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RESEARCH PAPER

Snap bean production using sunflowers as living trellises in the central high valleys of Mexico

Edgar Jesús Morales-Rosales, Omar Franco-Mora, and Andrés González-Huerta

Centro de Investigación y Estudios Avanzados en Fitomejoramiento. Universidad Autónoma del Estado de México. Campus Universitario El Cerrillo Piedras Blancas, Municipio de Toluca, Estado de México, C.P. 50200, México.

Abstract

E. J. Morales-Rosales, O. Franco-Mora, and A. González-Huerta. 2011. Snap bean production using sunflowers as living trellises in the central high valleys of Mexico. Cien. Inv. Agr. 38(1): 53- 63. The aim of this study was to assess growth, net assimilation rate, biomass production and pod yield in two snap bean cultivars sown in monoculture and combined with two sunflower cultivars at three localities in the State of Mexico, Mexico. The six treatments were evaluated in a 2 × 3 factorial experiment in a randomized complete block design with four replications. When F values were significant, the least significant difference test at the 5% level of significance was used. The principal component analysis was also used to study the interrelationship among the six treatments and seven variables. The results observed in the biplot indicated that the largest original variation in the data was adequately represented in the first two principal components since both accumulated 68.5%. This variability was classified into four groups: 'Criollo' + 'Sunbright' and 'Acerado' + 'Victoria' contributed to the better phenotypic expression of leaf area index, pod yield and pod length; 'Criollo', with best average performance for net assimilation rate, number of pods and total biomass; 'Criollo' + 'Victoria' and 'Acerado' + 'Sunbright', the former with the largest pod diameter; and 'Acerado', with the poorest performance in leaf area index, pod yield and pod length. Treatments 'Criollo' and 'Criollo' + 'Sunbright' showed the highest pod yield (7.66 and 7.70 $t \cdot ha^{-1}$, respectively), which is attributed to both, presented the highest values of leaf area index, total biomass and numbers of pods.

Key words: *Phaseoulus vulgaris*, *Helianthus annuus*, multiple crops, net assimilation rate, principal component analysis.

Introduction

Common bean (*Phaseolus vulgaris* L.) is a grain culture, which is also consumed fresh, and the fruit (pod) provides significant amounts of proteins, minerals and vitamin B complex to humans (Esquivel *et al*., 2006). Pod (snap bean) is an important vegetable at a national and international level as it is a low cost production source of protein, in addition to providing calcium and phosphorous to human feeding (Santos *et al*., 1997).

Snap bean has pods with a thick and succulent mesocarp and a reduced or null amount of fibers on walls and sutures. In addition to little fiber, the snap bean varieties have other

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Corresponding author: ejmoralesr@uaemex.mx

morphological and culinary features differentiating the species. Currently, the tendency is to increase the vegetable consumption in diet; therefore, an increased demand is expected at national and world level. Mexico may export snap beans to the United States; thus, varieties with production and quality demands must be developed, and also must have the features enabling mechanical harvest (Esquivel *et al.*, 2006).

Esquivel *et al.* (2006) reported a production of 55,000 tons of snap beans sowed in 8,500 hectares for Mexico, with an average yield of 6.5 t ha^{-1}. At domestic level, snap bean production extends across the States of Morelos, Sinaloa, Hidalgo, Puebla and Mexico; yields between 7.0 and 11.0 t ha^{-1} have been estimated for Mexico and Puebla, respectively (Salinas *et al.*, 2008). Pod production in the State of Mexico is focused on the local market, but plantation area has been decreasing (Garduño *et al.*, 2009).

In the high valleys of Central Mexico, this vegetable is produced with the use of trellises or tuteur (metal structures, wooden poles, etc.), which increase the production costs due to their high economic value. Additionally, the ecological problem is present, as the plantation of this species by farmers requires the uncontrolled cutting of slow regeneration forest species for tuteurs. The aforementioned factors make this culture unattractive for small farmers; therefore, the use of sunflower (*Helianthus annuus* L.) living tuteurs becomes an alternative, which work as trellises for bean plants.

Kandel *et al.* (1997), Sarandón and Chamorro (2003) and Garduño *et al.* (2009) have reported that the bean-sunflower association represents a good alternative for production, as both species complement mutually in the use of agricultural inputs. Complementation occurs when each species experiments less interspecific competence. In terms of available resources, complementation involves the capture of limiting resources (light, water, nutrients and space), where this is higher and/or more effective in species mixtures than in pure cultures (Tsubo *et al.*, 2003).

In addition to helping support the beans, an additional advantage offered by this production system is that sunflower plants provide additional earnings by the sale of cutting flowers or seeds (achenes) in the region under study.

The aim of this study was to evaluate the pod yield and yield components of two bean cultivars sown in monoculture and combined with two sunflower cultivars, in three localities of the State of Mexico, Mexico.

Materials and methods

Experiments

The research was made in the spring-summer cycle of 2006, in three localities of the State of Mexico, Mexico: El Cerrillo experimental field (19º 14´ N and 99º 42´ W; 2,640 masl) of the Faculty of Agricultural Sciences of Universidad Autónoma del Estado de México; Montecillo Experimental field (19º 29´ N and 98º 54´ W; 2,240 masl) of Colegio de Postgraduados and Centro Universitario Tenancingo (19º 00´ N and 99º 33´W; 2,060 masl) of Universidad Autónoma del Estado de Mexico. The dominant climate in El Cerrillo is subhumid, with rains in summer; the annual precipitation is 800 mm and the mean temperature is 12.7 ºC. In Montecillo, the climate corresponds to the least dry of arid climates with rains in summer, the mean temperature is 15 ºC, and the annual precipitation is 637 mm. The climate in Tenancingo is humid with rains in summer; the mean temperature is 18 ºC and the annual precipitation is 1,199 mm (Morales *et al.*, 2008; Garduño *et al.*, 2009).

The soil in El Cerrillo is vertisol, clay-loam texture, medium nitrogen content and 6.5 pH. In Montecillo, the soil is volcanic, with clay texture and 7.8 pH; the dominant soils are entisol and vertisol. Tenancingo is characterized by andosols soils of volcanic origin with sandy-loam texture and acid pH (6.3) (Morales *et al.*, 2008; Garduño *et al.*, 2009).

Six treatments were evaluated in each site, from the factorial arrangement of two bean cultivars, for grain with snap bean potential and indeterminate growth ('Criollo' and 'Acerado') and three sowing systems: in monoculture (pure crop), associated to 'Sunbright' sunflower (used as ornamental plant) and associated to 'Victoria' sunflower (for seed production). Both bean cultivars (improved) were provided by Instituto de Investigación y Capacitación Agropecuaria, Acuícola y Forestal of the State of Mexico (ICAMEX), the 'Sunbright' sunflower was purchased and the 'Victoria' sunflower was provided by the Departament of Ecophysiology of cultures of the Botanical Program of the Post Graduate School. The sowing, established under dryland conditions, was carried out on May 22 and 30, and June 2, 2006 (El Cerrillo, Montecillo and Tenancingo, respectively).

Experiments management

The experimental plots consisted on 4 furrows (at 0,80×5,0 m), but the useful experimental unit consisted on 2 central furrows in each plot; the distance between plants was 0,30 m in snap bean monocultures and 0,15 m in the associations (alternating one snap bean plant and another sunflower plant) (Garduño *et al*., 2009; Morales *et al*., 2008). For the pure crops plantation, trellises (tuteurs) were placed into the snap bean plants, using two wooden poles in each furrow of the experimental plot (distant at 5.0 m), joined with wire and raffia ribbons (lasso) and to the superior wire to tie the plants. The fertilization consisted on 80-90-00 of NPK; 40 nitrogen units and all the phosphorus were provided in the sowing and the rest of nitrogen was applied in the first weeding.

Data collection and measurements

During the research development days to emergence (E), flowering beginning (R6) and pods formation (R7) were recorded in snap bean, following the criteria by Rosales *et al*. (2001). The maximum temperatures (Tmáx) and minimum (Tmín) were recorded in the meteorological stations of the Faculty of Agricultural Sciences (El Cerrillo), of the Post Graduate School (Montecillo) and of the University Center Tenancingo. The thermal time (TT) was estimated with the Snyder residual method (1985):

$$TT=(T_{max}-T_{min}) / 2 - BT$$

The base temperature (BT) of snap bean was 8 ºC (Morales *et al*., 2008).

Two destructive samplings of three plants with full competence were made for each treatment and locality, at 30 days after sowing (DAS) and at harvest. The harvest was made when the crop was in phenological phase R7, with four cuts in each locality. The foliar area was measured in each sampling (in cm^2) with a foliar area integrator (Li-cor 3100) and the leaf area index (LAI) was estimated, according to the descriptions by Hopkins and Huner (2004):

$$LAI = (FA * PD) / 10{,}000\ cm^2$$

Where: FA is the foliar area and PD is the population density m^{-2}.

The net assimilation rate (NAR), total biomass (TB), pod yield (PY) and yield components as pods number (PN), pod length (PL) and pod diameter (PD) were estimated at harvest. The NAR was calculated according to Hopkins and Huner (2004):

$$NAR = \left[(DW_2 - DW_1 / FA_2 - FA_1)\ (LnFA_2 - LnFA_1 / t_2 - t_1)\right]$$

Where: DW_2 and DW_1 are the final and initial dry weights; FA_2 and FA_1 are the final and initial foliar area; and $LnFA_2$ and $LnFA_1$ are the natural logarithm of the final and initial foliar area.

Statistical analysis

The analyses of variance (ANOVA) were made for each locality and for each variable with a randomized block design in factorial arrangement. When the F values were significant, the Mean Comparison Test of the Minimal Significant Difference was applied at the 5 % level of significance. Both techniques were described by Martínez (1988). A Principal Component analysis was made to represent the effects of the six treatments simultaneously, the seven variables and the interrelations between treatments and variables. The statistical analysis was made with the program proposed by Sánchez (1995) to run in the System for Statistical analysis (SAS) in the DOS Operating System. This multivariate methodology was also described by González *et al*. (2007).

Results

El Cerrillo

There were no significant differences in variables among cultivars (P = 0.05). In monoculture, the maximum values were observed in net assimilation rate (NAR), total biomass (TB) and pod yield (PY) among sowing systems, overcoming the snap bean + 'Sunbright' association ('SB+ S') by 36.1; 37.5 and 18.2%, respectively, and the snap bean + 'Victoria' association by 31.9; 44.0 and 34.8%. For pods number (PN), the monoculture differed statistically (P = 0.03) from the 'SB + S' association and overcame the 'SB + V' sowing system by 27.7%. In regard to the cultivar × sowing system interaction, significant differences were not observed (P = 0.05) (Table 1).

Montecillo

The cultivars differed significantly (P ≤ 0.001) in NAR, TB, PY and leaf area index (LAI) (P = 0.009). In average, the cv. 'Criollo' showed higher values than cv. 'Acerado' by 17.2% (NAR), 20.7% (TB), 11.2% (PY) and 8.8% (LAI). The monoculture was superior to the 'SB+ S' and 'SB + V' associations in NAR, TB and PY in the sowing systems, and it was equal statistically in LAI (P = 0.04) to the 'SB + S', the simultaneous sowing (Table 2). The cultivar × sowing system interaction (Table 3) shows that the cv. 'Criollo' in monoculture conditions presented the high-

Table 1. Effects of two cultivars and three planting system on yield and yield components of snap bean in the Cerrillo, Mexico.

Cultivar	Leaf area index	Net assimilation rate ($g \cdot m^{-2} d^{-1}$)	Total biomass ($g \cdot m^{-2}$)	Pod diameter (cm)	Pod lenght (cm)	Pod number (m^{-2})	Pod yield ($g \cdot m^{-2}$)
'Criollo'	3.31 a[1]	1.41 a[1]	256.82 a[1]	1.23 a[1]	10.90 a[1]	423.00 a[1]	614.41 a[1]
'Acerado'	3.30 a	1.40 a	241.10 a	1.30 a	11.01 a	423.93 a	553.30 a
LSD	0.15	0.42	37.41	0.10	0.20	33.31	70.04
Planting system							
Monoculture	3.31 a	1.91 a	342.51 a	1.20 a	10.91 a	458.00 a	707.42
'SB + S'[2]	3.42 a	1.22 b	212.60 b	1.30 a	10.90 a	454.00 a	578.32 b
'SB + V'[3]	3.30 a	1.30 b	191.80 b	1.31 a	11.12 a	331.00 b	461.23 c
LSD	0.22	0.54	55.92	0.12	0.24	51.00	104.52
ANOVA							
Cultivar (C)	ns	ns	ns	ns	ns	ns	ns
Planting system (PS)	ns	*	***	ns	ns	***	***
C*PS	ns	ns	ns	ns	ns	ns	ns

[1]The means in the columns with the same letter are not statistically different according to the Least Significant Difference test (LSD) (P = 0.05). * = P ≤ 0.05, ** = P ≤ 0.01, *** = P ≤ 0.001, ns = not significant.
[2]Snap bean with sunflower 'Sunbright'.
[3]Snap bean with sunflower 'Victoria'.

est values in the variables LAI (1.59), NAR (1.81 g·m^{-2}·d^{-1}), TB (351.60 g·m^{-2}), PN (451.50 pods·m^{-2}) and PY (597.31 g·m^{-2}). However, when this cultivar was associated with sunflower 'Sunbright', the values reached in TB (329.71 g·m^{-2}), PN (447.30 pods·m^{-2}) and PY (576.70 g·m^{-2}) were statistically equal to their monoculture.

Tenancingo

The F values corresponding to NAR, pod diameter (PD) and pod length (PL) were significant ($P \leq 0.05$) for cultivars. The cv. 'Acerado' had a higher arithmetic mean (1.12g m^{-2}·d^{-1}) than the cv. 'Criollo' (0.88 g·m^{-2}·d^{-1}), but the 'Criollo' overcame 'Acerado' in PD and PL by 16.2 and 7.8%, respectively.

Table 2. Effects of two cultivars and three planting system on yield and yield components of snap bean in the Montecillo, Mexico.

Cultivar	Leaf area index	Net assimilation rate (g·m^{-2}·d^{-1})	Total biomass (g·m^{-2})	Pod diameter (cm)	Pod lenght (cm)	Pod number (m^{-2})	Pod yield (g·m^{-2})
'Criollo'	1.48 a[1]	1.28 a[1]	298.83 a[1]	1.17 a[1]	10.10 a[1]	442.11 a[1]	547.20 a[1]
'Acerado'	1.35 b	1.06 b	236.87 b	1.13 a	10.11 a	423.93 a	485.81 b
LSD	0.08	0.09	17.83	0.06	0.60	33.30	57.31
Planting system							
Monoculture	1.41 ab	1.36 a	298.95 a	1.12 a	10.20 a	440.00 a	545.06 a
'SB + S'[2]	1.50 a	1.01 b	268.55 b	1.18 a	10.11 a	425.10 a	515.41 b
'SB + V'[3]	1.34 b	1.15 b	236.06 c	1.16 a	10.10 a	433.97 a	489.05 b
LSD	0.12	0.14	13.00	0.09	0.90	50.00	26.50
ANOVA							
Cultivar (C)	**	***	***	ns	ns	ns	***
Planting system (PS)	*	***	***	ns	ns	ns	***
C*PS	**	***	***	ns	ns	*	***

[1]The means in the columns with the same letter are not statistically different according to the Least Significant Difference test (LSD) ($P = 0.05$). * = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$, ns = not significant.
[2]Snap bean with sunflower 'Sunbright'.
[3]Snap bean with sunflower 'Victoria'.

Table 3. Interaction Cultivar * Planting system on yield and yield components of snap bean in Montecillo, Mexico.

Cultivar	Planting system	Leaf area index	Net assimilation rate (g·m^{-2}·d^{-1})	Total biomass (g·m^{-2})	Pod number (m^{-2})	Pod yield (g·m^{-2})
'Criollo'	Monoculture	1.59 a[1]	1.81 a[1]	351.60 a[1]	451.50 a[1]	597.31 a[1]
	+ 'Sunbright'	1.56 ab	1.02 c	329.71 a	447.30 a	576.70 a
	+ 'Victoria'	1.30 cd	1.02 c	215.20 d	427.54 ab	467.60 cd
'Acerado'	Monoculture	1.22 d	0.90 c	246.31 c	428.50 a	492.81 bc
	+ 'Sunbright'	1.44 bc	0.99 c	207.40 d	402.90 b	454.11 d
	+ 'Victoria'	1.38 c	1.28 b	256.91 bc	440.40 a	510.50 b
LSD		0.14	0.16	30.80	25.30	30.00

[1]The means in the columns with the same letter are not statistically different according to the Least Significant Difference test (LSD) ($P = 0.05$).

There were significant differences (P = 0.007) among sowing systems in PD, PN, PY ($P \leq 0.001$) and TB. The pure crop presented the maximum values in TB (336.90 $g \cdot m^{-2}$) and PY (1036.00 $g \cdot m^{-2}$), overcoming the 'SB+ S' association by 14.1 and 16.4% and the 'SB + V' association by 6.86 and 8.94. The cultivar × sowing system interaction presented statistical differences ($P \leq 0.001$) in the variables LAI, TB, PD, PL, PN and PY (Table 4). The pure crop 'Acerado' did not differ statistically in TB, PN and PY of the 'Criollo' + 'Sunbrigth' and 'Acerado' + 'Victoria' associations and only overcame these associations arithmetically by 8.4 and 9.9%, respectively in the pod production (Table 5).

The thermal time accumulated in each of the phenological stages of the crop was similar in the three experimental sites, but the number of days to reach the stages E, R6 and R7 was different, with a smaller number of days in Tenancingo, with 10 days in E, 58 days at R5 and 98 days at R6 (Table 6).

Principal component analysis

This technique explained 69.5 % of the original total variation related to the seven variables evaluated: the principal component 1 (PC1) explained 43.7 % and the principal component 2 (PC2) explained 25.7 % (Figure 1).

The rest of the variables had positive values in PC1 (between 0.52 and 0.79), except by pod diameter (PD). The variables with the highest

Table 4. Effects of two cultivars and three planting system on yield and yield components of snap bean in Tenancingo, Mexico.

Cultivar	Leaf area index	Net assimilation rate ($g \cdot m^{-2} \cdot d^{-1}$)	Total biomass ($g \cdot m^{-2}$)	Pod diameter (cm)	Pod lenght (cm)	Pod number (m^{-2})	Pod yield ($g \cdot m^{-2}$)
'Criollo'	3.51 a[1]	0.88 b[1]	309.47 a[1]	1.60 a[1]	11.18 a[1]	694.23 a[1]	926.05 a[1]
'Acerado'	3.44 a	1.12 a	317.10 a	1.34 b	10.30 b	675.00 a	970.60 a
LSD	0.21	0.16	20.08	0.02	0.34	47.93	57.60
Planting system							
Monoculture	3.51 a	0.95 a	336.90 a	1.12 c	10.67 a	668.04 b	1036.00 a
'SB + S'[2]	3.56 a	1.03 a	289.21 b	1.18 b	11.00 a	643.18 b	865.63 b
'SB + V'[3]	3.36 a	1.03 a	313.75 ab	2.11 a	10.56 a	742.63 a	943.38 b
LSD	0.31	0.24	29.28	0.03	0.50	71.54	85.97
ANOVA							
Cultivar (C)	ns	**	ns	**	**	ns	ns
Planting system (PS)	ns	ns	**	***	ns	***	***
C*PS	***	ns	***	***	***	***	***

[1]The means in the columns with the same letter are not statistically different according to the Least Significant Difference test (LSD) (P = 0.05). * = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$, ns = not significant.
[2]Snap bean with sunflower 'Sunbright'.
[3]Snap bean with sunflower 'Victoria'.

Table 5. Interaction Cultivar * Planting system on yield and yield components of snap bean in Montecillo, Mexico.

Cultivar	Planting system	Leaf area index	Total biomass (g·m-2)	Pod diameter (cm)	Pod lenght (cm)	Pod number (m-2)	Pod yield (g·m-2)
'Criollo'	Monoculture	3.41 b[1]	309.91 b[1]	1.11 d[1]	11.24 a[1]	591.20 c[1]	892.40 b[1]
	+ 'Sunbright'	3.80 a	344.51 ab	1.17 c	11.21 a	810.30 a	1080.30 a
	+ 'Victoria'	3.31 b	274.00 c	2.52 a	11.10 a	681.20 b	805.46 b
'Acerado'	Monoculture	3.60 ab	363.90 a	1.13 d	10.10 b	744.88 ab	1179.60 a
	+ 'Sunbright'	3.31 b	233.91 d	1.18 c	10.79 a	476.06 d	650.96 c
	+ 'Victoria'	3.40 b	353.50 a	1.70 b	10.02 b	804.06 a	1081.30 a
LSD		0.37	34.80	0.03	0.59	83.00	99.70

[1]The means in the columns with the same letter are not statistically different according to the Least Significant Difference test (LSD) (P = 0.05).

Table 6. Phenology and thermal time of two cultivars of snap bean on each locality.

Locality	Sowing date	Emergence	Start of flowering	First cut pod	Fourth cut pod
El Cerrillo	May 22				
Phenology		13 das[1]	85 das	107 das	131 das
Thermal time		91 TU[2]	842 TU	1,059 TU	1,179 TU
Texcoco	May 30				
Phenology		11 das	75 das	96 das	120 das
Thermal time		98 TU	820 TU	1,049 TU	1,157 TU
Tenancingo	June 02				
Phenology		10 das	58 das	82 das	98 das
Termal time		88 TU	793 TU	1,036 TU	1,148 TU

[1]das = Days after sowing.
[2]TU = Thermal units.

positive values in PC2 (between 0.56 and 0.75) were pod yield (PY), leaf area index (LAI) and pod diameter (PD), while total biomass (TB) had the highest negative value (-0.59) (Figure 1).

In regard to the six treatments (combinations between the two bean cultivars and the three sowing systems), it was observed that 'Criollo' in monoculture (1), 'Criollo' + 'Sunbright' (2) and 'Acerado' + 'Victoria' (6) had positive values in PC1; the three remaining treatments had negative values in PC1. For PC2, only 'Criollo' + 'Victoria' (3) and 'Acerado' in monoculture (4) had the highest positive and negative contribution, respectively (Figure 1).

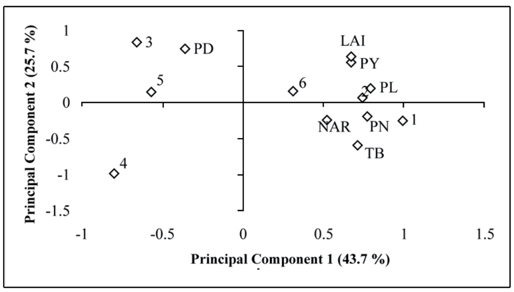

Figure 1. Interrelation between the six treatments (combinations between two cultivars of snap bean and three planting system) and seven variables evaluates. PY = pod yield; PN = pod number; PD = pod diameter; PL = pod length; TB = total biomass; NAR = net assimilation net; LAI = leaf area index.

In the interrelationships observed in the biplot of Figure 1, LAI, PY and PL had a positive and significant correlation with the treatments 2 and 6, while NAR, PN and TB had that correlation with treatment 1. Additionally, PD and treatment 3 were positive and significant.

Discussion

El Cerrillo

As there was a higher net assimilation rate, the photosynthetic efficiency in the monocultures was superior; therefore, the production of dry matter and pod yield in the pure crops was higher (Table 1). In parallel, when two plants grow and develop simultaneously, a relation of competition for the agricultural resources may be determined between the crops composing the association; the sunflower crop in this locality reduced the pod yields of the snap bean cultivation. Unlike the results from this study, Manu (1994) found that in the maize – snap bean association, the leguminous was the dominant cultivation presenting a NAR higher that its monoculture. The aforementioned factor contributed to the production of total biomass and grain yield of bean in this production system to be higher.

Montecillo

On average, the LAI was higher in the cv. 'Criollo' as the cultivation was growing, which confirms that this cultivar had a higher percentage of intercepted radiation and better efficiency in the use of this resource. Therefore, the biomass production and pod yield were higher in comparison to the cv. 'Acerado'. Likewise, the higher NAR indicates that in the snap bean foliage, 'Criollo' was more efficient in the photoassimilate production and, thus, it was associated to a higher speed of net photosynthesis (Garduño *et al*., 2009).

The lower NAR observed in the associated sowing systems resulted in a lower production of dry matter and pod yield (Table 2). The foregoing is explained by the competition exerted by the sunflower on the snap bean cultivars. This fact supports the reports by Santalla *et al.* (1999) who indicated that the yield and the index of bean harvest reduced significantly when they were sowed simultaneously with maize, due mainly to the competition for inputs generated by this species.

The 'Criollo' + 'Sunbright' association had a LAI and a PY similar to 'Criollo' in monoculture (Table 3), which shows that there was a complementation relationship in this specific association on the use of the agricultural resources. Therefore, the complementation occurs when species experiments less competition as they grow along. In terms of resources available, the complementation involves that the capture of the limiting resources is higher and/or their use is more effective in the species mixtures than in the monocultures (Loomis and Connor, 2002).

Tenancingo

The snap bean cultivars of 'Criollo' and 'Acerado' did not have significant differences in the pod yield. Likewise, as a consequence of a higher TB and PN, the monoculture expressed, on average, an increase in PY in relation to the sowing systems in association (Table 4); the foregoing confirms the reports by Garduño *et al*. (2009) who indicated that the snap bean yield is superior as the PN increases.

The cultivar × sowing system interaction shows that the 'Criollo' + 'Sunbright' and 'Acerado' + 'Victoria' associations presented a PY statistically equal to the cv. 'Acerado', the foregoing was due to the higher LAI (3,80) in the 'Criollo' + 'Sunbright' system and to the biomass production (353,50 $g \cdot m^{-2}$) in the 'Acerado' + 'Victoria' system, which was evident in a higher PN (Table 5). Morales and Escalante reported similar results (2004) when they associated 'Michoacán' bean and 'Victoria' sunflower, as the bean associated to sunflower presented a LAI and NAR similar to their monoculture and, therefore, the grain yield in both systems was similar.

The simultaneous snap bean with sunflower sowing did not affect the phenology of the leguminous within each locality (Rosales *et al*., 2001). However, the contrasts on the phenology of this species in the localities are attributed to the different mean temperatures: the mean temperature in El Cerrillo was 12.7 ºC, it was 15 ºC in Texcoco, and 18.2 ºC in Tenancingo; therefore, the snap bean grew earlier in the last site. The foregoing confirms the reports by Andrade *et al*. (1996) who mentioned that the environmental temperature is the main factor regulating the plants development.

In Tenancingo, the dates of the first and last snap bean cut (fourth cut) were August 22 and September 8, at 4 days-intervals; the cutting intervals in Montecillo and El Cerrillo were 6 days, where the first cuts were August 26 and September 8, respectively, and the dates of the fourth snap bean cut were September 19 and October 8, respectively (Table 6). These results are consistent with the reports by Esquivel *et al.* (2006), who recommended that the best sowing date to satisfy the local market in the Valley of Mexico is May 21.

Principal components analysis

The results observed in the biplot indicate that the higher percentage of the original data variation was represented adequately in the first two principal components, because together they explained 68.5 %. Therefore, the approximate variances and correlations inferred in Figure 1 may be interpreted reliably (González *et al*., 2007).

The dispersion of the six treatments in the four biplot quadrants confirms the existence of significant differences between the two snap bean cultivars dispersion, planted in the three crop crop systems, which are attributed mainly to the principal effects and their interaction. This variability was arranged in four categories: treatments 2 ('Criollo' + 'Sunbright') and 6 ('Acerado' + 'Victoria') which contributed to the best phenotypic expression of the leaf area index (LAI), pod yield (PY) and pod length (PL); treatment 1 ('Criollo'), with best average behavior for net assimilation rate (NAR), pods number (PN) and total biomass (TB); treatments 3 ('Criollo' + 'Victoria') and 5 ('Acerado' + 'Sunbright'), the first treatment with the highest pod diameter (PD); treatment 4 ('Acerado'), with the poorest behavior in LAI, RY and PL.

These results indicate that the best treatments were identified as 1, 2 and 6, with the highest pod yields (7.66; 7.70 and 7.56 t ha^{-1}, respectively). The superiority of treatments 1 and 2 is also attributed to their outstanding result in LAI (2.76 and 2.93), TB (306.1 and 295.6 $g \cdot m^{-2}$) and PN (413 and 461 pods). It may be also inferred that the 'Criollo' bean cultivar was genetically superior than cultivar 'Acerado', as it shows a higher response in monoculture and associated to both sunflower cultivars, except by treatment 6 ('Acerado' + 'Victoria') which produced 6.7 $t \cdot ha^{-1}$, 1.20 $g \cdot m^{-2} \cdot d^{-1}$ and 421 $pods \cdot m^{-2}$ (Figure 1).

In both monoculture and association, it is advisable to favor the best phenotypic expression of LAI, PL, PN, PD, NAR and TB in order to increase the pod yield (PY) in the six treatments, but treatments 1, 2 and 6, with the highest pod production, outstood mainly in LAI, TB and PN. Therefore, they could be the main yield components explaining the levels of interspecific competition and complementarity present between snap bean and sunflower.

This research showed that the associations between both species are agronomically viable, because the pod yields in monoculture and associated were similar within each bean cultivar, but the advantage of a better field use as both crops are planted simultaneously.

Resumen

E.J. Morales-Rosales, O. Franco-Mora y A. González-Huerta. 2011. Producción de frijol ejotero, utilizando espalderas vivas de girasol, en los valles altos del centro de México. Cien. Inv. Agr. 38(1): 53-63. El objetivo del presente estudio fue evaluar el crecimiento, la tasa de asimilación neta, la producción de biomasa y el rendimiento de vaina de dos cultivares de frijol ejotero en monocultivo y combinados con dos cultivares de girasol en tres localidades del Estado de México, México. Los seis tratamientos se evaluaron en un diseño en bloques completos al azar en arreglo factorial, con cuatro repeticiones. Cuando los valores de F fueron significativos se aplicó la prueba de la diferencia mínima significativa (DMS) al nivel de significancia del 5%. También se utilizó el análisis de componentes principales para estudiar la interrelación entre los seis tratamientos y las siete variables. Los resultados que se observaron en el biplot indican que el mayor porcentaje de la variación original de los datos se representó adecuadamente en los dos primeros componentes principales, debido a que ambos explicaron el 68,5%. Esta variabilidad se agrupó en cuatro categorías: 'Criollo' + 'Sunbright' y 'Acerado' + 'Victoria' que contribuyeron a la mejor expresión fenotípica del índice de área foliar, rendimiento de vaina y longitud de vaina; 'Criollo', con mejor comportamiento promedio para tasa de asimilación neta, número de vainas y biomasa total; 'Criollo' + 'Victoria' y 'Acerado' + 'Sunbright', el primero con el mayor diámetro de vaina; 'Acerado', con el comportamiento más pobre en índice de área foliar, rendimiento de vaina y longitud de vaina. Los tratamientos 'Criollo' y 'Criollo' + 'Sunbright' presentaron los más altos rendimientos de vaina (7,66 y 7,70 t ha^{-1}, respectivamente), lo cual se atribuye a que ambos presentaron los valores más altos de índice de área foliar, biomasa total y número de vainas.

Palabras clave: *Phaseolus vulgaris*, *Helianthus annuus*, cultivos múltiples, tasa de asimilación neta, análisis de componentes principales.

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