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ANALYSIS OF AGRONOMIC VARIABLES OF *Ocimum basilicum* L. UNDER ALTERNATIVE TILLAGE SYSTEMS AND STANDARD ORGANIC PRACTICES

[ANÁLISIS DE VARIABLES AGRONÓMICAS DE *Ocimum basilicum* L. BAJO SISTEMAS ALTERNATIVOS DE LABRANZA Y ESTÁNDARES ORGÁNICOS DE PRODUCCIÓN]

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SUMMARY

Little is known about the patterns of growth and development of basil (*Ocimum basilicum*) in arid environments. Even less is known when growing this crop under organic standards and conservational alternative tillage systems. An experiment on a certified-organic-field with three different systems of tillage was conducted on the Mexican state of Baja California Sur (BCS), with prevailing arid condition. Growth traits and yield of seeds of one most-used-cultivar (Nuffar) of basil in BCS were analyzed by employing principal components analyses (PCA). PCA showed a significant positive interaction of yield of seeds and foliar dry weight. PCA also showed a negative interaction of foliar area (FA) and number of knots. By using Pearson correlations the same interactions were identified plus positive correlations of plant height (PH) with number of knots, PH with FA, and PH with number of inflorescences.

Keywords*:* basil, organic agriculture, organic standards, green manure.

RESUMEN

Existe muy poca información acerca de los patrones de crecimiento y desarrollo de albahaca (*Ocimum basilicum*) en ambientes áridos. Menos información se tiene en relación al crecimiento de este cultivar cuando se produce bajo estándares de producción orgánica y sistemas alternativos de labranza conservacionista. En Baja California Sur - México (BCS), donde prevalece el clima árido, se desarrolló un experimento dentro de una parcela experimental con certificado orgánico usando tres diferentes sistemas de labranza. En el experimento se utilizó la variedad Nuffar de albahaca, de alta preferencia en BCS. Las variables de crecimiento y producción de semilla registradas se analizaron a través del Análisis de Componentes Principales (ACP). El ACP mostró una interacción positiva significativa del rendimiento de semilla y el peso seco foliar. Asimismo el ACP mostró una interacción negativa del área foliar y el número de nudos. A través de los coeficientes de correlación de Pearson se evidenciaron las mismas interacciones más las siguientes correlaciones positivas: altura con número de nudos, altura con área foliar y altura con número de inflorescencias.

Palabras clave: albacar, agricultura orgánica, normas orgánicas, abono verde.

INTRODUCTION

Basil (*Ocimum basilicum* L.) and other species of the same genus are widely used as herb and medicine (Murbach-Freire et al., 2005; Adigüzel et al., 2005). The demand for organically-produced basil is currently increasing because its therapeutic properties are mostly associated to organic production (Toyes-Aviles, 2003). This species is recognized for containing a number of unique phytochemicals in its leaves that favour human health (Juliani and Simon, 2002; Rice-Evans et al., 1997). Organic basil is the most important crop in the Mexican's state of Baja California Sur (BCS). This state exports the whole production to the United States of America and some European countries, where prevails the culture of consuming healthy food as part of the care system (Mukherjee and Wahile, 2006). Basil is used fresh, dried, and processed, for flavouring and fragrance, and in traditional medicines (Sharma et al., 1987). Apparently, this species is native to India (Hooker, 1885), naturalized in Africa, and widely adapted to Mediterranean countries (Garibaldi et al., 1997; Adigüzel et al., 2005). Organic basil has been grown well since about 15 years ago in BCS; however, intermittently, local growers have observed fails in productivity. Decrements are often attributed to aspects as the adverse characteristics of soil and clime in this region; which is one of the driest around the world (García-Hernández et al., 2005), and to maladjustment and lack of knowledge of cultivars.

The basil genotypes (seeds) that are grown in BCS come from Mediterranean countries, and local growers know the therapeutic properties of basil (Juliani and Simon, 2002; Rice-Evans et al., 1997; Adigüzel et al., 2005), but they have just general information about the technical specifications of such genotypes. Little is known about the patterns of growth and development of this crop in arid environments. Regarding that BCS´s basil-growers determine the international price of organic basil (SAGARPA, 2004), it results extremely important to study how the agronomic characteristics of basil are affected by organic and conservational practices in this arid region.

Analysis of both plant structure and attributes can be performed by means of the characterization, which allows knowing how one or more factors affect the response of a crop species. The characterization allows analyzing qualitative features using statistical approaches, as the standard deviation, variation coefficient, and mean; and quantitative features by means of ranges and multivariate analysis (Pla, 1986; Ovalles and Collins, 1988). The objectives of this experiment were: (a) to characterize the agronomic performance of one most-used-cultivar of basil in BCS, (b) to establish correlations among quantitative studied characters and (c) to define the variables with most influence on basil yield, seed production, and growth in arid environment, and under certified organic regime.

MATERIAL AND METHODS

The experiment was conducted on the experimental field of the Universidad Autonoma de Baja California Sur, nearly La Paz City, situated between 24° 10' N and 110° 19' W, at 18.5 m above sea level. Local climate is classified as Bw (h') hw (e) that is to say, dry desert, warm (García, 1981). Yearly mean temperature is between 22 and 23 ºC, and the annual mean precipitation oscillates between 100 and 250 mm, while the yearly mean evaporation varies from 1758 to 2472 mm (INEGI, 1997).

The seed (cultivar Nuffar) was provided by the rural organization "Organicos del Cabo", which annually grows around one-thousand hectare of basil with organic seed from Israel and other Mediterranean countries. Basil was cultivated from November 2002 to March 2003. Experimental plot size was 2500 m^2. Row distance was 80 cm and plant distance was 30 cm, such that population density was 3981 plants ha^{-1}. Plants were watered by drip irrigation at a rate of 5 mm day^{-1}. The characteristics of the irrigation water are presented in Table 1.

Cultural practices were performed according to the normative standards of the official organic program of the United States Department of Agriculture (NOP, 2002); in concordance, no chemicals for fertilization or pests' management were applied. Certification as organic field was granted by the Certification Agency Oregon Tilth (470 Lancaster Drive NE Salem, OR). Green manure was incorporated into the soil. The source of green manure was the dolichos bean (*Lablab purpureos*); which is widely cultivated in Central America as green manure in conservational agroecosystems (Beltrán-Morales et al., 2006). This green manure was produced two months before than sowing basil into the same experimental plot. Table 2 shows the amount of several nutriments that were supplied by the green manure

Table 1. Characteristics of the irrigation water used in this experiment.

Characteristic	Value
CE (dS m^{-1})	2.80
pH	7.92
CO_3 (ppm)	10.56
HCO_3 (ppm)	316.63
Cl_2 (ppm)	970.19
Ca (ppm)	193.14
Mg (ppm)	46.57
SO_4 (ppm)	48.44
K (ppm)	11.04
Na (ppm)	569.28

A randomized block design was used with three replications. The treatments were three levels of tillage: L1, conventional tillage with three tillage passes, one pass with a plough (tillage depth > 20 cm) and two passes with a field cultivator (tillage depth of between 7.5 and 10 cm); L2, reduced tillage with two passes with a field cultivator (tillage depth of between 7.5 and 10 cm); and L3, minimum tillage with a single pass with a field cultivator to incorporate the green manure (ASAE, 2002). Each plot had been cultivated with the same treatments by two years.

Table 2. Nutriment supplying by dolichos bean as green manure with yield of 55.44 ton ha^{-1}.

Nutriment	Supply (kg ha^{-1})
Ca	211.39
Mg	75.14
K	233.80
Na	123.58
Fe	16.80
Mn	2.34
Zn	0.39
Cu	0.39
P	36.22
Cl	208.46
NO_3-N	2.12
N	364.03
B	2.62

The soil was a loamy coarse sand (Bouyocus procedure, particle counter) containing 0.4 % organic matter (Walkley-Black procedure, muffle furnace with correction for $CaCO_3$) (ASA-SSSA, 1982). Before sowing, 10 soil samples from the 0-30 cm layer were analysed total N using the Kjendahl approach (Bremner and Mulvaney, 1982), and P content by the Olsen technique (Olsen and Sommers, 1982). These analyses showed the next values (mean ± standard deviation): 3.55 ± 0.59 mg Total N kg^{-1}, and 38.41 ± 23.25 mg P kg^{-1}.

The measured agronomic variables were: yield of seeds (YS), plant height (PH), foliar area (FA), number of inflorescences (NI), foliar dry weight (DW), number of knots (NK), and seed germination (%G). The obtained results were subjected to statistical descriptive analysis and multivariate analysis using the programs Statistica v. 6.0 and MultiVariate Statistical Package 3.13.

RESULTS AND DISCUSSION

It is important to mention the yield of dolichos bean that was produced for incorporation as green manure two months before the basil seedling. The fresh foliage of dolichos was of 55.44 ton ha^{-1}. Regarding this yield, the Table 2 shows the amount of each nutriment that was supplied by the green manure. Green manure is preferred over the use of animal manure in organic standards (NOP, 2002), and also in conventional systems because this kind of material can supply a higher amount of nitrogen in comparison with animal manure, which shows considerable N losses through ammonia volatilization (Gichangi et al., 2006).

The significant factor loadings from the principal component analysis (PCA) of basil agronomic variables were obtained as suggested by Ovalles and Collins (1988) and Gutiérrez-Acosta et al. (2002) after varimax rotation. The first three PCs explained 75 % of total variance (Table 3). The first PC (PC1) is characterized by the variable plant height (PH) alone. This result is relevant regarding that the Pearson correlations showed several significant correlations among PH and three other variables (Table 4).

The second PC (PC2) is characterized by the positive correlation of yield of seeds (YS) with foliar dry weight (DW). The third PC (PC3) was characterized by the negative correlation of foliar area (FA) with number of knots (NK). Thus, these results suggest a positive interaction between YS and DW, and a negative interaction between FA and NK.

The highest production of foliar mass (DW); which given the commercial presentation of basil is the most important economic variable, was observed at the treatment of minimum tillage. This effect is clearly represented in the Figure 1. The positive correlation found for DW and YS (Tables 3 and 4) coincides with the results of Morales-Rosales et al. (2007), which found a significant positive relationship among both variables (yield of seeds and biomass) in *Phaseolus vulgaris* (bean) and *Helianthus annuus* (sunflower). These authors also found a positive response of both variables to the availability of nitrogen and phosphorus. The response found here for basil could be supported by the green manure addition, which supplied up to 364.03 and 36.22 kg ha^{-1} of nitrogen and phosphorus, respectively (Table 1). Nevertheless, in the Figure 1 is observed that the highest production of seeds was significantly correlated with the conventional tillage.

In this context, the differences on yield of seeds, which are not explained by environmental adverse factors, as diseases, pests or poor fertility, can be studied on terms of three components (Evans, 1972). First of all, the capacity of assimilation by the own plant (size, duration and efficiency of photosynthetic apparatus) which can be modified by feeding back mechanisms that regulate the photosynthesis according to source-demand relationships. Secondly, the storing capacity of inflorescence, determined by the number and weight of grain or kernel and also by its ability to compete with other organs for photo-assimilates and growing regulators (Michael and Séller-Kelbitsch, 1972; Wallace and Yan, 1998). Thirdly, the capacity of the transporting system to mobilize photo-assimilates from the source point to the demand point.

The NK is one of the vegetative variables correlated with PH (Table 4), and as the commercial presentation of basil is designed by size of stems and number of knots, the number of knots is also important in basil, and physiologically could have an important role in the commercial yield (DW). The number of knots showed a similar trend to the longitudinal enlargement of branches.

Table 3. Loadings of the first two principal components (PC's) for the agronomic variables of *Ocimum basilicum* L. under arid environment and standard organic practices.

Variable	PC1	PC2	PC3
Yield of seeds	0.179896	**-0.622957**	-0.389592
Leaf area	0.365857	0.188369	**-0.515125**
Plant height	**0.563223**	-0.023665	0.041519
Number of knots	0.393647	-0.019143	**0.638327**
Number of inflorescences	0.455947	-0.309639	0.218347
Dry weight	-0.196931	**-0.655086**	-0.022525
% Germination	-0.339027	-0.224725	0.354255
Explained Variance	2.597615	1.668352	1.042421
Proportion of Total	0.371087	0.238336	0.148917

Values in boldface are the dominant in the eigenvector loadings by setting the level of significance at approximately 0.7.

Table 4. Correlation matrix of Pearson coefficients between physiological variables of *Ocimum basilicum* L. under arid environment and standard organic practices.

Value	Leaf area	Plant height	Number of knots	Number of inflorescences	Dry weight	% Germination	Yield of seeds
Leaf area	1.000						
Plant height	**0.519**	1.000					
Number of knots	0.061	**0.541**	1.000				
Number of inflorescences	0.212	**0.623**	0.465	1.000			
Dry weight	-0.274	-0.269	-0.094	0.006	1.000		
% Germination	-0.306	-0.331	-0.225	-0.134	0.350	1.000	
Yield of seeds	0.069	0.259	-0.032	0.400	**0.503**	-0.133	1.000

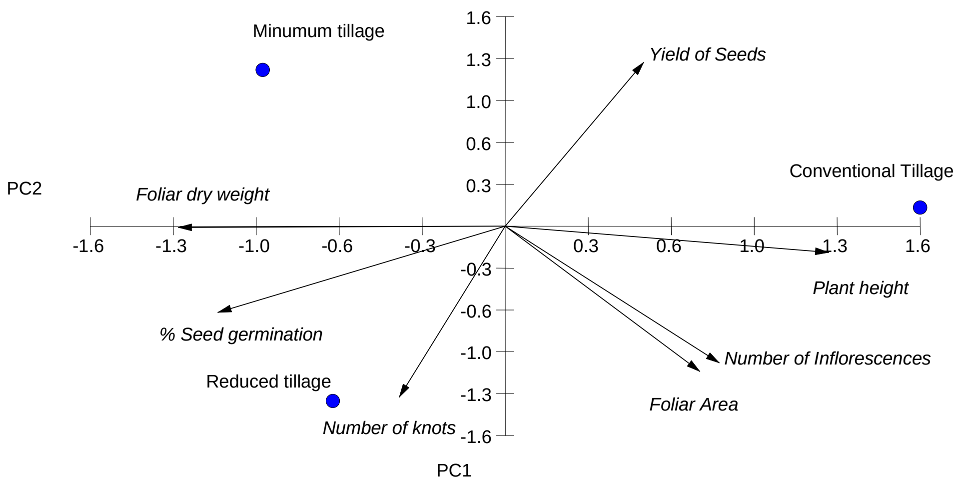

Figure 1. Principal components analysis for agronomic variables and three different tillage systems.

The significant relationship among the other vegetative variables NI and FA with PH is also observable in the Table 4 and showed in the figure 1. The response of vegetative variables was significantly correlated with the different tillage systems; however, the highest commercial production (DW) was registered for minimum tillage. A clearest difference among the tillage systems was expected taken into account that it has been reported a decrement on the number of knots in *Annona muricata* according to agroclimatic conditions, specifically a limitation on water availability. A negative effect on the number of knots could be critical because the number of potential sprouting points can change the internal competition for certain phytochemical compounds and this can limit the sprouting capacity (Wallace and Yan, 1998).

The most recurrent interactions took into account the PH (Tables 3 and 4). These results indicate that plant height is probably the most important agronomic variable of basil when it is grown on this arid environment under organic standards. The positive correlations between PH and NK, FA, and NI possibly indicates that higher foliar surface facilitate the capitation and fixation of light energy, making possible an increment on the translation of photoasimilates through the vegetative system.

The direct correlation of PH with NI and FA suggests the importance of these last two variables on the productivity of basil under the arid conditions as in the present work. In this context, Bugarin et al. (2002) mentioned that foliar area is useful to determine dry matter accumulation, yield, and quality of harvest; thus, this variable is fundamental on studies of plant development and plant nutrition (Schwartz et al. 1997). Respect to the reduction on the assimilative processes by a not correct formation of foliar surface, Gomes et al. (2000) mentioned that a water deficiency causes a reduction of such surface, which can be or not be amended in function of the development status, this could partially explain the differences in FA on the tillage systems because the soil on the treatments with reduced and minimum tillage showed a higher moisture content than the soil with conventional tillage due to less soil disturb. Our results are congruent with the report from Beltran-Morales et al. (2006), which made an experiment in similar arid conditions and pointed out increments on organic matter content and moisture capacity of soil by reducing mechanical tillage and after green manure incorporation.

The negative relationship between FA and NK could be explained considering that in the arid zones, the plant development depends significantly on the availability of water in the soil before the seedling. Water consuming before the flowering stage can limit this resource at the reproductive stage causing water deficit (Bolton, 1981). Water availability has influence on the foliar senescence, the declination of foliar area (Wolfe et al. 1988), the reduction of radiation interception, and yield (Connor et al., 1985). Given that the size and duration of the photosynthetic apparatus are related to yield, it is expected that the strategies to induce an increment of them, could have higher yield as a consequence.

In other hand, with the green manure, a certain amount of N is incorporated to the soil, and this nutrient causes foliar-area, and foliar-area-index (FAI) increment on most of crops (McCullough et al., 1994). As a reference, on cereals the increment on the number of leaves by N is a consequence of a higher number of stems, and also due to a higher foliar expansion (Blanchet et al., 1986; Muchow, 1988) fundamentally caused by a higher number and size of cells.

The duration of foliar area (DFA) is also higher in plants with N supplying. Thus, it can be expected that a crop with N can take more radiation, because this depends on the FAI and DFA (Muchow, 1988), and this could express a higher production of biomass. In addition, the variation on DFA, mainly during the reproductive stage is related to the variation on the seed yield in wheat and corn (Wolfe et al., 1988), because the seeds under development demand the highest amount of photo-assimilates which production depends mainly on the activity and duration of foliar-area in this stage. It has been demonstrated that N supplying delays the decrements of chlorophyll (Debata and Murty, 1983) and then is observed a longer photosynthetic activity. By this way, the nitrogen fertilization (364.03 kg ha^{-1}, Table 1) on the green manure incorporation can achieve a delay on the senescence of basil and a longest DFA as a consequence. An increment on foliar area can be expected when there is a significant availability of N, as observed on the treatments with green manure incorporation.

CONCLUSIONS

Dry weight (foliar mass) represents the economical yield of basil, this variable showed a significant positive relationship with yield of seeds. This interaction must be considered as a selection criteria on breeding programs of basil. This correlation has been observed in other studies and repeatedly (as in the present work) is explained by the availability of N and P, in this case supplied by the green manure. Dolichos bean demonstrated to be a good source of several nutrients in this arid conditions, especially for nitrogen (364.03 kg ha^{-1}), calcium (211.39 kg ha^{-1}), and potassium (233.80 kg ha^{-1}). This result is especially important regarding that under organic practices, the use of conventional fertilizers is prohibited, and the use of green manure is preferable over the use of animal manure. Yield of seeds showed the highest response to the conventional tillage, while the germination did not show any significant correlation with other variables of tillage treatments. The most recurrent significant interactions took into account the variable plant height; hence, plant height could be the most important agronomic variable of basil when it is grown on arid environments under organic standards. Plant height showed significant interactions with number of knots, number of inflorescences and foliar area, accordingly, the specific role of each variable as well as their interactions should be used in future studies regarding the characterization of basil.

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