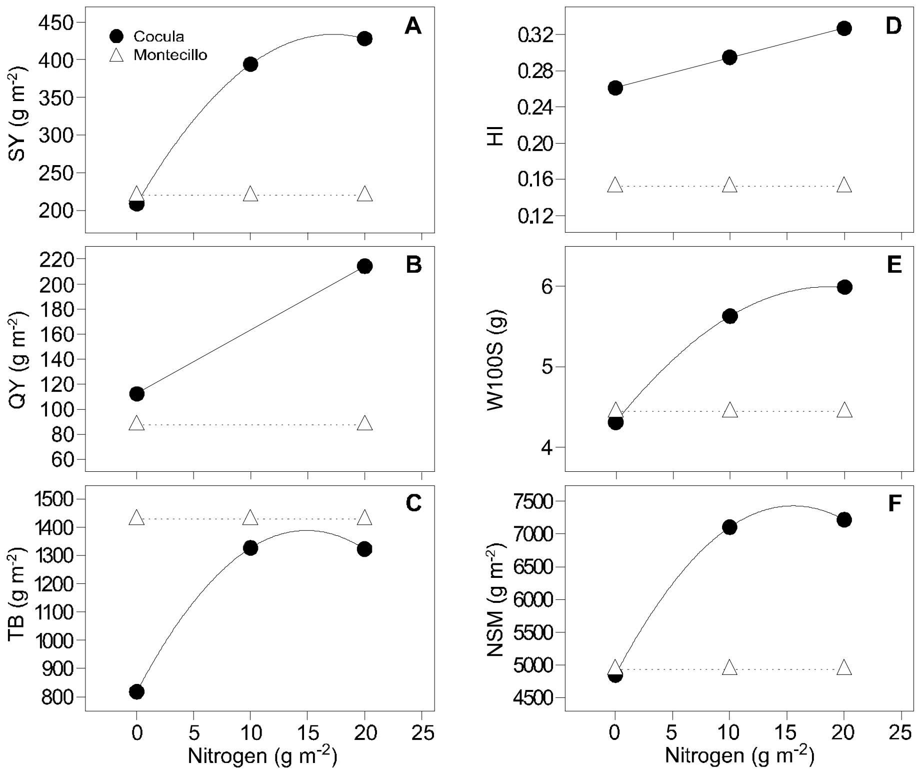

*Figure 3: Effect of interaction environment * nitrogen on seed (A) and oil yields (B), total biomass (C), harvest index (D), weight of 100 seeds (E) and number of seeds per m^2 (F)*

The greater TB production, but smaller seed and oil yield (SY and OY), can be related to a greater accumulation of photoassimilates in stems, leaves and receptacles and a low translocation to the reproductive organs (seeds), a phenomenon that can be influenced by the differences in environmental conditions of the sites where the experiments were conducted (Figure 4).

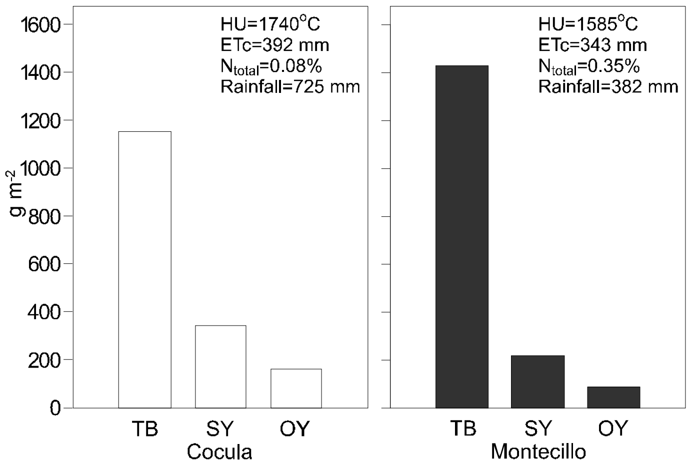

Figure 4: Total biomass (TB), seed yields (SY) and oil yields (OY) with relation to the heat units (HU), accumulated evapotranspiration (ETc), total nitrogen and rainfall in sunflower cv. Victoria in contrasting environments

In Cocula, N provoked significant changes in the HI, with increases at a rate of 0.003 per g N m^{-2} applied (Figure 3D). The highest HI (0.33) was obtained with the application of 20 g N m^{-2}, while under temperate environmental conditions there were no observed differences, HI being on average 0.15. In the hot environmental condition increases of 0.18 were observed in the HI, relative to that obtained in the moderate environment. The higher HI obtained in the former environment is linked to higher seed production relative to total biomass production and, evidently, to greater rainfall during the crop cycle. In this regard, Fernandez-Martinez *et al.* (1993), found the highest HI when the sunflower was cultivated under adequate conditions of moisture (irrigation), and a smaller HI when cold winter temperatures coincided with fertilization and seed formation.

Yield and its components

The number of seeds per m^2 (NSM), weight of hundred seeds (W100S) and seed yield (SY) were affected significantly by the environment (E), nitrogen (N) and the interaction environment * nitrogen (E*N) (Table 4).

The highest values of NSM, W100S (Table 5) and SY (Table 6) were found in Cocula, 1454 seeds m^2, 0.87 g, and 123 g m^{-2}, respectively. The potential yield of sunflower is highly dependent on environmental conditions during the crop's life cycle (Bange *et al.*, 1997). In head area (HA), we observed a slightly larger HA (17 cm^2 larger) in Cocula, although the statistical differences were non-significant.

Application of 10 g N m^{-2} resulted in increases of 1442, 0.52 g, 27 cm^2 and 100 g m^{-2} in NSM, W100S, HA and SY, respectively (Tables 5 and 6). The highest SY obtained with nitrogen was related to increases in NSM, P100S and HA of sunflower. Significant increases in the yield and its components produced by increases in nitrogen fertilization were observed in sunflower (Escalante, 1992; Escalante and Ramírez, 1995). Moreover, it was observed that the components most related with yield are the number of seeds per plant (Steer *et al.*, 1984) and head size (Sharma, 1994).

Regarding the interaction E N, Figures 3A, 3E, and 3F show the response to N observed in both environments, in terms of SY, W100S and NSM variables (Tables 7 and 8).

According to the orthogonal polynomial test, we observed highly significant effects in the tested trends in Cocula, while in Montecillo no effects were observed (Table 7).

In Cocula, SY increased with increasing dosages of N, obtaining a maximum of 433 g m^{-2} with application of 17.26 g N m^{-2}. After that, yield decreased at a rate of 0.75 g m^{-2} per g m^{-2} of N applied. In Montecillo, we did not observe significant increases, obtaining an average of 220 g m^{-2} (Figure 3A). According to the polynomial selected, it is feasible to obtain a SY 213 g m^{-2} higher in Cocula than in Montecillo. The differences in SY as a response to N in the two locations is highly associated with the initial fertility of soil in experimental locations. While in Cocula the nitrogen content was poor (0.08%), N concentrations in Montecillo were high (0.35%).

The W100S in Cocula (Figure 3E) increased significantly with increases of nitrogen, generating a maximum of 5.99 g when 18.75 g N m^{-2} were applied, 1.55 g higher than the highest W100S in Montecillo. After this maximum, the W100S declined at a rate of 0.005 g per g N m^{-2}, until seeds were produced with a weight of 5.98 g with application of 20 g N m^{-2}. In Montecillo, significant increases from N application were not observed the average W100S being 4.44 g (Figure 3E).

The number of seeds per m^2 (NSM), as with the other variables in Cocula, increased with N, reaching a maximum of 7430 with application of 15.55 g N m^{-2}. After that, NSM decreased at a rate of 10.73 per g N m^{-2} to a minimum of 7216 seeds produced with 20 g N m^{-2}. In Montecillo, we obtained an average of 4933 seeds per m^2, 2497 seeds per m^2 less than in Cocula (Figure 3F). The greater NSM produced in hot climate conditions can be associated with a greater availability of water and nitrogen during the seed-filling period, since more rainfall occurred in this environment.

Research conducted with sunflower in different environments indicates that with nitrogen applications, mainly when the soil is poor in this nutrient, seed yield (Sarmah *et al.*, 1994; Vivek *et al.*, 1994), number of seeds per m^2 (Vega, 1999), the weight of 100 seeds (Sarmah *et al.*, 1994), and head size (Vivek *et al.*, 1994) tend to increase.

In this study, the greater response to the N applied in the hot climate environment (Cocula) can be related to low concentrations of initial nitrogen in soil, greater rainfall, HU and ETc (Figure 4).

Oil content and yield (OC, OY)

Oil content (OC) was affected significantly by the environment (E) and nitrogen (N), while oil yield was affected by the environment (E), nitrogen (N) and the interaction environment * nitrogen (E*N) (Table 4).

In Cocula, sunflower showed higher OC (Table 5) and oil yield (OY) (Table 6). The increases in Cocula were 10.24% in OC and 75.47 g m^{-2} in OY. The oil concentration in the seed was especially affected by environmental temperature and moisture during the seed-filling period (Škorić, 1992). The subhumid hot climate in this region was an environment that favored the higher percentage of seed production and oil yield.

With 20 g N m^{-2}, OC decreased by 1.63% but OY increased by 49.76 g m^{-2}, owing to a higher seed yield (Tables 5 and 6). A decrease in oil content, as applications of nitrogen increased, was also found by Zubriski and Zimmerman (1974) in varieties of oilseed sunflower. However, the increase in seed yield with N application also increased oil yield.

In Figure 3B the response to N in both environments can be observed, and Tables 7 and 8 show the orthogonal polynomial test and the respective regression equations.

Oil yield (Figure 3B) in the hot climate (Cocula) increased at a rate of 5.09 g m^{-2} per g N m^{-2} with increases of 0 to 20 g N m^{-2}. The highest OY (214 g m^{-2}) in this environment was obtained with applications of 20 g N m^{-2}; this was 126 g m^{-2} higher than the OY obtained in Montecillo (87.76 g m^{-2}). In this environment, despite higher temperatures, the higher soil moisture level allowed more nutrients, especially nitrogen, to be available and resulted in greater seed and oil production. In this regard, Alessi *et al.* (1977) indicated that in conditions of water deficit in soil during seed development, oil concentration decreased.

Water use efficiency (WUE, g m^{-2} mm^{-1})

The WUE values for total biomass (TB), seed yield (SY) and oil yield (OY) were significantly affected by environment (E), nitrogen (N) and interaction E*N (Table 4).

In Cocula, WUE (0.88 and 0.42 g m^{-2} mm^{-1}) was high for SY and OY, with used-water values of 0.27 and 0.16 g m^{-2} mm^{-1} higher than those obtained in Montecillo. The higher TB production in Montecillo, generated the highest WUE with 4.16 g m^{-2} mm^{-1}, 1.21 g m^{-2} m^{-1} higher than that obtained in Cocula (Table 6). The high WUE in Cocula was due to the fact that in this environment higher seed and oil yields were obtained and that ETc values were similar. Salera and Baldini (1998), evaluating WUE for seed yield of sunflower, found the highest values in environments with adequate soil moisture under both rainfed conditions (1.02 g l^{-1}) and irrigation (1.0 g l^{-1}).

With applications of 10 and 20 g N m^{-2} the highest values in WUE for TB and SY were obtained, with 3.78, 3.85 and 0.85, 0.79 g m^{-2} mm^{-1}, respectively. With 10 g N m^{-2}, increases of 0.75 and 0.26 g m^{-2} mm^{-1} in WUE of TB and SY, respectively, were obtained (Table 6).

With respect to the interaction E*N, Tables 7 and 8 show the results of the orthogonal polynomial test and the regression equations of better fit.

WUE for TB (Figure 5A) was higher in Montecillo; however, there were no significant increases from the effect of N, with an average of 4.16 g m^{-2} mm^{-1}. In Cocula, with a lower WUE, we observed increases in WUE as the dosage of N increased, reaching a maximum (3.50 g m^{-2} mm^{-1}) when 15.00 g N m^{-2} was supplied to the soil. After maximum WUE, it decreased at a rate of 0.007 g m^{-2} mm^{-1} of used water, until it reached a low of 3.37 g m^{-2} mm^{-1} with 20 g N m^{-2}.

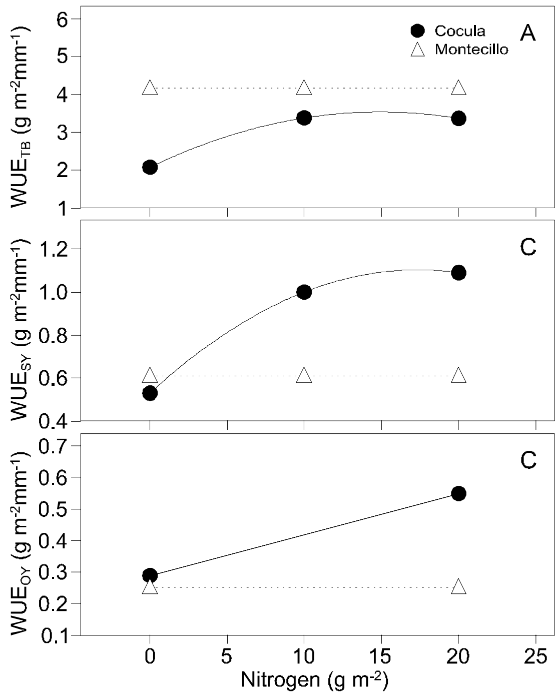

*Figure 5: Effect of interaction environment * nitrogen on the water use efficiency for total biomass (A), seed (B) and oil yields (C)*

The WUE for SY in the hot environment increased significantly with increases in N. The high WUE (1.10 g m^{-2} mm^{-1}) was obtained when 17.34 g N m^{-2} were applied; however, with increased dosages of N, WUE declined at a rate of 0.002 g m^{-2} mm^{-1}

per g N m^{-2}, until reaching 1.09 g m^{-2} mm^{-1} with 20 g N m^{-2} (Figure 5B). In Montecillo, we found a smaller, but not significantly different, WUE from the effect of N, obtaining an average of 0.61 g m^{-2} of seed per mm of consumed water.

With respect to the WUE for OY, a significant linear trend was found with N applications in Cocula (Figure 5C). Thus, the highest WUE (0.55 g m^{-2} mm^{-1}) was found when 20 g N m^{-2} was applied, while in Montecillo, there was no significant response (0.25 g m^{-2} mm^{-1} on average). The increase in WUE obtained in Cocula was 0.30 g m^{-2} mm^{-1}.

In Cocula, with similar ETc rates, seed and oil yields were significantly superior to those obtained in Montecillo (semi-arid temperate climate); therefore, WUE was greater under hot subhumid environmental conditions. In this regard, Sinclair *et al.* (1984) mentions that a geographic solution to increasing WUE can be related to crop production in those regions with wetter climates in which ETc is reduced.

CONCLUSIONS

Phenology, yield and its components and the water use efficiency of sunflower (*Helianthus annuus* L.) were affected by the environment in which the crop grew.

Nitrogen fertilizer application affected yield and its components and water use efficiency of sunflower.

Nitrogen differentially affected yield and its components and water use efficiency of sunflower cv. Victoria in both environments under study.

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FENOLOGIA, RENDIMIENTO Y EFICIENCIA EN EL USO DEL AGUA EN FUNCION DEL AMBIENTE Y NITRÓGENO

RESUMEN

Durante el temporal de 1998, se estableció un experimento de campo en Cocula, Gro. (clima cálido subhúmedo, Awo) y en Montecillo, Méx. (clima semiárido, BS_1), con el propósito de evaluar el efecto del nitrógeno (0, 10 y 20 g m^{-2}) y el ambiente sobre la fenología, el rendimiento y sus componentes, la eficiencia en el uso del agua (EUA), así como la evapotranspiración (ETc) y unidades calor (UC) acumuladas durante el ciclo de crecimiento del cultivo de girasol (*Helianthus annuus* L.) cv. Victoria. La siembra se realizó el primero de junio a la densidad de 7.5 pl m^{-2} en los dos ambientes. En Cocula, las temperaturas máximas y mínimas y precipitación ocurrieron en mayor intensidad, mientras que el suelo fue pobre en nitrógeno total, en relación con Montecillo. El crecimiento del cultivo, el rendimiento y sus componentes, así como la eficiencia en el uso del agua se afectaron significativamente por el ambiente, el nitrógeno y la interacción ambiente * nitrógeno. El ciclo de cultivo en ambiente cálido se acortó en 36 días, con una mayor acumulación de UC y ETc. El rendimiento y sus componentes y la eficiencia en el uso del agua fueron significativamente superiores en Cocula. El nitrógeno afectó positivamente las variables evaluadas. El efecto interactivo ambiente * nitrógeno, se observó claramente, ya que mientras en Cocula se encontró respuesta al nitrógeno en la mayoría de las variables evaluadas, en Montecillo, no existió.

PHÉNOLOGIE, RENDEMENT ET EFFICACITÉ DE L'UTILISATION DE L'EAU EN FONCTION DES ENVIRONS ET DE L'AZOTE CHEZ LE TOURNESOL

RÉSUMÉ

Au cours de la saison des pluies de 1998, des champs expérimentaux ont été conçus dans les localités de Cocula, Guerrero (climat chaud subhumide, Awo) et Montecillo, Mexico (climat semi-aride, BS_1) dans le but d'évaluer l'influence de l'azote (0, 10 et 20 g m^{-2}) et du milieu sur la phénologie, le rendement et les composantes du rendement, l'efficacité de l'utilisation de l'eau (WUE), l'évapotranspiration des semailles (Etc) et les unités thermiques (HU) accumulées au cours de la période de végétation du tournesol (*Helianthus annuus* L.), de la sorte Victoria. Les semailles ont été faites le 1er juin avec une densité de 7.5 plantes m^{-2} dans les deux régions climatiques. Dans la localité de Cocula comparativement à celle de Montecillo, les températures maximales et minimales étaient plus extrêmes, les précipitations plus intensives et le sol globalement plus pauvre en azote. Le milieu, l'azote et l'interaction milieu * azote ont eu une influence importante sur la croissance des plantes, le rendement et les composantes du rendement ainsi que sur l'efficacité de l'utilisation de l'eau. Dans la localité au climat chaud, la période de végétation a été plus courte de 36 jours et l'accumulation HU et Etc plus grande. Le rendement, les composantes du rendement et l'efficacité de l'utilisation de l'eau ont été significativement plus importants dans la localité de Cocula. L'azote a eu une influence positive sur les paramètres analysés. On peut dire que l'influence de l'interaction milieu * azote a été clairement sensible car dans la localité de Cocula, la réaction à l'administration d'azote a été visible pour tous les paramètres, ce qui n'a pas été le cas dans la localité de Montecillo.