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Root System, Phenology and Yield of Sunflower in Relation to Nitrogen and Phosphorus

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Abstract: Sunflower is a crop of world interest that is acquiring economic importance in Mexico. The aim of this study was to determine the effect of nitrogen (N) and phosphorus (P) on the growth of the root system and its relationship with the canopy dry matter and yield and its components of sunflower (*Helianthus annuus* L.). The planting of cv. Victoria was conducted in Montecillo Mex., of temperate climate in a vertisol under conditions of seasonal rainfall on 16 May, with population density of 5 plants per m^2. Treatments consisted in supply 0–200 kg ha^{-1} of N and P. The time to phenological stages was similar between treatment. The N and in minor degree the P increased grain yield (GY) and oil yield (OY) by increases in the grains number (GN), capitulum area (CA), canopy dry matter (CDM) and radical area (RA). In contrast, the P increase RDM but decrease the CDM/RDM relation. The effect of the interaction N * P on GY, OY indicates it is necessary to seek the best combination of N and P for increased the production of sunflower. The size grain and oil content in the grain did not change with N and P. The growth cycle was 122 days, with a seasonal ETc of 207 mm and 1,369°C d (Heat unit, HU).

RESUMEN: El girasol es un cultivo de interés mundial que está adquiriendo importancia económica en México. El objetivo del presente estudio fue

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determinar el efecto de nitrógeno (N) y fósforo (P) sobre el crecimiento del sistema radical, su relación con el vástago y rendimiento de aceite girasol (*Helianthus annuus* L.). La siembra de cv. Victoria se realizó en Montecillo Méx., de clima templado en un vertisol bajo condiciones de lluvia estacional, el 16 de mayo, con densidad de población de 5 plantas por m^2. Los tratamientos consistieron en el suministro de 0 a 200 kg ha^{-1} de N y P. La ocurrencia de las etapas fenológicas fue en tiempo similar en los tratamientos. El N y en menor grado el P incrementaron el rendimiento en grano (RG) y de aceite (RA) por incrementos en el número de granos, área del capítulo, materia seca del dosel (MSD) y área radical (AR). En cambio, el P aumentó la acumulación de materia seca en la raíz (MSR) pero redujo la relación MSD/MSR. El efecto de la interacción N*P sobre el RG y RA, indica que se requiere determinar la mejor combinación de N y P para lograr una mayor producción del girasol. El tamaño del grano y el contenido de aceite en el grano no presentaron cambios significativos con el N y P. La duración del ciclo de crecimiento fue de 122 días, con una ETc estacional de 207 mm y 1369 UC (°C d).

RÉSUMÉ: Le tournesol est une culture d‘intérêt mondial qui a acquis une importance économique au Mexique. L‘étude présente a comme objetif de déterminer l‘effet de l‘azote (N) et du phosphore (P) sur la croissance du système radical, de sa relation avec le descendant (rejet) du le rendement de l‘huiled´ un tournesol (*Helianthus annuus* L.). Les semailles de cv. Une premiére Victoire s‘est réalisée a Montecillo Méx., dans un climat tempéré d´ un bas vertisol des conditions de pluie saisonnière le 16 mai, une densité de population de 5 plantes par m^2. Les traitements ont consisté l‘approvisionnement de 0 à 200 kg N et de P par hectare. La circonstance des étapes fenológiques sest réglisec dans un temps similaire aux traitements. Le N et dans un moindre degré le P, ont augmenté le rendement du grain (RG) et de huile (RA) par des développements realisés dans le nombre de grains et d‘aire, et secteur le chapitre, matière sèche de la doivent (MSD) et la superficie radical. En revanche, le P. a augmenté l‘accumulation de matière sèche dans racine (MSR) mais a réduit la relation MSD/MSR. L‘effet de l‘interaction N*P sur le RG et RA, indique qu'il faut déterminer le meilleur dosage de N et P pour parvenir à une meilleure production du tournesol. La taille des grains et le contenu de l‘huile sur le grain n‘ont présenté changements avec le N et P. La durée du cycle de croissance a été de 122 jours, avec Etc. saisonnier de 207 mm et 1369 unités chaleur (°C d).

Key words: *Helianthus annuus* L., canopy dry matter, root area, oil content, grain number

Introduction

Sunflower is a crop of world interest that is acquiring economic importance in Mexico, because it can be used as a forage plant (Escalante *et al.*, 2008), their residues of harvest for weed control (Rodríguez *et al.*, 1998). The oil from the grains (ranging from 35–40%, Skorić and Marinković, 1986), can be used as cooking oil, margarine preparation. Likewise, its grains can used as food of birds and rabbits; medicinal use and the recent interest in the production of biodiesel (Flagella *et al.*, 2006), among others. So, the studies on the strategies that lead to increased yield and quality of same one justify themselves. The root system is the structure of the plant with functions of support and absorption, but in a way similar to other structures it can be affected by the application of nutriments. Nitrogen (N) and phosphorus (P) are determinants to the growth and yield of crops (Mengel and Kirby, 1987). The application of N increases root growth of sunflower under hydroponics (Escalante, 1995; Monsalve *et al.*, 2009), which may be reflected in the canopy dry matter biomass and yield (Escalante, 1999). In contrast, Pasda and Diepenbrock (1991) reported that N causes reductions in root growth of sunflower but increases leaf area. In relation to the Naphade and Naphade (1991) indicate that the application of P in sunflower increases the length and radical weight; and Muralidharudu *et al.* (2003), indicate increase in the grain yield. Escalante (1999) notes that under residual moisture, the supply of N increases the capitulum area, grain number and consequently the sunflower yield. Similar trends have been observed with P (Sathiyavelu *et al.*, 1994). Fernández and Ramirez (2000) indicate that in maize (*Zea mays* L.), the P increased the root area and that the magnitude of the response depends on the source of P and the genotype. Nevertheless, the studies on the performance of the root system depending on the fertilization with N and P, and consequently on the dry matter production, yield and its components are limited. The aim of the study was to determine the effect of the N and P on the root system growth and its relation with the canopy dry matter, grain yield, oil yield and its components in sunflower in the region of high valleys.

Materials and methods

The study was conducted in Montecillo Mex., of temperate climate under conditions of seasonal rainfall in a vertisol, pH 7.7, 2% organic matter and 40 kg inorganic N ha^{-1}, 46 ppm phosphorus, bulk density 0.9 g cm^{-3} and EC of 0.72 dS m^{-1}. Planting sunflower cultivar Victoria was held on May 16, in rows of 0.80 m apart, with a density of 5 plants m^{-2}. Treatments consisted in supply 0 (N0, P0) to 200 kg N and

P (N +, P +), which generated four treatment combinations: 1) N+ P +; 2) N+ P0; 3) N0P +; and 4) N0P0. The experimental design was a split plot with four replications. Was recorded the crop phenology according to Schneiter and Miller (1981). To physiological maturity (PM, R9, five plants of each plot were harvested to assess: the canopy dry matter (CDM, g m^{-2}), grain yield (GY, dry matter (DM) accumulated in the grain, 10% humidity, g m^{-2}), grain size (GS, weight per grain, mg), grain number m^{-2} (GN) and the capitulum area (cm^2, CA), grain oil content (%, OC), was determined by nuclear magnetic resonance, the oil yield (OY) that was calculated using the following equation: OY = (OC × GY)/100. When sunflower reach PM, the root of five plants were harvest in a soil profile of 0.40 m × 0.40 m × 0.40 m (64 dm^3) per each plant, to determine the root area or surface (dm^2, using an integrator of area, RA), root DM (RDM, g) and the ratio of CDM/RDM (CR, g g^{-1}). To data for each variable was applied a variance analysis, the comparison test of Tukey (0.05) and correlation analysis with SAS 9.1 statistical package (SAS, 2003). In addition, during the crop development mean of maximum temperature (Tmax) and minimum (Tmin), precipitation (PP, mm) and evaporation (EV, mm) was recorded. Crop evapotranspiration (ETc) was calculated by the equation : ETc = EV × K × Kc; where EV = evaporation tank type “A”, K = coefficient of tank (0.7) and Kc = crop coefficient (0.8) according to Doorenbos and Pruitt (1986). Also the heat units (HU, °C d) with the equation HU = Tmean – Tb (Snyder, 1985), where Tb is base temperature. This was considered a Tb = 6°C (Merrien, 1986).

Results and discussion

Phenology and climate elements

Between treatments, the differences in the time of occurrence to phenological phases was one or two days. So, thus in general, the emergence occurred at 11 days after planting (dap); the appearance of the capitulum or stage R1 at 59 dap, flowering (anthesis, R5) at 78 dap close to report by Escalante and Rodríguez (2010) con 80 dap, and PM (R9) to 122 dap. This cycle length was close to that reported by Aguilar *et al.* (2002) with 117 dap, for the same study region and cultivar. In Figure 1, one observes that during the vegetative stage the average of Tmax and Tmin was 25° C and 9°C; while during the reproductive stage was 22°C and 9°C, respectively. These temperatures are close to the optimal range (18°-25°C) for the development of this specie (Doorenbos and Kassam, 1979). Also, during most of the period of planting (S) to flowering (R5) and R5 to PM (R9), the EV exceeded the PP causing severe water stress which limited crop growth and yield. The seasonal EV and PP

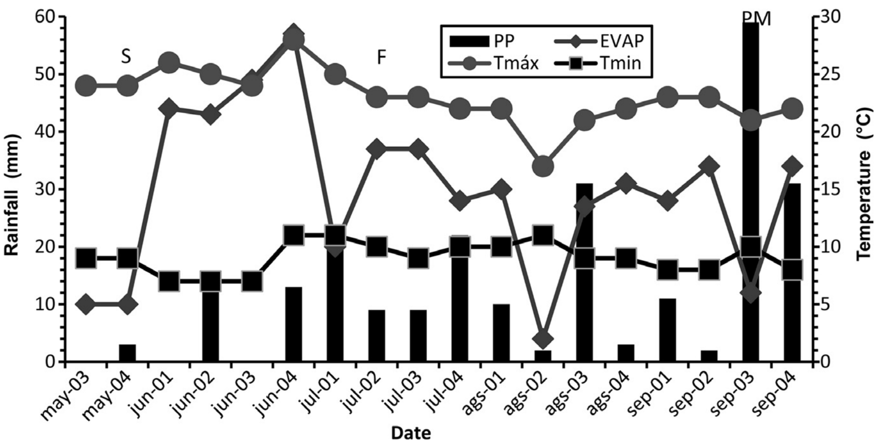

Figure 1: Mean weekly maximum temperature (Tmax), minimum (Tmin), the weekly amount of rainfall (PP, mm) and evaporation (EV, mm) during crop growth cycle. Montecillo Méx. *S* = planting; *F* = flowering (anthesis); PM = physiological maturity. Number after month indicate the week of each month.

was 490 mm and 210 mm, respectively. The seasonal ETc was 207 mm (72 mm was during the vegetative stage and 135 mm during the reproductive). The seasonal HU was 1369°C d (819°C d from S to R 5 and 550°C d of R5 to R9). Aguilar *et al.* (2002) reported seasonal ETc (370 mm), PP (394 mm) and HU (1,435°C d); Morales *et al.* (2006) (1,521°C d) higher than that reported in this study.

Root area, root dry matter, canopy dry matter and canopy dry matter/root dry matter relation

The root area (dm^2, RA) and root dry matter (gm^{-2}, RDM), canopy dry matter (gm^{-2}, CDM) and ratio of CDM/RDM (CRR, $g\ g^{-1}$) shown significant changes by effect of N, P and $N \times$ P. Table 1, indicates that the sunflowers fertilized with N and P, showed higher RA and RDM. The highest increase of RA was achieved with N (13 $dm^2\ m^{-2}$) followed by P (10 $dm^2\ m^{-2}$) and derives in major RDM (28% and 68%, respectively) in relation to N0 and P0. Similar trends have been reported with N by Escalante (1995) and P by Naphade and Naphade (1991).The increased allows the root system occupy larger volume of soil and higher absorption of nutriments and water. In relation to CDM, the largest increase (28%) was achieved with the N (Escalante, 1999), and was lower with P (9%). This is possibly due to the plants accumulated greater DM in the root system to expense of canopy DM, indicating a lower CRR relationship as shown in Table 1. The CDM of this study was 32 % higher than that

Table 1: Root area (RA, $dm^2\ m^{-2}$), root dry matter (RDM, $g\ m^{-2}$), canopy dry matter (CDM, $g\ m^{-2}$) and canopy dry matter/root dry matter relation (CRR, $g\ g^{-1}$) in sunflower (*Helianthus annuus* L.) as a function of N and P. Montecillo Mex.

Treatment	RA $dm^2\ m^{-2}$	RDM $g\ m^{-2}$	CDM $g\ m^{-2}$	CRR $g\ g^{-1}$
N+	24 a	355 a	1,830 a	7 a
N0	12 b	315 b	1,324 b	4 b
Tukey (0.05)	2	13	34	0. 4
Prob. F	***	***	**	***
P+	24 a	430 a	1,645 a	4 b
P0	13 b	240 b	1,508 b	7 a
Tukey (0.05)	2	35	53	0.3
Prob. F	***	***	***	***
Mean	18	335	1,577	5

**, *** $P < 0.01, < 0.001$, respectively. For each mean of N and P, similar letters indicate that the differences are not statistically significant according to the Tukey test (0.05).

reported by Aguilar *et al.* (2002) for the same cultivar and region. These differences may be related to variations in weather conditions from one year to another in the same locality. The interaction N * P, shows that the treatment *N* + P +, presented the greatest RA, RDM and CDM; followed by *N* + P, N0P+ and N0P0 that showed the lowest values. *N* + P+ exceeded to N0P0 in 2.3, 1.2 times and 48% the value of RA, RDM and CDM, respectively (Table 2). These results indicate the need to seek the

Table 2: Root area (RA, $dm^2\ m^{-2}$), root dry matter (RDM, $g\ m^{-2}$), canopy dry matter (CDM, $g\ m^{-2}$) and canopy-root relation (CRR, $g\ g^{-1}$) in sunflower (*Helianthus annuus* L.) as a function of the interaction N*P. Montecillo Mex.

Treatment	RA $dm^2\ m^{-2}$	RDM $g\ m^{-2}$	CDM $g\ m^{-2}$	CRR $g\ g^{-1}$
N + P+	29 a	435 a	1,882 a	4.3 b
N + P0	20 b	425 a	1,778 b	9.1 a
N0P+	18 b	286 b	1,409 c	3.3 c
N0P0	6 c	195 c	1,238 d	4.3 b
Mean	18.4	335	1,577	5.3
CV (%)	7	1.4	8	5
Tukey (0.05)	2.9	10	28	0.06
Prob. F	***	***	***	***

*** $P < 0.001$. For each mean of treatments, similar letters indicate that the differences are not statistically significant according to the Tukey test (0.05); CV = coefficient of variation.

best combination of N and P, in order to achieve a greater DM accumulation both in the root system as the canopy of sunflower. On the other hand, the highest CRR of the sunflower N+ compared to N0, indicates a greater DM in the sunflower canopy more than in the root. In contrast, the CRR more high in P0 that $P+$, indicates that the phosphorus promotes a greater DM accumulation in the root in relation to the canopy (Table 1).

Grain yield, its components, oil content in grain and oil yield

Grain yield (GY), grain number (NG) and the capitulum area (CA) and oil yield (OY) showed significant increases due to main factors of N, P (Table 3) and $N \times$ P (Table 4). The increase due to N and P in the GY was 45% and 20%, in GN was 37% and 12%, in CA 30% and 19%; and in OY 45% and 20%, respectively (Table 3). The increase in the GY and CA by N, has also been found under irrigation by Khaliq and Cheema (2005), De Giorgio *et al.* (2007) in semiarid conditions and by Killi (2004) at population density differents. The GS (mg) and oil content (OC, %) were not affected by changes in these nutriments. The GS and OC average was 55 mg and 40%, respectively. Similar trends with respect to N in other environments, have been reported by Escalante (1999) and P by Sathiyavelu *et al.* (1994). These results indicate that, since the GS and OC are the components with greater stability

Table 3: Grain yield, its components, grain oil content and oil yield in sunflower in function of N and P. Montecillo Mex.

Treatment	GY $g\ m^{-2}$	GS mg	GN m^{-2}	CA cm^{-2}	OC (%)	OY gm^{-2}
N+	349 a	56 a	6,225 a	289 a	40 a	141 a
N0	241 b	53 a	4,525 b	275 b	40 a	98 b
Tukey (0.05)	45	4	113	13	4	11
Prob. F	***	NS	***	*	NS	**
P+	323 a	57 a	5,684 a	318 a	40 a	130 a
P0	268 b	52 a	5,067 b	246 b	40 a	108 b
Tukey (0.05)	10	5	271	13	2	6
Prob. F	***	NS	***	***	NS	***
Mean	295	55	5,375	282	40	119

***, * $P < 0.001$, 0.05, respectively; NS = no significant differences ($P > 0.05$). For N and P similar letter indicate that the differences are not statistically significant according to the Tukey test (0.05); GY = grain yield; GS = grain size; GN = grains number; CA = capitulum area; OC = oil content; OY = oil yield.

Table 4: Grain yield, its components, grain oil content and oil yield in sunflower in function of interaction $N \times$ P. Montecillo Mex.

Treatment	GY g m^{-2}	GS mg	GN m^{-2}	CA cm^{-2}	OC (%)	OY gm^{-2}
N + P2	368 a	58 a	6,380 a	350 a	41 a	147 a
N + P0	331 b	56 a	6,070 a	286 b	40 a	134 b
N0P+	278 c	54 a	4,987 b	263 c	40 a	111c
N0P0	205 d	51 a	4,064 d	228 d	40 a	83 d
Mean	295	55	5,375	282	40	119
CV (%)	13	6	16	12	3	13
Tukey (0.05)	21	8	409	22	3	13
Prob. F	***	NS	***	***	NS	***

***, * $P < 0.001$, 0.05, respectively; NS = no significant differences ($P > 0.05$). For N*P similar letter indicate that the differences are not statistically significant according to the Tukey test (0.05); GY = grain yield; GS = grain size; GN = grains number; CA = capitulum area; OC = oil content; OY = oil yield.

to changes in N and P. The GN and CA are aiming to increase for greater GY and OY. The GY, OY, GN and CA of the present study was higher than reported by Aguilar *et al.* (2002) for the same region, genotype and supply of N, who reported 262 g m^{-2}, 115 g m $^{-2}$, 4,154 grains m^{-2} and 299 cm^2, respectively; and by Escalante and Rodríguez (2010) who reported a GY of 1,055 g m^{-2}. In contrast, the OC (44%) and GS (64 mg) were higher than that found in this study (41%). These differences may relate to the particular climatic conditions of each year of planting. In Table 4 that shows the effect of the interaction $N \times$ P, indicated that the treatment with $N \times$ P is achieving the highest GY (268 gm^{-2}) and OY (147 gm^{-2}), which exceeded 10% to $N +$ P0, 32% to N0P+ and 78% to N0P0. For GN and CA be observed a similar response. The yield components as GS and OC showed no significant differences between treatments, and the average was 55 mg and 40%, respectively (Table 4).These results indicate that the search for the best combination for the dose of N and P for sunflower, is critical for achieving a greater area radical, accumulation of dry matter in the canopy, production of grain and oil. Similar responses to the interaction $N \times$ P in the GY, have been reported by Zubillaga *et al.* (2002).

Correlations between the grain yield, oil yield, its components and radical area

Correlation of a particular character with other characters contributing to grain yield is of great importance in indirect selection of genotypes for higher grain

Table 5: Pearson correlation coefficients (r) between root area, grain yield, oil yield, its components and canopy dry mater of sunflower (*Helianthus annuus* L.) as a function of N and P. Montecillo Mex. Average data of four replications of treatments.

	RA	GY	OY	GS	GN	CA	CDM
RA	1.0	0.95***	0.95***	0.66**	0.93***	0.90***	0.88***
GY	**0.95*** **	**1.0**	**0.99*** **	**0.68** **	**0.95*** **	**0.85*** **	**0.96*** **
OY	0.96***	0.99***	1.0	0.70**	0.93***	0.96***	0.96***

Note: Top figure in each cell is the correlation coefficient (r), lower figure is the probability F (**, *** $P < 0.01$, 0.001, respectively). RA = radical area; GY = grain yield; OY = Oil yield; GS = grain size; GN = grain number; CA = capitulum area; CDM = canopy dry matter.

yield. In Table 5, which shows the relationship between the oil yield (OY) and its components with the variables of the root system, it is observed that the increase in GY, OY is associated with increases in GN, CA and CDM; and that these increases are related to increase in RA. The GY and OY showed a close correlation ($r = 0.99$). The highest correlation of GY also was observed with GN and CA by Tahir *et al*. (2002). A positive relationship between the root growth and growth canopy in sunflower has also been shown by Nagarathna *et al*. (2012). It was concluded that grain number, capitulum area and radical area were important characters to improve grain and oil yield. This emphasizes that selection based on these characters will be more effective in improving grain yield.

Finally, was observed that the N and in minor degree the P increased the GY and OY for increases in the GN, CA, CDM and RA. The effect of the interaction $N \times P$ on the OY indicates that it is necessary to look for the best combination of N and P fertilization to achieve a major expression of the growth and yield of the sunflower. The GS and OC did not present changes with the N and P. Grain number, capitulum area and radical area were important characters to improve grain and oil yield. The duration of the cycle of growth was 122 days, with one ETc seasonally of 207 mm and 1,369 HU.

Conclusions

With the nitrogen and in minor degree with the phosphorus, it was achieved to increase the radical area, dry matter, the capitulum area, the grain yield and oil yield. The size grain and the content of oil in the grain were not affected by the nitrogen and phosphorus. The phosphorus stimulated the accumulation of dry matter in the root that generated a lower relation canopy dry matter/root dry matter. An effect of the interaction nitrogen × phosphorus was observed on the canopy dry matter, area radical, grain yield, oil yield and its components as grain number and capitulum area. The radical area presented a close correlation with canopy dry matter, grain yield, oil yield, grain number and capitulum area.

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