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Effect of gibberellic acid on postharvest of sunflower and its potassium fertilization in alkaline soil

Efecto del ácido giberélico en postcosecha de girasol y su fertilización potásica en suelos alcalinos

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Abstract. Sunflower is a crop that is used as ornamental, oleaginous, forage, and currently as a bioremediation plant, of hard water affected soils. For this reason, the main objective of this investigation was to study the effect of potassium fertilization on yield under field conditions, and the effect of gibberellic acid (GA_3), at postharvest of inflorescences. Two experiments were established, under field and laboratory conditions. In the field experiment, four levels of potassium, 0, 50, 100 and 150 kg/ha were evaluated, under a randomized complete block design and four replicates (4×4) = 16 experimental units. The variables evaluated were agronomic and biological yields, harvest index, leaf area index and intercepted radiation. The variables in the laboratory were: diameter of the stem, basal diameter of the stem, weight of tubular flowers, vase life and days at opening of the capitulum. Treatments consisted of six levels of GA_3 and five replicates (6×5) = 30 experimental units, evaluated under a completely randomized design. The results indicated, that the maximum values for agronomic and biological yields were obtained with the application of 150 kg/ha of potassium. The maximum intercepted radiation was reached at 90 days after sowing on all treatments. In the laboratory, the longer vase life was obtained with the application of 20 and 40 mg/L of GA_3 including the control. As for the opening of capitulum, the control opened in less time, while the concentrations of 40 and 60 mg/L of GA_3 delayed the opening of the capitulum. From this work it is concluded, that the sunflower responds positively to potassium fertilization under soil alkalinity conditions. The application of GA_3, in post-harvest conditions affected the inflorescences of the species, delaying the opening of the capitulum.

Keywords: Agronomic yield; Biological yield; Radiation intercepted; Vase life.

Resumen. El girasol es un cultivo que se utiliza como ornamental, oleaginosa, forraje, y actualmente como planta de biorremediadora, de suelos afectados por aguas duras. Por tal motivo, el objetivo principal de esta investigación fue estudiar el efecto de la fertilización potásica bajo condiciones de campo, sobre el rendimiento, así como el efecto del ácido giberélico (AG_3), en postcosecha de inflorescencias. Para ello, se establecieron dos experimentos, bajo condiciones de campo y laboratorio. En el experimento de campo, se evaluaron cuatro niveles de potasio, 0, 50, 100 y 150 kg/ha, bajo un diseño de bloques completos al azar y cuatro repeticiones (4×4) = 16 unidades experimentales. Las variables evaluadas fueron rendimiento agronómico y biológico, índice de cosecha, índice de área foliar y radiación interceptada. Las variables en laboratorio fueron: diámetro de capitulo, diámetro basal del tallo, peso de flores tubulares, vida de florero y días a apertura del capítulo. Los tratamientos consistieron en seis niveles de AG_3 y cinco repeticiones (6×5) = 30 unidades experimentales, evaluadas bajo un diseño completamente aleatorizado. Los resultados indicaron, que los máximos valores para rendimiento agronómico y biológico, se obtuvieron con la aplicación de 150 kg/ha de potasio. La máxima radiación interceptada, se alcanzó a los 90 días después de la siembra para todos los tratamientos. En laboratorio, la mayor vida de florero se obtuvo con la aplicación de 20 y 40 mg/L de AG_3 incluido el testigo. En cuanto a la apertura de capítulo, el testigo abrió en menos tiempo, mientras que las concentraciones de 40 y 60 mg/L de AG_3 retrasaron la apertura del capítulo. De este trabajo se concluye, que el girasol responde de manera positiva a la fertilización potásica en condiciones de alcalinidad del suelo. La aplicación de AG_3, en condiciones de postcosecha afecta las inflorescencias de la especie, retrasando la apertura del capítulo.

Palabras clave: Rendimiento agronómico; Rendimiento biológico; Radiación interceptada; Vida de florero.

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INTRODUCTION

In the Valley of Tehuacán-Cuicatlán prevail soils with high salt content, because it remained, some million years ago, at the bottom of the seabed. Lowering the sea, its soil remained to date with a structure of calcium and sodium salts. Added to this and as a consequence of the above, the water used to irrigate crops has a high salt content. So, it is interesting to seek a crop that allows neutralize the chemical conditions mentioned above. Thus, sunflower (*Helianthus annuus* L.) is a plant that originated in northern Mexico and southeastern United States of America, and belongs to the family of the Asteraceae (Cantamutto et al., 2010; Pearson et al., 2010; Sanchez-Muniz et al., 2016). This plant for many years has been used for the extraction of oil from its seeds (Kartika et al., 2006), fodder (Morales-Rosales et al., 2007) and in recent years has been a very important ornamental crop in Mexico, specifically in flower growing areas by generating jobs and money (Díaz-López et al., 2010). Physiologically it is considered as a plant that has a high photosaturation point, due to its great bearing, that is resistant to drought (Ghobadi et al., 2013), and is also considered for bioremediation of soils, both degrading polycyclic aromatic hydrocarbons (Tejeda-Agredano et al., 2013), and reducing the concentrations of heavy metals such as cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni) and lead (Pb) within an hour of treatment (Eapen et al., 2007). Also, it has the property of secreting H^+ ions, which has the property of modifying the reaction of the same, making it more acidic (Feizi & Jalali, 2015). For optimal growth, sunflower requires 100 kg/ha of nitrogen, reaching a yield of 352 g/m^2 (Vega et al., 2001). On the other hand, Escalante et al. (2007) mention that the addition of 120 kg/ha of nitrogen, produces an agronomic yield of 412 g/m^2. Regarding the response of fertilization with P, Baumer (1999) mentioned that sunflower presents a positive response. Yields of 2100 kg/ha have been obtained after applying 60 kg/ha of (P_2O_5). However, there are no reports in relation to the agronomic and postharvest performance in the sunflower crop.

Moreover, potassium is an alkali metal element, which is considered as macroelement, and involved in important physiological processes in plants such as opening and closing of stomata. At the cellular level it is a major factor in the sodium and potassium pump; in postharvest physiological processes it is responsible for fruit quality, as this gives fruits the strength in both the endocarp and mesocarp (Salisbury & Ross, 2004; Rodriguez, 2005; Taiz et al., 2015). A positive effect on seed yield in sunflower has also been documented when both potassium and phosphorus fertilizers are used (Amanullah & Khan, 2010; Amanullah & Khan, 2011).

Gibberellic acid (GA_3) is a growth regulator that is involved in germination, flower induction, parthenocarpy (Su et al., 2001) and fruit mooring (Pérez-Barraza et al., 2008). Also, it has had a favorable effect when it was administered it as a supplement in postharvest pulse solutions of thidiazuron plus sucrose. Under these conditions, it has increased vase life by a further 0.8 days in Dutch iris (*Iris* × *hollandica*) cut flowers (Macnish et al., 2010). GA_3 also presents an improving effect on flower opening in vase life and favors the delay of early leaf yellowing of cut tulips (*Tulipa* spp.) due to the application of ethephon (Van Doorn et al., 2011). Sunflower had also been suitable for callus induction from hypocotyl and cotyledon explants on six different genotypes (Bayraktaroglu & Dağüstü, 2011).

Vase life is considered as the time that takes the flowers look nice or having appropriate qualitative properties such as: swollen petals, turgid stems, etc. (Cruz et al., 2006). This makes the flowers reach a good price at the market, thus translating into profits for producers. In this regard, there are many techniques to achieve this, ranging from the application of plant growth regulators to addition of some energy molecules such as glucose (Hernández-Hernandez et al., 2009). Thus, the aim of this study was to determine the effect of potassium fertilization under field conditions including dry weather and alkaline soil, and evaluate the effect of GA_3 on the sunflower inflorescences during postharvest conditions.

MATERIALS AND METHODS

Location of the experiment, weather and soil. The present study was conducted at the Universidad Tecnológica de Tehuacán, located at 18° 24' 51" north latitude, 97° 20' 00" west longitude and 1409 masl. Under a climate Bs_1(w')eg, corresponding to a dry climate with more than 18 °C to 27 °C lower than annual average temperature; rainfall from June to September with an annual rainfall greater than 400 mm and lower than 600 mm, and presence of a drought intraestival. The oscillation of temperature between the warmest and the coldest month is greater than 7 °C and lower than 14 °C. The warmest month is presented before the summer solstice for the zone that occurs in April. During the sunflower growing season, minimum and maximum temperatures, and the amount of monthly precipitation were determined with the help of an automated weather station (Davis Pro-2). The data collected with the station contributed to devise the ombrothermic diagram. Soil was a lithosol with a depth of 0.12 m, pH 8.4, electrical conductivity of 6.4 dS/m, 1.5% organic matter, cation exchange capacity of 12.5 cmol(+) /kg air-dried soil, and a percentage of saturated bases of 14.8; 3.5; 0.8 Cmol(+)/kg for Ca^{++}, Mg^{++} and K^+, respectively, which were determined with a Hanna photometer HI83225-01 multiparametric model. Nitrogen was determined by Kjeldahl's method. Phosphorus was calculated by the Olsen method. The initial levels of these nutrients were 7.2 mg/kg N and 6.1 mg/kg P, respectively.

Germplasm and establishment of the experiments. The germplasm used consisted of sunflower achenes cv. Victoria open-pollinated, donated by the genebank of the Laboratory of Ecofisiología de Cultivos from the Colegio de Postgraduados, campus Montecillo. They were sown in a topological arrangement (0.20 × 0.80) resulting in a population density of 6.25 plants per square meter. Experimental plots were four and consisted of planting beds with 6.0 m long, 1.5 m wide and 0.2 m high. The sampling was destructive and included three randomly selected plants for measuring the response variables. Only plants that were in full competition were sampled to avoid the border effect caused by plants positioned at the edge of the experimental plots. The whole experiment was fertilized with 100 kg/ha of nitrogen, whose source was urea, CH_4N_2O, (46% N) and 100 kg/ha of phosphorus, whose source was calcium triple superphosphate, $Ca_3(PO_4)_2$, (46% P_2O_5). The effect of potassium on the growth and yield in the cultivation of sunflower was evaluated, where treatments were four levels of potassium: 0, 50, 100 and 150 kg/ha, the source was potassium chloride, KCl (60% K_2O).

For the laboratory stage, the vase life of sunflower inflorescences was evaluated. These were subjected to different solutions of GA_3 at different concentrations: 0, 20, 40, 60, 80 and 100 mg/L. The inflorescences were cut in the morning at the phenological stage R_4, which is when the ray florets are visible from the top of the capitulum, but it remains closed (Bakht et al., 2010). They were taken to the laboratory for evaluation of vase life.

Response variables under field conditions. Response variables for this stage were agronomic yield, which was determined by weighing, using a digital scale model OBI-207134. The total weight of capitulum's achene was measured, expressing the results in g/plant. The biological yield was determined considering the total plant structures (stems, leaves, involucre, ray florets and achenes) were weighed with a OBI-207134 scale to express the result in g/plant. The harvest index was calculated using the equation: $HI=\frac{AY}{BY}$, where: *HI* is the harvest index, *AY* is the agronomic yield, and *BY* is the biological yield. Intercepted radiation was measured using a Ceptometer, LP-80 model, that measures radiation in a range of 400 to 700 nm. Leaf area index, was determined by $LAI=\frac{(LA)\,(PD)}{1000}$, where: *LAI* is the leaf area index, *PD* is population density, and *LA* is the leaf area of the crop, which is determined by: $LA= (L)\,(W)\,(0.7)$, where: *L* is the length of the leaf, *W* is the leaf width and 0.7 is an adjustment factor in sunflower. The experimental unit consisted of six plants of which two plants were randomly taken to evaluate the response variables.

Postharvest response variables. Response variables assessed at this stage of the experiment were: capitulum diameter and basal stem diameter, which were measured with a digital Vernier model 3756-D, expressing the result in centimeters. Weight of tubular flowers: the total disk tubular flowers after pollination proceeded to separate the capitulum at the end of the experiment was obtained using a scale model OBI-207134, and results were expressed in grams. Vase life was determined by counting the number of days that the inflorescences remained in the vase under optimal conditions (*i.e.*: when the ray florets remained *turgid* and the capitulum did not bend at an angle greater than 90°). Opening days of the capitulum: the total number of days whenever the cut inflorescences were fully opened at the R_4 stage; results were expressed in days.

Experimental designs. The field experiment was conducted under a completely randomized block design, with the mathematical model: $Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$ where: Y_{ij} is the response variable of the i-*th* level potassium, in the j-*th* repetition; μ is the true overall average; τ_i is the effect of the i-*th* potassium level; β_j is the effect of the j-*th* block; ε_{ij} is the experimental error of the i-*th* level of potassium in the j-*th* block or repetition (Infante & Zárate, 1990). Useful plots were the central plants of the experimental unit.

For the vase life experiment, it was tested a completely randomized design, under the following mathematical model: $Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$ where: Y_{ij} is the response variable of the i-*th* level of GA_3 in the j-*th* repetition; μ is the true overall average; τ_i is the effect of the i-*th* level of GA_3; ε_{ij} it is the experimental error of the i-*th* level of GA_3 in the j-*th* repetition (Infante & Zárate, 1990). For this phase, five repetitions were made, taking two samples for the evaluation of the variables. The experimental unit was formed by a vase of one-liter volume containing the inflorescence and a pulse solution with different levels of GA_3. When the response variables were significant in both stages, a multiple comparison test of Tukey was applied at a significance level of 5% probability of error.

RESULTS AND DISCUSSION

Maximum and minimum temperatures, precipitation during the course of the experiment are presented in Figure 1. It can be seen that the maximum temperature ranged between 27.9 °C and 30.9 °C, while the minimum between 4.8 °C and 14.5 °C. The maximum precipitation occurred in the month of September and then it gradually decreased until December. Total precipitation during the cycle of planting to maturity was 90.1 mm, with which the crop developed without problems.

Agronomic and biological yields and harvest index. The analysis of variance for these response variables are presented in Table 1. This shows that both the biological and agronomic yield showed highly significant differences, while the harvest index showed only significant differences. Regarding the coefficient of variation indicates that the data were statistically reliable, because they ranged between 5.75% and 14.02%.

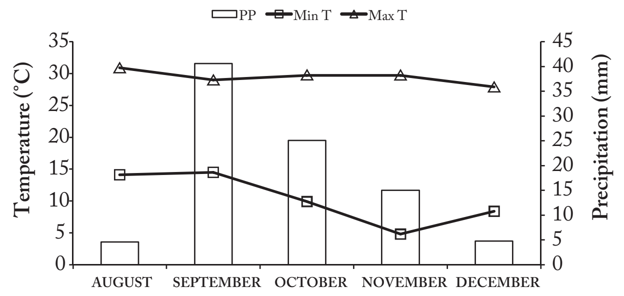

Fig. 1. Maximum (Max T) and minimum (Min T) temperatures, and average monthly precipitation (PP) during the growing season of sunflower (*Helianthus annuus* L.) under four levels of potassium at the Universidad Tecnológica de Tehuacán. Summer/Fall 2014 cycle.
Fig. 1. Temperaturas máxima (Max T) y minima (Min T), y precipitación mensual promedio (PP) durante la estación de crecimiento de girasol (*Helianthus annuus* L.) expuesto a cuatro niveles de K en la Universidad Tecnológica de Tehuacán. Ciclo verano/otoño 2014.

Table 1. Analysis of variance and comparison of treatment means for three response variables of sunflower (*Helianthus annuus* L.) sown in the field, and exposed to four levels of potassium at the Universidad Tecnológica de Tehuacán. Summer/Fall 2014 cycle.
Tabla 1. Análisis de varianza y comparación de los promedios de los tratamientos para tres variables de respuesta de girasol (*Helianthus annuus* L.) sembrado en el campo y expuesto a cuatro niveles de K en la Universidad Tecnológica de Tehuacán. Ciclo verano/otoño 2014.

TREATMENT	AY	BY	HI
kg/ha	g/plant		
T_0	15.00 c	27.00 c	0.55 a
T_{50}	11.00 d	33.33 bc	0.32 b
T_{100}	20.00 b	49.00 b	0.40 ab
T_{150}	46.00 a	108.00 a	0.42 ab
DSH	3.45	19.92	0.15
ANOVA	**	**	*
CV %	5.75	14.02	14.02

Means within columns with the same letter are statistically equal according Tukey at P≤0.05. AY, agronomic yield; BY, biological yield; HI, harvest index; ANOVA, analysis of variance; CV, coefficient of variation; * and **, significant at 0.05 and 0.01, respectively.
Los promedios dentro de cada columna con la misma letra son estadísticamente iguales de acuerdo a Tukey a P≤0,05. AY, rendimiento agronómico; BY, rendimiento biológico; HI, índice de cosecha; ANOVA, análisis de varianza; CV, coeficiente de variación; * y **, significativos a 0,05 y 0,01, respectivamente.

After applying 150 kg/ha potassium (K_2O), the highest agronomic seed yield (46.00 g/plant) was obtained above other treatments; the lower yield corresponded to the application of 50 kg/ha potassium (11.00 g/plant) (Table 1). These data differ with those reported by Escalante (1999), who worked with two genotypes of sunflower in Cordova, Spain. The mentioned yields of 33 g/plant, 28% less than values reported in this investigation. This could be largely to the different genotypes studied and the different climates where each study was carried out.

For biological yield, application of 150 kg/ha potassium had the highest dry biomass yield (108.00 g/plant) outstripping the other treatments. The lower yield corresponded to the control with 27.00 g/plant. It is important to highlight that the treatment with 100 kg/ha potassium presented a biological yield of 49.00 g/plant, while that with 50 kg/ha potassium only got 33.33 g/plant.

The harvest index for the treatment of 150 kg/ha potassium was 0.42, while the lowest value, although not significantly different (P>0.05) from the previous one, was 0.32 at 50 kg/ha potassium. The highest (P<0.05) harvest index was obtained when there was no fertilization with K_2O.

Figure 2 shows the intercepted radiation (IR) and leaf area index (LAI) to four treatments of gibberellic acid application. Intercepted radiation curves rose from 0 to 90 days after sowing (DAS), while they declined from 90 and 120 DAS. This response might be due to that lower leaves of sunflower were lost by abscission effect, causing the radiation to penetrate to the lower strata of the plant, thus reducing the intercepted radiation. Concerning the dynamics of LAI, upward trends were from 0 to 90 DAS and thereafter they declined from 90 to 120 DAS. This effect is very likely because of the lower leaves of the plant began senescence; this variable behaved similar to the intercepted radiation. This effect has also been mentioned by Diaz et al. (2012), who reported that during the cycle of sunflower cv. Victoria in mild weather, leaf area decreased as well as the LAI at 105 DAS.

Postharvest study. Five response variables were measured at this stage of sunflower inflorescences based on six levels of GA_3 (Table 2). So, the analysis of variance showed significant differences for capitulum diameter (Fig. 3), weight of tubular flowers, vase life and opening days of the capitulum. Basal stem diameter, despite having different numerical values between treatments, was not statistically significant. Under this same trend, the coefficient of variation presented values very reliable since it fluctuated in a range of 2.18% to 13.43%, being this last value the corresponding to the non-significant variable. Our findings are consistent with those of Saeed and Hassan (2014). These authors tested five concentrations of gibberellic acid (0-200 mg/L) on cut gladiolus flowers, and found that 25 mg/L showed the longest time taken to open the florets, and the floret opening increased vase duration life and fresh weight. Also, Gholami et al. (2011) reported that pulsing with a solution of sucrose at lower concentrations along with GA_3 (10 mg/L) was promising in increasing vase life of cut roses "Red One".

Regarding the multiple comparison test of the largest capitulum diameter, it was concluded that by adding 20, 60, 80 and 100 mg/L of GA_3 including the control, treatments were

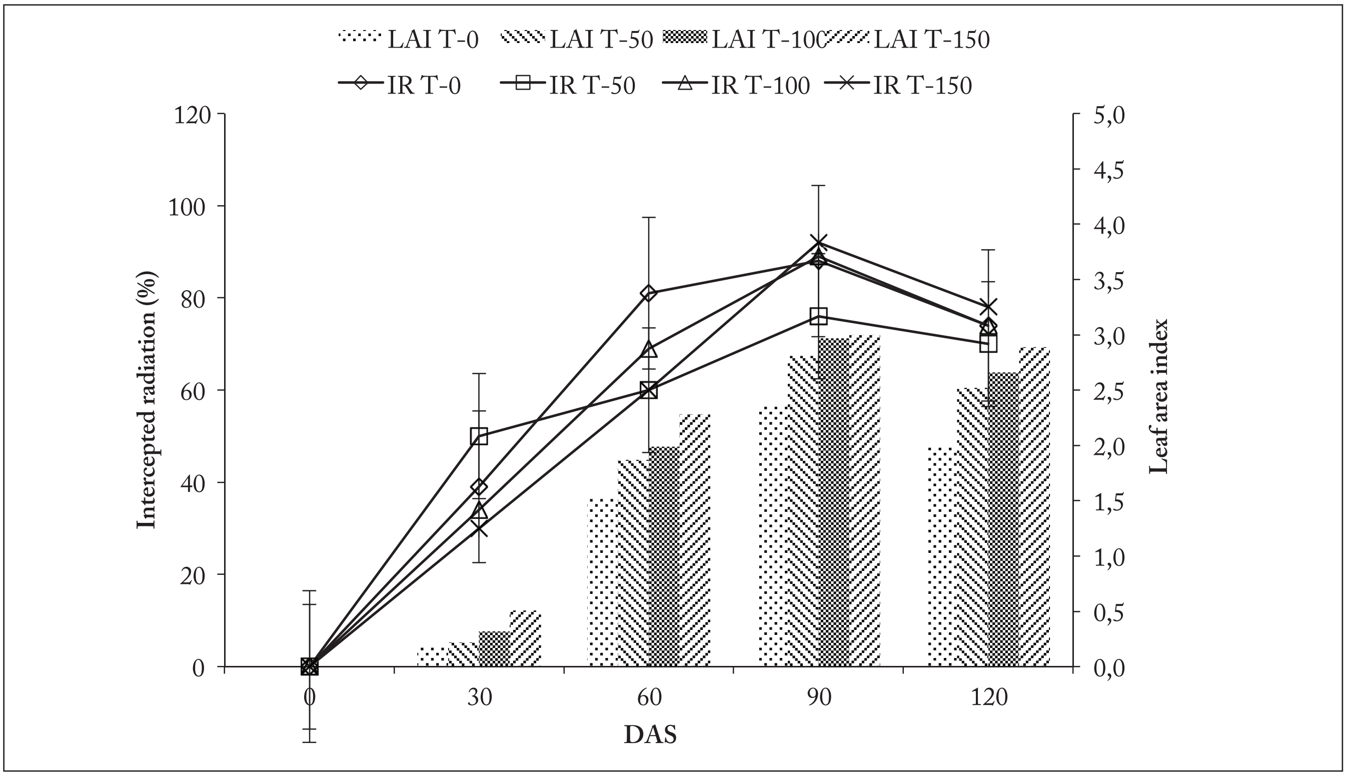

Fig. 2. Variation on intercepted radiation (IR) and leaf area index (LAI) in sunflower (*Helianthus annuus* L.) with time under four treatments of potassium at the Universidad Tecnológica de Tehuacán. DAS, days after sowing. Summer/Fall 2014 cycle.
Fig. 2. Variación en la radiación interceptada (IR) e índice de área foliar (LAI) en girasol (*Helianthus annuus* L.) en diferentes momentos de su ciclo de crecimiento (días) después de haber sido expuesto a cuatro tratamientos de K en la Universidad Tecnológica de Tehuacán. DAS, días después de la siembra. Ciclo verano/otoño 2014.

Table 2. Analysis of variance and comparison of means for five postharvest response variables of sunflower (*Helianthus annuus* L.) depending on gibberellic acid (GA3) at the Universidad Tecnológica de Tehuacán. Summer/autumn cycle 2014.
Tabla 2. Análisis de varianza y comparación de promedios para cinco variables de respuesta después de la cosecha de girasol (*Helianthus annuus* L.) después del tratamiento con distintas concentraciones de AG3 en la Universidad Tecnológica de Tehuacán. Ciclo verano/otoño 2014.

Tratamiento Mg/L (AG_3)	DC	BSD	WTF	VL	COD
	cm		g	días	
T_0	5.62 a	3.06 a	38.10 b	6.40 a	2.00 c
T_{20}	6.45 a	3.20 a	35.50 b	6.66 a	3.00 b
T_{40}	3.25 b	3.53 a	9.66 c	5.90 a	4.00 a
T_{60}	6.25 a	3.86 a	11.43 c	4.20 b	4.00 a
T_{80}	5.90 a	4.10 a	54.36 a	3.43 b	3.00 b
T_{100}	6.78 a	4.06 a	65.53 a	3.53 b	3.00 b
DSH	1.24	1.34	12.10	0.90	0.91
ANOVA	*	n.s	*	*	*
CV%	7.96	13.43	12.33	6.56	2.18

Means within columns with the same letter are statistically equal according Tukey at P≤0.05. DC, capitulum diameter; BSD, basal stem diameter; WTF, weight of tubular flowers; VL, vase life; COD, capitulum opening days; ANOVA, analysis of variance; CV, coefficient of variation; *, **, ns, significant at 0.05, 0.01 and not significant, respectively.
Los promedios dentro de cada columna con la misma letra son estadísticamente iguales de acuerdo a Tukey a P≤0,05. DC, diámetro del capítulo; BSD, diámetro del tallo en la base; WTF, peso de flores tubulares; VL, vida en el florero; COD, días de apertura del capítulo; ANOVA, análisis de varianza; CV, coeficiente de variación; *, **, ns, significativos a 0,05; 0,01 y no significativo, respectivamente.

Fig. 3. Effect of high doses of GA3 (60, 80 and 100 mg/L), on the diameter of the inflorescences of the capitulum in the vase life of sunflower (*Helianthus annuus* L.).
Fig. 3. Efecto de altas dosis de GA3 (60, 80 y 100 mg/L) en el diámetro de las inflorescencias del capítulo durante la vida de dichas inflorescencias de girasol (*Helianthus annuus* L.) en el florero.

statistically equal. The treatment with the smaller capitulum diameter occurred with 40 mg/L of GA_3. The same response was observed in *Rosa* spp. (De la Cruz-Guzmán et al., 2007), who reported that the floral diameter increased with the addition of aluminum sulfate + 8-HQL in acidic medium. These authors also mentioned that the response of the diameter is influenced by a higher water absorption in this medium, because it thrives in fewer microorganisms that can clog the xylem and phloem conduits, thus causing the decreased floral diameter.

Weight gain of tubular flowers was the highest at the higher concentrations of 80 and 100 mg/L GA_3 with 54.36 and 65.53 g, respectively; the lower weight occurred in the treatments 40 and 60 mg/L GA_3 with 9.66 and 11.43 g. Most vase life was at concentrations from 0 to 40 mg/L GA_3 with 6.40, 6.66, and 5.90 days. These vase lives were greater than the other treatments. This physiological response has been confirmed even in flower vegetables (Baixauli & Maroto, 2011), where studies with different doses of gibberellic acid on two cultivars of artichoke, showed that the application of GA_3 did not improve the precocity, final production and quality of the capitulums. Finally, the greatest capitulum opening days corresponded to 40 and 60 mg/L AG_3, being four days. Thereby the least capitulum opening days in the control was two days.

CONCLUSIONS

The major both agronomic and biological yields, and the harvest index were achieved with high levels of Potassium 150 kg/ha (K_2O). The highest radiation intercepted was obtained for a LAI of 3.0. Most radiation intercepted by the crop occurred at 90 DAS. The ratio of LAI vs intercepted radiation for the crop of sunflower in the study area was adjusted at increasing logarithmic models. Concentrations of 40 and 60 mg/L GA_3 affected positively the vase life increasing it until six days. Likewise, these concentrations of GA_3 delayed up to four days the opening of sunflower capitulums, and showed the highest capitulum diameter.

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