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BIOMASS, YIELD AND LAND EQUIVALENT RATIO OF *Helianthus annus* L. IN SOLE CROP AND INTERCROPPED WITH *Phaseolus vulgaris* L. IN HIGH VALLEYS OF MEXICO

[BIOMASA, RENDIMIENTO Y USO EQUIVALENTE DE LA TIERRA DE *Helianthus annus* L. EN UNICULTIVO Y ASOCIADO CON *Phaseolus vulgaris* L. EN VALLES ALTOS DE MÉXICO]

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SUMARY

The aim of the present study was to estimate the production of biomass, yield, yield components and land equivalent ratio (LER) of sunflower 'Victoria' (*Helianthus anuuss* L.) in sole crop and intercropped with three cultivars of bean (*Phaseolus vulgaris* L.) 'Acerado', 'Criollo' and 'Michoacán' in two localities of the State of Mexico (El Cerrillo and Montecillo). To estimate the LER, the individual analyses of variance were carried out in each locality for the seed yield of sunflower and bean. In El Cerrillo, the seed yield on the average (306.8 g m^{-2}) surpassed Montecillo by 15.2%. On the average in the both sites, 'Victoria' (309.9 g m^{-2}) surpassed in seed yield the associations 'Victoria' + 'Acerado' (13.0%), 'Victoria' + 'Michoacán' (11.5%) and 'Victoria' + 'Criollo' (9.2%). All of the intercropping systems showed values of LER higher than 1.67; moreover, the associations 'Victoria' + 'Michoacán' and 'Victoria' + 'Criollo' presented values of 1.80 at El Cerrillo and Montecillo, respectively, the sunflower intercropped with 'Michoacán', 'Criollo' or 'Acerado' represents a good option for the farmers of the high valleys of State of Mexico.

Key words: Competition; complementary; multiple crops.

RESUMEN

El objetivo del presente estudio fue estimar la producción de biomasa total, rendimiento, componentes y razón equivalente de la tierra (RET) de girasol 'Victoria' (*Helianthus annuus* L.) en unicultivo y asociado con tres cultivares de frijol (*Phaseolus vulgaris* L.) 'Acerado', 'Criollo' y 'Michoacán' en dos localidades del Estado de México (Cerrillo y Montecillo). Para estimar la RET, se efectuó en cada localidad el análisis de varianza individual para el rendimiento de semilla de girasol y frijol. El Cerrillo (306.8 g m^{-2}) superó en promedio a Montecillo en el rendimiento de semilla en 15.2%. 'Victoria' (309.9 g m^{-2}) superó en promedio a las asociaciones 'Victoria' + 'Acerado' (13.0%), 'Victoria' + 'Michoacán' (11.5%) y 'Victoria' + 'Criollo' (9.2%). Todas las asociaciones mostraron valores de RET superiores a 1.67. Asimismo, las asociaciones 'Victoria' + 'Michoacán' y 'Victoria' + 'Criollo' presentaron valores de 1.80 en ambas localidades, lo anterior indica que el girasol asociado con 'Michoacán', 'Criollo' o 'Acerado' representa una buena opción para los agricultores de los valles altos del Estado de México.

Palabras clave: Competencia; complementación; cultivos múltiples.

INTRODUCTION

In the high valleys of the central zone of Mexico, multiple crops are widely used by the farmers of the region, mainly because of the lack of land ownership and to the roughness of the topography. Since before the Conquest, the associated crops have been used in this country, especially the intercropping of maize (*Zea mays* L.) with annual legumes. The combination of sunflower with bean is attractive for the producers, because it guarantees bean own-consumption and good economic income with the sunflower production (Morales *et al.*, 2006).

The competition generated by plant species sharing the same space is defined as a process through which the crops limit the resource mutually in such a way that it does not satisfy its demand (nutritional, physiological etc.), thus generating a reduction in the survival, growth and yield of the individual plants of the crop or

its reproduction (Kruk and Satorre, 2003). Complementary effects occur when each species growing next to another does not experience a negative effect in its growth and development. In relation to the available resources, complementary effect implies that the capture of the limiting resources is higher and therefore their use is more effective in the intercropped species with respect to the sole crop (Maddonni and De la Fuente, 2003).

The Land Equivalent Ratio (LER) is the sum of the fractions of the intercropped yields divided by the sole-crop yield. LER is calculated using the equation LER = Σ (Ypi/Ymi), where Yp is the yield of each crop or variety in the intercrop or polyculture, and Ym is the yield of each crop or variety in the sole crop or monoculture. For each crop (i) a ratio is calculated to determine the partial LER for that crop, the partial LERs are summed to give the total LER for the intercrop (Darish *et al*., 2006). A LER value of 1.0, indicates no difference in yield between the intercrop and the collection of monocultures (Mazaheri and Moveysi, 2004). Any value greater than 1.0 indicates a yield advantage for intercrop. A LER of 1.2 for example, indicates that the area planted to monocultures would need to be 20% greater than the area planted to intercrop for the two species to produce the same combined yields. In a sense, the LER measures the levels of intercrop interference going on in the cropping system. Theoretically, if the agro ecological characteristics of each crop in mixture are exactly the same, the total LER should be 1.0 and the partial LERs should be 0.5 for each. A total LER of higher that 1.0 indicates the presence of positive interferences among the varieties or crops components of the mixture, an also mean that any negative interspecific interference that exists in the mixture is not as intensive as the intraspecific interference that exists in the monoculture. Avoidance of competition or partitioning of resources is probably occurring in the mixture (Willey and Osiru, 1981).

Some investigators have reported studies where sunflower is intercropped with other species. Legumes (annual) were sown with sunflower at the same time and at growth stages V4 and V10 (4 and 10 developed leaves, respectively) of sunflower, concluding that the legumes sown at the same time significantly reduced the production of biomass and the seed yield of the sunflower, as a result of the competition for resources between the component species of the association. On the other hand, when sowing was carried out in growth stages V4 and V10, the competition for the resources was lower and therefore the production of dry matter and the seed yield of the sunflower did not differ significantly from the control (Kandel *et al*., 1997).

In Texcoco, Mexico, when 'Victoria' sunflower was evaluated in two planting systems (sole crop and intercropped with bean) the yield and yield components of sunflower did not show significant differences (Morales *et al*., 2006). In other trial, the harvest index and plant height were affected when the sunflower was associated to soybean (*Glycine max* (L.) Merr.) and mungo bean (*Vigna mungo* L.). In contrast, the variables of stem diameter, capitulum diameter, seeds per capitulum and weight of 100 seeds were not significantly reduced (Ibrar *et al.*, 2002).

In the combined system sunflower – peanut (*Arachis hipogaea* L.), no significant statistical differences were detected on number of seeds per capitulum, the percentage of filled seeds, the seed yield and weight of 100 seeds, respect to the sole crop. The LER obtained was 1.45 (Sahoo *et al.*, 2003).

The aim of the present study was to evaluate the total biomass, seed yield, yield components and land equivalent ratio of the 'Victoria' sunflower in sole crop and intercropped with three cultivars of bean ('Acerado', 'Criollo' and 'Michoacán') in two highlands of Mexico (El Cerrillo and Montecillo).

MATERIAL AND METHODS

The study was carried out during the spring-summer cycle of 2006 in two localities of the State of Mexico. El Cerrillo is located at 19º 14' N and 99º 42' W; 2640 m altitude. It has an average rainfall of 800 mm and 12.7º C mean annual temperature. The pH of the soil is 6.5 with a medium level of nitrogen (55 kg N ha^{-1}), with 2.7% organic matter. Montecillo is located at 19º 29' N and 98º 54' W, with an altitude of 2240 m, average annual rainfall of 558.5 mm and mean monthly temperature of 15 ºC; the soil had a pH of 7.8 with an initial content of organic matter of 3.8 and 47 kg N ha^{-1} in inorganic form.

During the development of the crop, it was recorded daily the maximum and minimum temperature as well as the rainfall, then an average (mean decennial) and a sum decennial was determined, respectively.

To estimate the total biomass, seed yield and yield components of sunflower in sole crop and intercropped with bean, the following treatments were considered in each locality: 'Victoria' sunflower in sole crop and the three intercropped systems 'Victoria' + 'Criollo', 'Victoria' + 'Acerado' and 'Victoria' + 'Michoacán' bean. To estimate the LER in addition to the mentioned treatments, at the same time and the two localities, beans 'Criollo', 'Acerado' and 'Michoacán' were growth under sole crop conditions (sown with wood trellises). The experimental plot was comprised by four rows of 5 m, each separated by 0.80 m, the two

intermediate rows were considered as the useful plot, eliminating 0.5 m from each side. The sowing in each locality was carried out on 22 May in El Cerrillo, and on 30 May in Montecillo. The distance between plants was 0.25 m; in the intercropping system bean and sunflower seeds were placed together. The soil fertilization was with the formula 80 – 90 – 00 (Morales *et al*., 2008) using urea as nitrogen source (46% N) triple calcium super phosphate (46% $P_2 O_5$) as source of phosphorus, all of the phosphorus and half of the nitrogen were applied at sowing, the other half of nitrogen was applied when the crops had six expanded leaves. Experimental design was a randomized complete blocks with four replicates in a factorial arrangement, where the study factors were the planting system and the localities.

At harvest, total biomass (TB), seed yield (SY), area of capitulum (AC), number of seeds m^{-2} (NS), weight of 100 seeds (WHS) and harvest index (HI) of the sunflower were evaluated. Harvest index is a measurement of crop yield: the weight of a harvested product as a percentage of the total plant weight of a crop (Kohashi, 1993). The estimation of the TB was done in three sunflower plants that were dried at 80 ºC in a forced air oven until reaching constant weight. The land equivalent ratio (LER) was estimated through the following relationship (Willey and Osiru, 1972):

$$LER = \frac{Yij}{Yii} + \frac{Yji}{Yjj}$$

Where:
Yij = Yield of sunflower under intercropping conditions
Yji = Yield of bean under intercropping conditions
Yii = Yield of sunflower under sole crop conditions
Yjj = Yield of bean under sole crop conditions

The combined analysis of variance over two localities was made for all variables (Gomez and Gomez, 1984). The individual analysis of variance (ANOVA) for each locality was applied to the seed yield of each sole crop for both bean and sunflower. The computer software was used SAS 8.0. When the F values were significant, the Tukey comparison of means test was applied.

RESULTS

Figure 1 presents maximum temperature (MT), minimum temperature (mT), and accumulated rainfall during the 2006 growing season at the two localities. At El Cerrillo, it is observed that the values of MT and mT varied between 6 and 23 ºC, respectively. Total rainfall during the development of this experiment was 719 mm, from which 46.6% (345 mm) occurred from sowing to the onset of flowering and the other 374 mm rained during seed formation. At Montecillo, it is observed that the extreme values of MT and mT were 32 and 4.2 ºC, respectively. Total rainfall during the growing cycle was 444 mm; 225 mm fell from sowing to the onset of flowering (57.4%) and 189 mm rained from flowering to physiological maturity (42.6%). Mean temperature at each locality was 14.7 and 18.2 ºC, for El Cerrillo and Montecillo, respectively.

The means comparison of localities indicates that El Cerrillo was the best site for sunflower (Table 1) in sole crop and intercropped due to the higher values of SY, HI and AC respect to Montecillo (Figure 2). The SY, HI and AC at El Cerrillo surpassed Montecillo by 15.2, 14.7 and 6.7%, respectively. Respect to the planting systems, the means comparison revealed that the sunflower 'Victoria' in sole crop, obtained the highest averages in all the variables evaluated except of WHS. In SY, 'Victoria' surpassed by 13.0, 11.5 and 9.2% the combinations of 'Victoria' + 'Acerado', 'Victoria' + 'Michoacán' and 'Victoria' + 'Criollo', respectively. In the variable TB, 'Victoria' in sole crop (1280.1 g m^{-2}) and intercropped with 'Criollo' (1239.5 g m^{-2}) obtained a similar production of dry matter. The intercropping 'Victoria' + 'Acerado' showed the lowest values in all of the variables evaluated with the exception of HI and WHS (Table 1).

In Figure 2 (a), it can be observed that the sole crop 'Victoria' (346.5 g m^{-2}) in the locality El Cerrillo presented the maximum seed yield, in addition, a tendency is observed in Montecillo where the seed yield of 'Victoria' did not present any difference in seed production when it is intercropped with the bean cultivars. Numerically, the intercropping sunflower + bean in the locality of El Cerrillo presented higher seed production with respect to the sole crop of sunflower in Montecillo.

In this sense, the interaction locality × planting system was highly significant in the variables SY, AC, NS. The Figure 2, shows the behavior of variables SY, AC and NS in the two localities studied. The cultivar Victoria in sole crop (El Cerrillo) presented the highest SY (346.5 g m^{-2}). The association Victoria + Criollo in Montecillo, presented the highest AC (304.2 cm^2). Victoria at both sites showed the highest values for the variable number of seeds.

The Michoacán bean had the highest yields. In El Cerrillo, this cultivar produced 155.4 and 132.5 g m^{-2} in sole crop and intercropped with 'Victoria', respectively, while in Montecillo, seed production was 155.3 g m^{-2} (sole crop) and of 152.5 g m^{-2} (intercropped with 'Victoria') (Table 2). The LER shown in Table 3 indicates that all the associations

presented values higher than the unit, being outstanding 'Victoria' + 'Michoacán' and 'Victoria' + 'Criollo' with 1.80 at Cerrillo and Montecillo, respectively. It is important to point out that in El Cerrillo, sunflower gave the highest value of LER (values close to 1), whereas in Montecillo, the values of LER of both species were similar.

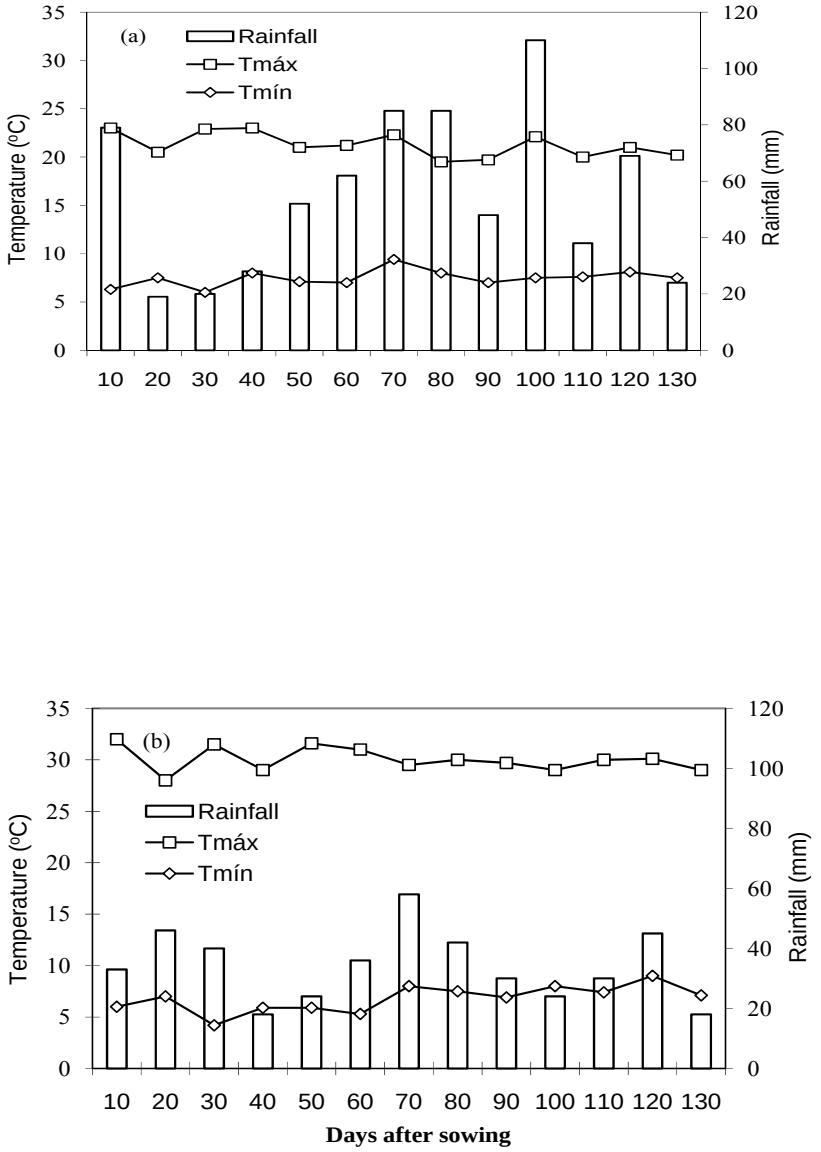

Figure 1. Minimum and maximum temperatures (mean decennial) and rainfall (sum decennial), during the growth stage of sunflower in sole crop and intercropped with common bean in El Cerrillo (a) y Montecillo (b).

Table 1 Effects of localities and planting system on seed yield and yield components of sunflower.

Locality	TB (gm^{-2})	SY (gm^{-2})	HI (%)	AC (cm^2)	SN (m^2)	WHS (g)
El Cerrillo	1227.1 a	306.8 a	25.1 a	254.5 b	4300.0 a	7.3 a
Montecillo	1221.7 a	260.1 b	21.4 b	272.8 a	4314.0 a	7.2 a
Tukey	43.9	7.3	0.9	4.0	108.6	0.2
Planting System						
Victoria	1280.1 a	309.9 a	24.3 a	274.1 a	4751.6 a	7.2 a
Vic + Mich	1222.5 ab	274.4 b	22.5 b	262.1 b	4445.5 b	7.2 a
Vic + Cri	1239.5 a	281.3 b	22.9 ab	266.4 b	4133.0 c	7.2 a
Vic + Ace	1155.6 b	269.5 b	23.4 ab	252.0 c	3900.1 d	7.3 a
Tukey	83.5	13.9	1.6	7.5	177.4	0.3
Anova						
Locality	ns	***	***	***	ns	ns
Planting System	***	**	*	***	***	ns
L * S	ns	***	Ns	***	***	ns

Means followed by the same letters on one column are not significant different according Tukey. Vic = sunflower 'Victoria'; Mich = bean 'Michoacán'; Cri = bean 'Criollo'; Ace = bean 'Acerado'; TB = Total biomass; SY = Seed yield; HI = Harvest index; AC = Area of capitulum; SN = Seed number m^{-2}; WHS = Weight of one hundred seeds; * = $P \leq 0.05$; ** = $P \leq 0.01$; *** = $P \leq 0.001$; ns = not significant.

Table 2. Seed yield of common bean in sole and intercropping system.

Treatment	Common bean seed yield (kg ha^{-1})		
	El Cerrillo	Montecillo	Mean
'Michoacán'	154.4 a	175.3 a	165.4 a
'Criollo'	135.2 ab	120.4 c	127.8 bc
'Acerado'	121.7 bc	106.9 cd	114.3 cd
'Victoria' + 'Michoacán'	132.5 ab	152.5 b	142.5 b
'Victoria' + 'Criollo'	127.2 bc	97.9 d	112.6 d
'Victoria' + 'Acerado'	101.4 c	91.3 d	96.4 e
Tukey	25.2	18.9	14.7

Within a column for each specie, means followed by the same letters are not significantly different according to Tukey (0.05)

Table 3. Land equivalent ratio of sunflower and common bean in sole and intercropping system.

	Land equivalent ratio (LER)					
	Cerrillo			Montecillo		
Victoria	Sunflower	Common bean	Total	Sunflower	Common bean	Total
Victoria	1	-	1	1	-	1
Michoacán	-	1	1	-	1	1
Criollo	-	1	1	-	1	1
Acerado	-	1	1	-	1	1
Victoria + Michoacán	0.93	0.87	1.80	0.85	0.85	1.70
Victoria + Criollo	0.97	0.81	1.78	0.86	0.94	1.80
Victoria + Acerado	0.91	0.85	1.76	0.84	0.83	1.67

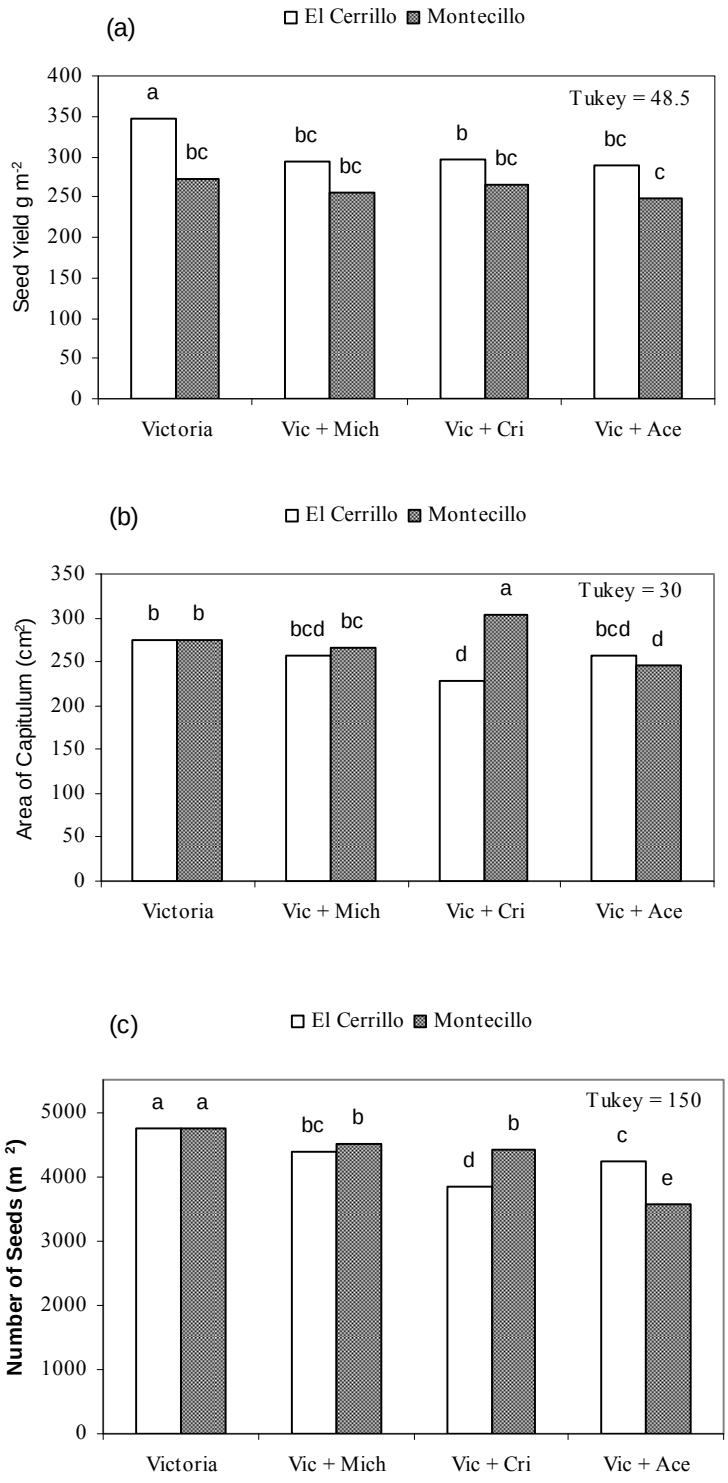

Figure 2. Seed yield (a), area of capitulum (b) and number of seeds (c) of sunflower in two localities of the State of Mexico. The bars with same letters are not significantly different according to Tukey.

The coefficients of simple linear correlation between seed yield and its components which are shown in Table 4, indicate that the variables TB (P <0.05), HI (P <0.001) and NS (P <0.05) were positively and significantly correlated with seed yield; these were the characteristics that influenced yield expression.

Table 4. Simple linear correlation coefficient (r) between seed yield and yield components the sunflower.

Seed yield versus	r	P
Total biomass	0.43	*
Harvest index	0.84	***
Area of capitulum	0.022	ns
Seed number m^{-2}	0.44	*
Weight hundred seeds	0.014	ns

* = $P \leq 0.05$; ** = $P \leq 0.01$; *** = $P \leq 0.001$; ns = not significant.

DISCUSSION

Rainfall at El Cerrillo was higher than at Montecillo during the experiment. What is by the SY average at Montecillo was lower in both cropping systems. These results agree with Sarandón and Chamorro (2003), who observed advantages of the crops (annual) that share the same space are frequently registered when they are developed under conditions in which the rainfall is not less than 500 mm.

Essentially, there was a reduction in all the characteristics in associated to sunflower (most significantly on SY, TB, HI, AC and NS), compared to this as a sole crop. That could be due to that sole sunflower did not experience competition for light, water and nutrients. Fukai and Trenbath (1993) pointed out that when two species are associated, the crops interact in such a way that when one exerts a negative effect on the other, the principal of competition is established. Kandhro *et al*. (2007) affirm that when sunflower is intercropped with mungo bean (*Vigna radiate* L.), the yield of sunflower was diminished by 23.9% respect to it is sole crop due to the effect of the competition between the two species. Khan *et al.* (1999) report a yield of sunflower in unitary planting of 1867 kg ha^{-1}, and when it is intercropped with soybean, it was reduced by 23.8%. Saleem *et al*. (2003) mention that the intercropping sunflower - mungo bean is better than the sole crop of sunflower, regarding what to seed yield, although the adverse effects in the principal crop (22.5% less yield respect to the individual planting of sunflower) was compensated by the seed production supplied by the mungo bean.

The relationship of complementary resources originates when at least one of the component species of the association exerts a positive effect on the other (Fukai and Trenbath, 1993). In this sense, although there were significant differences, when sunflower 'Victoria' was intercropped here, the competition from beans was not so accentuated, given that the seed yield achieved by 'Victoria' under this planting system was reduced 13% ('Victoria' + 'Acerado') and 9.2% ('Victoria' + 'Criollo') average; thus it is thought that there was a certain complementation in the use of the inputs for the agricultural production between the two species.

On the other hand, two factors are said to interact if the effect of one factor changes as the level of the other factor changes (Gomez and Gomez, 1984). In these sense, in the traits SY, AC and NS the 'Victoria' in sole crop and intercropped with bean interacted with the locality (Figure 2). At El Cerrillo, 'Victoria' in sole crop had the highest SY, but when planted at Montecillo the yield was significantly reduced. The same phenomenon occurred when the sunflower was associated with bean. In general, there were a greater NS and AC in both planting systems when they were sown in Montecillo respect to El Cerrillo.

The highest yields of 'Michoacán' bean in sole crop and intercropped in both localities (Table 2), agree with Morales *et al*. (2006) on a study where were evaluated three cultivars of bean 'Canario 107', 'Bayomex' and 'Michoacán' intercropped with sunflower 'Victoria' in Texcoco, Mexico. These investigators found a higher seed yield in 'Michoacán' (351 g m^{-2}) respect to the other bean cultivars. However, this production was not different from the statistical viewpoint when 'Michoacán' was established as sole crop (381 g m^{-2}).

Based on the LER, the associated crops produced between 76 and 80% more at El Cerrillo and between 67 and 80% at Montecillo. The high values of LER presented by sunflower in the locality El Cerrillo (Table 3) indicate that this was the dominant crop in the intercropping, coinciding with what was found by Muhammad *et al*. (2007) in the intercropping sunflower – canola (*Brassica campestris*), in which sunflower presented a LER value of 0.95 and that of canola was 0.75. In Montecillo, the values of LER were equitative between the component species of the binary planting system, with the exception of 'Victoria' + 'Criollo' (0.86 and 0.94, respectively), therefore it is believed that the sunflower and bean complemented each other mutually in the utilization of the resources for agricultural production. In another study, Sarandón and Chamorro (2003) found a LER of 1.99 in the combined system sunflower – maize, an amount higher than the values reported in the present investigation.

The positive and significant correlation of seed yield with TB, NS and HI partially confirmed the findings of Cantagallo *et al*. (1997) and López *et al*. (1999), who reported that the number of seeds per surface unit and seed weight are the two components that have the strongest influence on the expression of yield.

CONCLUSION

The locality of El Cerrillo (306.8 g m^{-2}) was the best planting site, given that the seed yield on the average surpassed Montecillo by 15.2%. In the planting systems, 'Victoria' (309.9 g m^{-2}) was higher in seed yield than the associations 'Victoria' + 'Acerado' (13.0%), 'Victoria' + 'Michoacan' (11.5%) and 'Victoria' + 'Criollo' (9.2%); however, the production of sunflower biomass in sole crop was not significantly different from 'Victoria' associated with 'Michoacán' and with 'Criollo'. The interaction locality × planting system was significant for seed yield, area of capitulum and number of seeds per square meter.

The intercropping in El Cerrillo surpassed in seed yield all of the treatments evaluated (including 'Victoria' in sole crop) in the locality of Montecillo. Seed yield was positively and significantly correlated with total biomass, harvest index and number of seeds per square meter, these being the variables which influenced the expression of this character. All of the associations evaluated showed values of land equivalent ratio higher than 1.67, the association 'Victoria' + 'Michoacán' being outstanding, which presented a value of 1.80 in both localities. This suggests that the sunflower intercropped with 'Michoacán', 'Criollo' or 'Acerado' represents a good alternative for the small producers of the high valleys of Mexico.

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