Article

Theorgano-mineral fertilization on the yield of faba bean in soil and hydroponics in protected agriculture

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Abstract

The faba bean is a crop of great social and economic importance in the High Valleys of the Central Table of Mexico, having as a final destination the human and animal consumption. Despite its importance, grain yields are low, with inadequate fertilization being one of the reasons. The present investigation was carried out with the purpose of determining the effect of organo-mineral fertilization on the yield of faba bean, soil and substrate tezontle. The research was conducted from December 2013-April 2014, in the municipality of San Pedro Cholula, Puebla, under greenhouse conditions, using Cochinera Cultivation seed. Two factors were studied: foliar liquid biofertilization and Steiner nutrient solution concentration at 50% and 100%. The biofertilizers studied were from Taiwanese continuous flow digesters located in the municipalities of San Felipe Teotlalcingo and Huejotzingo, Puebla. The experimental design of the works was completely random and factorial treatment arrangement, with five repetitions. The results showed that, for the cultivation in soil, the treatments did not present differences in the yield of fresh fruit, but there were significant differences in yield of dry fruit where the application of liquid biofertilizer from San Felipe Teotlalcingo had the best results. While the application of a complete organo-mineral fertilization in tezontle substrate resulted in the best response in yield of fresh and dry fruit.

Keywords: *Vicia faba* L., digested liquid fertilizers, hydroponics.

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Introduction

The faba bean (*Vicia faba* L.) is a crop of great social and economic importance in the High Valleys of Mexico (Guadarrama *et al*., 2007), occupying the third place in production within the grain legumes (Díaz and Escalante, 2009). The faba bean is a source of protein, its contents range between 24-37% dry grain, depending on the variety, so it has valuable applications in human and animal food (Crepon *et al*., 2010).

Despite its importance, faba bean grain yields are low, being a rainfed crop that has limited yield (Pichardo *et al*., 2013). The main factors that cause the reduction of yields are: pests and diseases, drought and inadequate fertilization (Stoddard *et al*., 2010). In the state of Puebla, during the years 2011-2013 dry faba bean yields of 0.36, 0.98 and 1.03 t ha^{-1} respectively were registered under rainfed conditions (SAGARPA, 2014). So, there is a strong need to improve performance through new fertilization alternatives.

Biofertizantes, are natural organic materials products of biological recycling or prepared by man, that applied to the soil allow to increase the fertility or productive capacity replacing partially or totally the chemical fertilization (Armenta *et al*., 2010). In this sense, Garfí *et al*. (2011); Zirkler *et al*. (2014) mention that digestates from continuous flow digesters have potential to be used as biofertilizers, however, their study as such is scarce and their physicochemical characteristics depend on other factors such as the type of raw material to be fermented, conditions of the digestion process, the origin and type of manure. In addition to this, biofertilizers are a complement to crop nutrition (Svensson *et al*., 2004). If you also consider the fact that in the field, there is a marked tendency to reduce the use of agrochemicals due to its high costs and environmental damage.

On the other hand, hydroponics in greenhouses have shown to have outstanding effects in the production of crops such as vegetables (Sánchez *et al*., 2009). In this way, the combined application of mineral fertilizers supplemented with digested fertilizers is an effective measure to increase the efficiency of these and increase crop yield (Gissén *et al*., 2014).

The objective of this work was to evaluate the effect of an organo-mineral fertilization on the yield of the faba bean crop produced under greenhouse conditions in soil and hydroponics.

Materials and methods

The present study was conducted in the greenhouse used by the Protected Agriculture research group of the Puebla Campus of the Postgraduate School and located in the community of San Agustín Calvario (19° 03’ 00’’ north latitude, 98° 20’ 04’’ west longitude, altitude 2 164 m), municipality of San Pedro Cholula, Puebla. The tunnel-type rustic greenhouse has a metal structure and plastic cover made of transparent polyethylene of 175 μm or 700 gauge thickness, with 30% shade.

Cultivation in soil

The agricultural land was obtained from a land belonging to the producer and ejidatario Heron Quiroz Sanchez from the municipality of San Felipe Teotlalcingo, Puebla. The soil was collected at a depth of 0-30 cm. The dry soil was taken to greenhouse, hovered and filled with 10 kg pots.

The physical-chemical analysis of soil (Table 1), presented a sandy-loam texture with percentages of sand, silt and clay of: 61.2, 28.0 and 10.8 respectively, an acidic pH, a high content of organic matter (MO). The electrical conductivity (CE) had a zero salinity effect.

Table 1. Chemical analysis of the soil used in faba bean cultivation.

pH	CE (ds m^{-1})	MO (%)	N (%)	N-NH_4^+	N-NO_3^-	P	K	Na	Fe	Cu	Zn	Mn	Ca	Mg
				ppm									(meq 100 g^{-1})	
5.19	0.73	3.77	0.07	20	38	0.04	0.04	0.1	47	1	1	10	4	2

Cultivation in tezontle substrate

As a substrate, red tezontle with a granulometry of approximately 0.5-2 mm was used, for its use it was disinfected in a dilution of water and sodium hypochlorite for 24 h and then washed with well water and filled with 10 kg pots.

Conduction of experiments

In both jobs, the planting was carried out on December 12, 2013, depositing three faba bean seeds from the cochinera cultivar. Prior to planting, there was a saturated irrigation, in the management of the crop the practices carried out were: 1) thinning, when the plants were approximately 10 cm high, leaving two plants per pot; 2) weeding; 3) irrigation, from sowing and during two weeks the irrigation was with well water, later it began with the application of the treatments, the quantity and frequency of the applied irrigations was increased during the crop cycle; and 4) tillering of tillers. The handling of the temperature was done manually leaving the curtains of the greenhouse open during the day. Data were recorded on the temperature and humidity inside the greenhouse during the investigation period (Table 2).

Table 2. Average temperature and humidity recorded in the November 2013-April 2014 period.

Month	Temperature (°C)			Humidity (%)		
	Maximum	Minimum	Average	Maximum	Minimum	Average
November	33.6	10	21.8	80	24.8	52.4
December	34.9	8.3	21.6	78	21	49.5
January	34.9	12.9	23.9	70.5	21	45.8
February	40.2	6.6	23.4	65	20	42.5
March	40.8	8.8	24.8	67	20	43.5
April	41.9	12.7	27.3	66	21.4	43.7

Treatments on soil and hydroponics

Two factors were evaluated: nutrient solution concentration (factor A) and foliar liquid fertilization (factor B).

For factor A, the common levels studied in soil and hydroponics were: 1) 100% nutrient solution (SN100%) and 2) 50% nutritive solution (SN50%). A third level was studied in soil, which was 3) water as a control.

For factor B for both soil and hydroponics, three levels were tested: 1) liquid biofertilizer from San Felipe Teotlalcingo (BSF); 2) Huejotzingo liquid biofertilizer (BHu); and 3) a witness (T). The combination of factors and levels gave a total of nine treatments in soil and six treatments in hydroponics. The distribution of greenhouse treatments for both works was done under a completely randomized experimental design with five repetitions.

Biofertilizers

The biofertilizers originated from bovine manure submitted to Taiwanese continuous flow digesters (Lansing *et al*., 2008). The digesters were located in the municipalities of San Felipe Teotlalcingo and Huejotzingo, Puebla, the identification of biofertilizers was made according to the name of the municipalities. In the municipality of San Felipe Teotlalcingo, cattle feed was an abundant consumption of corn silo, grains and seasonal fruits of the region, as well as controlled grazing. In Huejotzingo cattle feed was composed of corn silo, green alfalfa and concentrate (food, bran, broken corn).

To obtain the biofertilizer, the digestate was sieved with a mesh screen to separate solid fraction and work with the liquid fraction as a biofertilizer. The liquid biofertilizers were applied five times during the whole cycle of the culture at a concentration of 20% in an interval of 15 days in both culture media. Chemical analyzes were performed on biofertilizers to determine the content of nitrogen, phosphorus, potassium, calcium, magnesium, sodium as well as micronutrients such as copper, iron and zinc.

Nutritious solution

The formulations of the nutritive solutions were made from Steiner's universal solution (Steiner, 1984), in its preparation the physical and chemical characteristics of the water were taken into account (Table 3) and soluble chemical fertilizers were used: potassium nitrate (KNO_3), calcium nitrate (Ca (NO_3)), monopotassium phosphate (KH_2PO_4), potassium sulfate (K_2SO_4); microelements (Ultrasol™) and phosphoric acid.

Table 3. Analysis of the physical and chemical characteristics of the water used in faba bean irrigation.

Parameter	Value (meq L^{-1})	Parameter	Value (mep L^{-1})	Parameter	Value (meq L^{-1})
pH	7.85[1]	Ca^{2+}	1.3	Cu^{2+}	0
CE	0.79[2]	Mg^{2+}	4.43	B^-	0
NO_3^-	0.08	SO_4^{2-}	3	Chlorides	1.8
NH_4^+	0.28	Fe^{2+}	0	Carbonates	0.2
$H_2PO_4^-$	0.41	Mn^{2+}	0.004	Bicarbonates	2.2
K^+	0.077	Zn^{2+}	0	Na^+	0

Source: Aparicio (2013) [1]= dimensionless units; [2]= units in dS m^{-1}.

Variables evaluated

The variables studied were: yields of fresh fruit, yield of dry fruit and dry weight of leaf, stem and root. The harvest was made 120 days after sowing.

The drying of leaf, stem, root and fruit was done in Thermo scientific stove at a temperature of 60 °C for 48 h. The yield of dried fruit was made with 10% humidity as suggested by (Pichardo *et al*., 2013).

Statistic analysis

Obtained the data of the cultivation of ground and hydroponics faba bean were analyzed statistically by means of an analysis of variance and comparison of means with Tukey test ($\alpha \leq 0.05$), using the statistical program SAS version 9.0 (SAS, 2004).

The nutrient content data in biofertilizers were also subjected to an analysis of variance and comparison of means with Tukey test ($\alpha \leq 0.05$).

Results and discussion

The analysis of variance for the nutrient content shows that there was a highly significant statistical difference for the potassium and sodium content, for the case iron only showed significant differences, the rest of the nutrients did not show statistical significance (Table 4).

Table 4. Mean squares and statistical significance of the nutrient content in digested biofertilizers.

FV	GL	N	P	K	Ca	Mg	Na	Fe	Cu	Zn
Tr	1	17107 ns	3745407 ns	336629^{**}	15067.5 ns	1940.4 ns	36983.1^{**}	940.9^{*}	0.035 ns	0.08 ns
E	2	2383.4	209819.2	729	7706.3	368.3	18.2	17.7	0.004	0.03
CV	-	7	21	3	16	9	3	8	16	8

FV= variation factor; gl= degrees of freedom; Tr= treatments; *, **= statistical significance at 0.05 and 0.01 probability, respectively; ns= not significant; E= error; CV= coefficient of variation in (%).

In the mean comparison test the biofertilizers showed differences. The highest concentration of nutrients was presented in the biofertilizer of the municipality of Huejotzingo. In both cases the content of nitrogen (N), phosphorus (P) and potassium (K) showed high values with respect to the other nutrients (Table 5), a condition that according to Rowell *et al*. (2001) offers a value as a fertilizer due to the concentrated amount and its given form. According to Romero *et al*. (2013) concentrations should be for N (>350 mg L^{-1}), P (>10 mg L^{-1}) and K (> 740 mg L^{-1}). Calcium and magnesium were present in biofertilizers after the decomposition of organic matter (Chen *et al*., 2008). Sodium (Na) was present in low concentrations since values above 3, 500 mg L^{-1} have inhibitory effects for bacteria (Feijoo *et al*., 1995). The concentrations of copper iron (Fe), (Cu) and zinc (Zn) were low, especially for (Zn< 200 and Cu< 70 mg L^{-1}) which are considered heavy elements, in this way it is possible to use the fertilizer in a potential way (Romero *et al*., 2013).

Table 5. Nutrient content of liquid bio-fertilizers used in faba bean.

Municipality	Nutrients (mg L^{-1})								
	N	P	K	Ca	Mg	Na	Fe	Cu	Zn
SF	670.6 a	3193.3 a	516.9 b	480.5 a	189.5 a	24.3 b	36.9 b	0.5 a	2.3 a
Hu	801.4 a	1257.9 a	1097.1 a	603.2 a	233.6 a	216.6 a	67.6 a	0.3 a	2 a

Values with the same letter within columns are statistically the same based on the Tukey test ($p \leq 0.05$). DSH= honest significant difference. SF= San Felipe Teotlalcingo; Hu= Huejotzingo.

Cultivation in soil

The analysis of variance for the cultivation of faba beans in soil shows that there were highly significant statistical differences in the variables of dry weight of leaf, stem and fruit yield in treatments and for factor A. There was no statistical significance in treatments and factors for weight dry root and yield of fresh fruit in faba bean (Table 6).

Table 6. Mean squares and statistical significance in treatments applied to faba bean in soil culture medium.

FV	gl	Leaf	Stem	Root	Fresh fruit	Dry fruit
Treatments	8	56.3^{**}	130.8^{**}	57.3 ns	956.2 ns	162.9^{**}
Factor A	2	160.3^{**}	336.7^{**}	183.8^{*}	903.2 ns	150.9^{*}
Factor B	2	5.4 ns	117^{*}	4.4 ns	706.7 ns	281.8^{**}
A * B	4	29.7^{*}	34.7 ns	20.5 ns	1107 ns	109.5^{*}
Error	18	13	30.4	21.5	1075.8	27.8
CV	-	17	15	31	26	16

FV= variation factor; gl= degrees of freedom; *, **= statistical significance at 0.05 and 0.01 probability, respectively; ns= not significant; CV= coefficient of variation in%; factor A= soil fertilization; factor B= foliar fertilization.

In the mean comparison test, the treatments showed differences in the variables studied. For the leaf dry weight variable, the SN100% treatment stands out with a value of 28.3 g $plant^{-1}$. The BHu SN50% and BSF SN50% treatments are presented as the best with 44.6 g $plant^{-1}$ in dry stem weight. The root dry weight did not show significant statistical differences (Table 7).

These results are similar to those obtained by Condori *et al*. (1997) when finding differences in dry weight of leaves, but not of root in cultivated faba bean in soil, the tendency to increase the weight of foliage increases when fertilizers are applied. Guadarrama *et al.* (2007) point out that the application of fertilizers in particular nitrogen (N) significantly increases the total biomass, with the stem having the highest dry matter allocation, an effect that also occurred in this work, the highest weight corresponded to the stem weight and is associated with the interaction between biofertilizer and a 50% fertilization application. Muñoz *et al*. (2001) conclude that the increase of dry matter in each structure of the plant is due to a greater photosynthetic activity in leaves, promoted by a high concentration of chlorophyll and N leaf.

Table 7. Dry weight of leaf, stem and faba bean root grown in soil.

Treatment	Dry weight (g plant^{-1})		
	Leaf	Stem	Root
BSF SN100%	22.3 ab	32.3 ab	10 a
BHu SN100%	23.6 ab	41.3 ab	14.3 a
BSF	18.6 ab	33.3 ab	19.6 a
BHu	13.3 b	30.3 ab	19.6 a
BSF SN50%	22 ab	44.6 a	16.6 a
BHu SN50%	23.6 ab	44.6 a	12.3 a
T	17.3 b	28.3 b	20 a
SN100%	28.3 a	28.6 b	8 a
SN50%	19.6 ab	38.3 ab	14.6 a
DSH	10.3	15.7	13.2

Values with the same letter within columns are statistically the same based on the Tukey test ($p \leq 0.05$). DSH= honest significant difference. BSF= liquid biofertilizer from San Felipe Teotlalcingo; liquid biofertilizer from Huejotzingo; SN50% and SN100%= nutritive solution at 50 and 100% respectively.

Regarding the performance of fresh fruit, the results show that although the treatments were statistically equal, the BSF treatment showed the highest yield with 159.9 g plant^{-1}, the other treatments showed lower values, the variable performance of the dry fruit showed statistically significant differences, the BSF treatment excels with 43.3 g plant^{-1} (Figure 1).

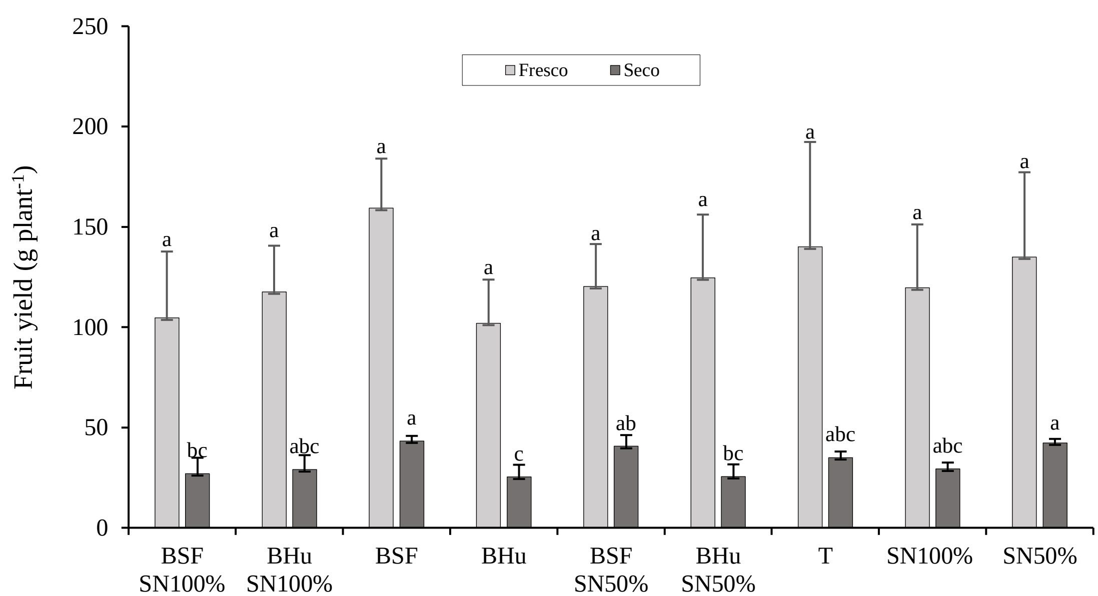

Figure 1. Yield of fresh and dry fruit obtained in treatments applied to the cultivation of faba bean in soil. Means with the same letter are statistically the same based on the Tukey test ($p \leq 0.05$). Vertical lines on the bars indicate the standard error. BSF= liquid biofertilizer from San Felipe Teotlalcingo; liquid biofertilizer from Huejotzingo; SN50% and SN100%= nutritive solution at 50 and 100% respectively.

The results of this investigation differ from those found by Guadarrama *et al*. (2007); Osman *et al*. (2010) when reporting that the application of inorganic fertilizers mainly of nitrogen tends to increase the yield of faba bean grain. Since the best yield was achieved with the BSF treatment, it could be mentioned that the cultivation of faba bean in soil does not need the application of chemical fertilizers, only that of foliar fertilizers to increase production, Mínguez *et al*. (1993) indicate that, due to biological nitrogen fixation in faba beans, potential yields can be achieved without any type of nitrogen fertilizer, which reduces nitrate leaching and improves the energy efficiency of crops. The amount of N fixed is associated with humidity, a deficit of it reduces modulation and therefore production (Guérin *et al*., 1991). Under greenhouse conditions soil moisture was controlled.

Cultivation in tezontle

The results of the analysis of variance show that there was no significance in dry leaf and stem weight in treatments and study factors. For root dry weight there were highly significant values in dry root weight for treatments and for factor A and B, but not for their interaction. While in yield of fresh fruit and dry fruit significant and highly significant differences were observed respectively (Table 8).

Table 8. Mean squares and statistical significance in treatments applied to faba bean cultivation in tezontle culture medium.

FV	gl	Leaf	Stem	Root	Fresh fruit	Dry fruit
Treatments	5	23.7 ns	53.4 ns	20**	675.5*	155**
Factor A	1	1.3 ns	186.8 ns	18**	462.8 ns	3.5 ns
Factor B	2	54.1 ns	10 ns	40.7**	508.9 ns	108.7*
A * B	2	5 ns	30 ns	0.5 ns	1834*	277**
Error	12	19.1	50.2	1.5	171.3	23.7
CV	-	23	22	13	11	17

FV= variation factor; gl= degrees of freedom; *, **= statistical significance at 0.05 and 0.01 probability, respectively; ns= not significant; CV= coefficient of variation in (%); factor A= soil fertilization; factor B= foliar fertilization.

In the results of the comparison of means test, the effect of treatments did not show statistical differences in leaf and stem dry weight (Table 9). Regarding root dry weight, the BSF SN50% treatment with a value of 13.3 g plant^{-1} stands out. Muñoz *et al*. (2011) indicate that a greater development of the root could be attributed to the capacity of infiltration and storage caused by the stability and size of the aggregates what could happen in the substrate tezontle. In substrates there is a greater exploration of the root system and therefore an immediate availability of the nutrients obtained from the hydroponics system (García *et al*., 2003).

Table 9. Dry weight of leaf, stem and faba beans root in tezontle culture medium.

Treatment	Dry weight (g plant^{-1})		
	Leaf	Stem	Root
BSF SN100%	22.6 a	28.3 a	10.6 ab
BHu SN100%	18.3 a	28.3 a	8 bc
BSF SN50%	20.3 a	38 a	13.3 a
BHu SN50%	17.6 a	36.6 a	9.6 b
SN100%	17 a	30 a	6 c
SN50%	18.3 a	31.3 a	7.6 bc
DSH	12.1	19.4	3.4

Values with the same letter within columns are statistically the same based on the Tukey test ($p \leq 0.05$); DSH= honest significant difference; BSF= liquid biofertilizer from San Felipe Teotlalcingo; liquid biofertilizer from Huejotzingo; SN50% and SN100%= nutritive solution at 50 and 100% respectively.

Significant statistical difference between treatments was observed. For the yield of fresh fruit the BSF SN100% treatment is presented as the best with 142.3 g plant^{-1} followed by Bhu SN100% with 131.3 g plant^{-1}, the remaining treatments have lower figures (Figure 2).

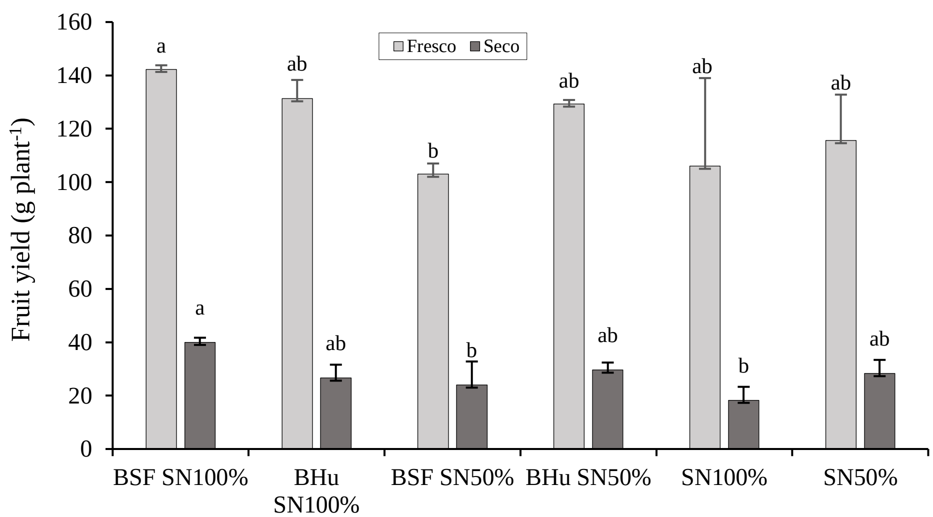

Figure 2. Yield of fresh and dry fruit obtained in treatments applied in tezontle. Means with the same letter are statistically the same based on the Tukey test ($p \leq 0.05$). Vertical lines on the bars indicate the standard error. BSF= liquid biofertilizer from San Felipe Teotlalcingo; liquid biofertilizer from Huejotzingo; SN50% and SN100%= nutritive solution at 50 and 100% respectively.

The above results show the BSFSN100% treatment as the best in substrate tezontle, which suggests the convenience of complete organo-mineral nutrition; however, to decrease the use of chemical fertilizers, it would be expected that 50% concentrations would be highlighted.

These results are similar to those obtained by García *et al*. (2003) to obtain the best yields in the faba bean crop under a hydroponic system.

Mínguez *et al*. (1993) states that the yield of faba bean cultivation will depend on its ability to adapt to different environments. Likewise, López *et al*. (2005) express that the environmental conditions govern the yield of the seed, in this investigation the conditions under greenhouse (temperature and humidity), as well as the availability and assimilation of chemical and organic nutrients obtained from biofertilizers and nutritive solutions.

Comparison of faba bean yields in soil and tezontle

The cultivation of faba bean in soil and tezontle presented six treatments in common, to which a comparison was made.

The cultivation of faba bean in tezontle showed better yields with respect to the soil in the treatments BSF SN100% and BHu SN100%. But this behavior of the substrate was affected when the treatments were only based on the nutritive solutions, SN100% and SN50%, obtaining lower values in the latter. When this happened, the soil had a better response, with the SN50% treatment standing out in this case.

The results of the comparison of yields differ from those of García *et al*. (2003) who found a better response of the hydroponic system in substrate than in a well prepared soil, associating that in hydroponics the effects of a greater infrastructure and radical system reflect greater grain yield.

When the application of biofertilizers and average concentrations of nutrient solution was applied (BSF SN50%) and (BHu SN50%), the most uniform values of faba bean yield were presented in the tezontle culture medium. The behaviors were similar for the dry weight of the faba bean fruit in both culture media. The results obtained in the study variables of the faba bean crop show different behaviors in soil and substrate tezontle in grain production.

Zabłudowska *et al*. (2009) mention that there is evidence that plants respond differently when they are cultivated in hydroponics or in soil; Dickinson *et al*. (2009) conclude that despite these limitations, the authors tend to extrapolate the results of hydroponics to the field and, as a result, many studies are too optimistic and unrealistic, also mentions that a plant can be very efficient occupying nutritive solutions but its assimilation will be affected by the conditions in the open field. These affirmations also take real importance in the application of biofertilizers in cultivated plants (with substrate tezontle and soil, under greenhouse or open field, with irrigation under temporary conditions) so these results are not possible to extrapolate. The use of hydroponic systems discerns in physiological responses in faba beans and other crops even when cultivated with the same materials Tavakkoli *et al*. (2012).

Conclusions

The application of foliar liquid biofertilizers in faba bean cultivation in soil improves grain yields, but not chemical fertilizers. However, in substrate tezontle the best grain yields of the faba bean crop are with an application of complete organo-mineral fertilization.

The effects of organo-mineral fertilization are shown differently in soil and substrate tezontle so it is not overwhelming and it is hardly possible to make a generalized recommendation of these.

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