Colegio de Postgraduados

Physico-chemical properties of the soil and effect of chemical fertilizers on the nutritional quality of *ayocote* runner bean (*Phaseolus coccineus* L.)

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ABSTRACT

Ayocote runner bean (*Phaseolus coccineus* L.) is a pulse native to the temperate areas of Mexico. A high bean yield can be obtained through the proper combination of variety, environment, and agronomical practices.

Objective: To determine the physico-chemical properties of the soil, as well as the effect of six chemical fertilizer formulas applied in the field on the soluble carbohydrate and protein content of *ayocote* runner beans in three municipalities of Puebla.

Design/Methodology/Approach: Twenty representative pods were collected per site where each fertilizer formula was applied. One-hundred seeds were ground to quantify in triplicate the soluble carbohydrate and protein content. Soil samples were subjected to a granulometry process prior to their chemical analysis. The ANOVA and mean test procedures of the SAS software were used for the statistical analysis of the information.

Results: *Ayocote* runner bean samples recorded the best physical and nutritional properties in Calpan, where the soil had remarkable physical and bio-chemical properties at a depth of 20-40 cm. The best nutritional characteristics in seeds were recorded with the 80-60 N-P kg per hectare formula.

Study Limitations/Implications: More sites should be studied to assess with greater accuracy the environmental effect.

Findings/Conclusions: Evaluation environments recorded variations in soil texture and the nutrient and organic matter content required for plant nutrition. Fertilizer formulas with high N and P contents favor the protein and soluble carbohydrate content, consequently improving the nutritional quality of the seeds.

Key words: *Phaseolus coccineus*, environmental effect, physical and nutritional properties, soil type, beans.

INTRODUCTION

Ayocote runner bean (*Phaseolus coccineus* L.) is a pulse native to the temperate regions of Mexico. It has a great productive potential and it is mainly used as food, although the whole plant (flowers, pods, seeds, and forage) can be used (Rojas *et al.*, 2017). The seed yield (SY) of a given crop depends on several factors, including: soil type, weather, cultivar, crop management, plant density (which can determine the SY increase), cycle

length, growth behavior of the crop, fertilization, and water availability (Rojas *et al.*, 2017). *Ayocote* runner bean is known as *ayecotli*, *frijolillo* ("little bean"), *frijol de risa* ("laughter bean"), *yexixima*, and *frijolón*. It is widely distributed in the Valley of Mexico, from 2,300 to 3,000 m.a.s.l. It can be found in pastures, scrublands, and pine and oak forests (Vargas *et al.*, 2013).

In the municipalities of Libres and Serdán, Puebla, ayocote runner bean is sown as a monoculture, while, in the states of Hidalgo, Mexico, and Tlaxcala, it is sown under a polyculture system (along with corn or common bean). *P. coccineus* is also grown and consumed in the highlands of the state of Chiapas. Meanwhile, in the states of Chihuahua, Durango, and Zacatecas, *patol* (*ayocote* runner beans with white seeds) is produced along with the common seasonal bean; its seeds have diverse and dotted patterns, depending on the state (Vargas *et al.*, 2011; Vargas *et al.*, 2013).

The main problems faced by bean cultivation in Mexico are diseases, pests, drought, and low temperatures. Fungi that take part in endomycorrhizae can reduce the damage caused by pests (including nematodes) or pathogenic fungi (Garza *et al.*, 2003). Bean plants inoculated with mycorrhizae (specifically, *Glomus mosseae*) grow more and have a greater yield in soils with low P availability (Khalil *et al.*, 2015).

A high seed yield can be achieved with the proper combination of variety, environment (temperature and relative humidity), and agronomic practices (García *et al.*, 2003). Bean cultivation requires the application of several macronutrients, including N, P, and K. N usually has a greater impact on growth, yield, and quality; meanwhile, P plays an important role during seedling germination and development, root development, fertilization, and the start of fruiting; finally, K is important for the permeability of cell membranes, intracellular acid-base balance, development and accumulation of reserve materials, and the regulation of the water status of crops (Ancín, 2011.).

The aim of this research was to determine the physico-chemical properties of the soil and the effect of six chemical fertilizers, applied in the field, on the nutritious quality of ayocote runner beans, in three municipalities of the state of Puebla.

MATERIALS AND METHODS

Study area

The soil and black runner bean samples (classified as Population 89) were collected in the following sites: Calpan, municipality of San Andrés Calpan; Santa María Tianguistenco, municipality of San Miguel Huejotzingo; and Santa María Zacatepec, municipality of Juan C. Bonilla (Figure 1) (INEGI, 2009 a,b,c). Several N (60 and 80 units) and P (40, 60, and 80 units) levels were evaluated per hectare (ha), resulting in six fertilization formulas: 1) 60-40; 2) 60-60; 3) 60-80; 4) 80-40; 5) 80-60; and 6) 80-80. The plant density (80,000 and 100,000 plants per ha) resulted in a total of 12 treatments with 3 repetitions each, established in the field under an experimental design with a 6×2 factor. The experimental plots were identified at the time of harvest and a five-plant sample was taken from each of the three repetitions for each fertilizer formula. One-hundred seeds were extracted from representative pods of each sample. The beans were subsequently ground, used to produce flour, or analyzed.

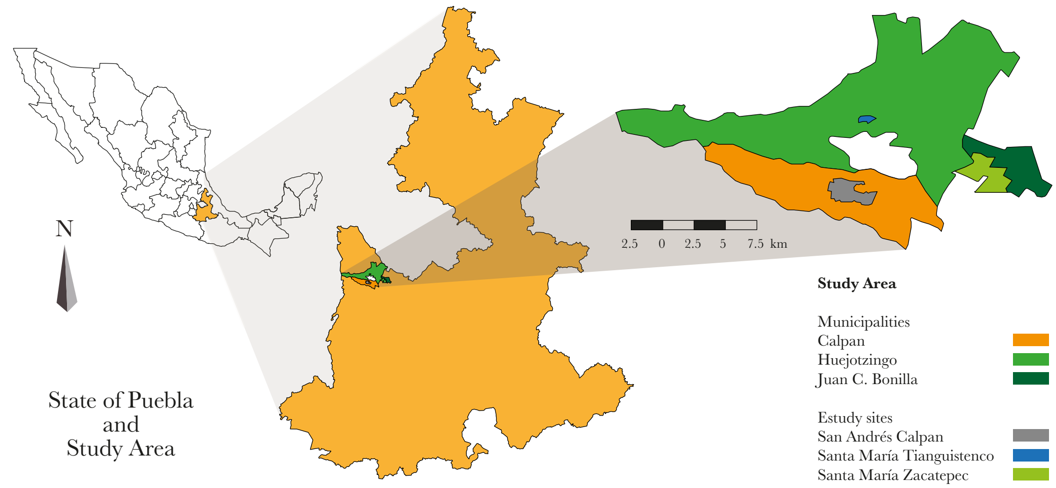

Figure 1. Study sites.

Physico-chemical properties of the soil samples

A homogenous sample was prepared from five subsamples taken from five squares at two depths (0 to 20 and 20 to 40 cm). The following soil variables were evaluated: granulometry (no. 4, 10, 20, 40, and 200 meshes), field humidity, residual humidity, texture determination (Bouyoucos method), total N, mineral N, organic matter (ashes and oxidizable organic matter), pH (Conductronic® PC18 potentiometer), electrical conductivity (RCYAGO® C-600 ph meter), TDS (Total Dissolved Solids), RP (Reduction Potential), salinity, and Ca and Mg availability in the soil (NOM-021-RECNAT-2000; Mendoza and Espinoza 2017). All determinations were made in triplicate.

Characteristics of runner beans

One-hundred seeds per fertilizer formula were analyzed per evaluation site. The seeds were ground and put in sealable bags and a Thermo-Scientific™ Evolution 300 UV-Vis spectrophotometer was used to determine the soluble carbohydrate content in the plant material. Likewise, the Micro Kjeldahl method was used to determine the protein content (Alvarado-López *et al.*, 2019). Finally, determinations were also carried out in triplicate.

Statistical analysis

The ANOVA and Tukey's test ($P=0.05$) procedures from the SAS software were used for the statistical analysis of the data.

RESULTS AND DISCUSSION

Physico-chemical properties of the soil

Santa María Zacatepec has sandy loam soil (0-20 cm) and loamy sand (20-40 cm). The soil in Calpan is sandy loam (0-20 cm) and loamy clay sand (20-40 cm). Finally, most soils in Santa María Tianguistenco are sandy loams (0-20 cm) and loam (20-40 cm).

Table 1. Analysis of variance of the soil variables of three sites in three municipalities of the state of Puebla.

Source of variation	pH	CE	MOX	COT	NT	Ca	Mg
LOC	0.0665ns	1150.3889*	1.3102*	0.0046ns	0.00009ns	14590.1033*	49595.6228***
REP(LOC)	0.0262ns	98.7222ns	0.1345ns	0.0418ns	0.0001ns	6613.3144ns	549.2053ns
PROF	0.2964**	112.500ns	1.7797*	0.0103ns	0.0003ns	70205.0169*	150434.4843***
LOC*PROF	0.2815**	123.500ns	0.3567ns	0.0046ns	0.0006*	112222.288***	3694.3435*
CV	1.8669	16.5923	26.6777	16.6518	12.0658	15.76932	5.457948
Media	6.6028	48.2778	1.6133	1.8694	0.0851	323.7465	452.7427

ST (LOC): site; REP(ST) (REP(LOC)): repetition per site; DEP (PROF): depth; ST*DEP (LOC*FERT): site per depth; CV: coefficient of variation; EC (CE): electrical conductivity; OOM (MOX): oxidizable organic matter; TOC (COT): total organic carbon; TN (NT): total nitrogen; Ca: calcium; Mg: magnesium; ns: non-significant differences; and *, **, and ***: $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$ statistical significance, respectively.

Table 1 shows significant EC, OOM, Ca, and Mg differences per site. Significant differences were recorded in the pH, OOM, Ca, and Mg variables at the two soil sampling depths. Meanwhile, significant pH, Ca, and Mg differences were recorded, depending on the site-depth interaction. Both nutrients are available at both depths (0-20 and 20-40 cm) and in the three study sites. Ca and Mg influence crop growth and development. On the one hand, Ca helps to neutralize the soil, regulates the operation of cell membranes, reduces the phytotoxicity of B, and participates in the development of enzymes, among other effects. On the other hand, Mg improves cellular hydration and osmotic pressure, regulates acidity, is part of the reserve compound of seeds, and activates several enzyme systems involved in the metabolism of protein synthesis, among other functions (Urbano-Terrón, 2011; Millán-Martín, Abadía-Bayona and Heras-Cobo, 1981).

Characteristics of runner beans

Table 2 shows the amount of soluble carbohydrates and proteins in runner beans as a percentage of dry matter. Significant carbohydrate differences were recorded per site,

Table 2. Analysis of variance for the variables recorded in ayocote runner beans, resulting from application of six fertilizer formulas in three sites of three municipalities from the state of Puebla.

Source of variation	Soluble carbohydrates (%)	Proteins (%)
LOC	281.9709***	1.1880ns
REP(LOC)	0.0302ns	1.1664ns
FERT	56.9604***	2.8533*
LOC*FERT	199.9764***	3.2803***
CV	0.4164	4.3519
Media	40.4411	18.3520

ST (LOC): site; REP(ST) (REP(LOC)): repetition per site; FERT: fertilizer formula; ST*DEP (LOC*FERT): site per depth; CV: coefficient of variation; ns: non-significant differences; and *, **, and ***: $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$ statistical significance, respectively.

fertilization, and site per fertilization; meanwhile, significant differences in proteins can only be found in fertilization and site per fertilization. Differences in protein and carbohydrate content could be associated with the application of fertilizers in the soil, the environment, and even different cultivars (Alvarado-López *et al.*, 2019).

Figure 2 shows that the samples from site 1 recorded the lowest carbohydrate content, followed by site 3 and site 2 (highest value). Therefore, the soil fertility properties of Calpan, along with the nutrients supplied through chemical fertilizers, enable a higher accumulation of soluble carbohydrates (CAR). The carbohydrates levels of the samples from the three study sites are lower than the 64.41% results reported by Bernardino *et al.*, (2016); those carbohydrates mainly consisted of starch with various amylose and amylopectin concentrations.

Figure 3 shows that fertilizer formulas 4 and 5 (80-60 and 80-40 N-P, respectively) had a statistically higher carbohydrate content, while the best carbohydrate accumulation in the bean had been recorded with the 60-60 N-P fertilizer formula. The use of N in ayocote

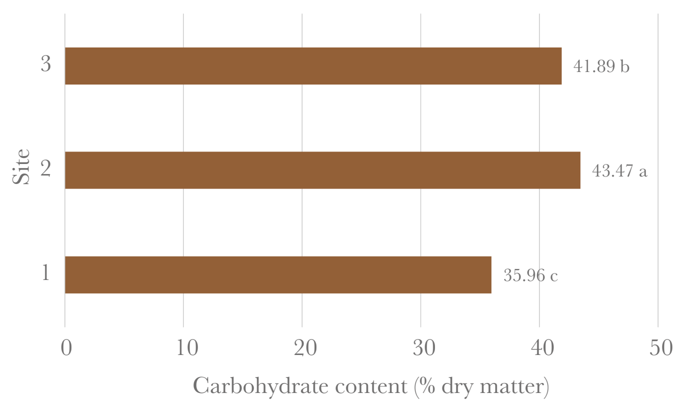

Figure 2. Dry soluble carbohydrate (CARB) content in *ayocote* runner bean samples, depending on the location of the crop. ST 1 (LOC 1): Santa María Zacatepec, municipality of Juan C. Bonilla; ST 2 (LOC 2): Calpan, municipality of San Andrés Calpan; ST 3 (LOC 3): Santa María Tienguistenco, municipality of San Miguel Huejotzingo. Values with the same letter are not statistically different (P≤0.05.)

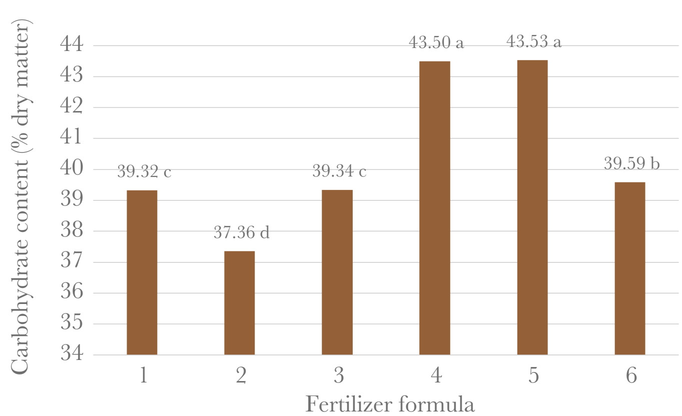

Figure 3. Carbohydrate content (CARB) of *ayocote* runner bean samples, depending on the fertilizer formula (N-P) applied during its cultivation: 1) 60-40; 2) 60-60; 3) 60-80; 4) 80-40; 5) 80-60; and 6) 80-80. Values with the same letter are not statistically different (P≤0.05.)

runner bean cultivation increases its carbohydrate and protein content, since the seeds are mainly composed of 40% carbohydrates, 25% proteins, and 15% other mineral substances and lipids (Rojas, Escalante, and Aguilar, 2023; Vargas-Vázquez et al., 2020). These results match the findings of this research: a fertilization doses with a higher N content resulted in higher carbohydrate levels.

Figure 4 shows that formula 6 (80-80 N-P) has a higher protein level (19.11%) than the other fertilization doses. The protein data obtained are higher than the 18.4 and 18.0% results reported by Pérez-Herrera *et al.* (2002) and Corzo-Ríos *et al.*, (2020), respectively. However, they are much lower than the 20.46, 21.93, and 21.7% reported by Osorio-Díaz *et al.* (2004), Bernardino *et al.* (2016), and Jacinto-Hernández *et al.* (2019), respectively.

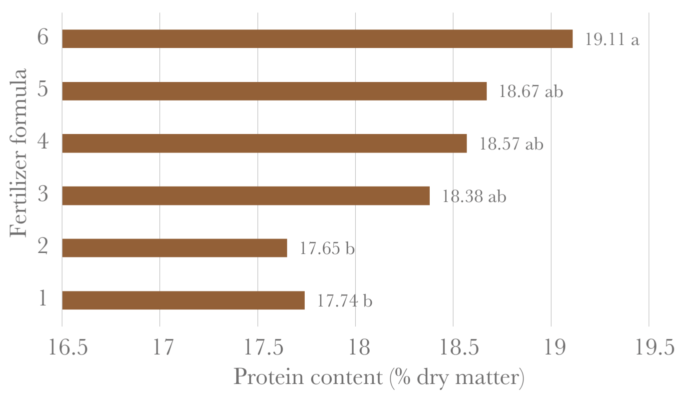

Figure 4. Protein content of *ayocote* runner bean samples, depending on the N-P formula applied during its cultivation: 1) 60-40; 2) 60-60; 3) 60-80; 4) 80-40; 5) 80-60; and 6) 80-80. Values with the same letter are not statistically different (P≤0.05.).

CONCLUSIONS

The statistical differences between the physical properties and fertility of the soils of the study sites depended on the type of soil and could be observed both in the variation of the soil texture and in the nutrient and organic matter content required for plant nutrition, among other variables.

Fertilizer formulas with high N and P content favor the protein and soluble carbohydrate content, consequently improving the nutritional quality of seeds.

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