PEDOLOGIC INDICATORS OF *Phaseolus vulgaris* CROPS IN THE COLOMBIAN DRY CARIBBEAN, *IN SITU* STRATEGY †

[INDICADORES EDAFOLÓGICOS DEL CULTIVO DE *Phaseolus vulgaris* EN EL CARIBE SECO COLOMBIANO, ESTRATEGIA *IN SITU*]

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SUMMARY

Background. In Colombia, people have intended to increase food production by using new alternatives in under-used areas, such as the dry Caribbean soils, where practical evaluation methods for cultivated soils are required. **Objective.** To evaluate the association and reliability of *in situ* methods to measure soil quality indicators, in comparison to laboratory analyses. **Methodology.**The quality of soils where the common bean is cultivated in the periods of pre-planting and post-flowering was determined in six locations at Cesar and La Guajira. Sensory analytic methods for these indicators: structure, effective rooting depth, superficial organic matter, soil cover, soil aeration, erosion control, infiltration rate and biota, were correlated to chemical microbiological variables, measured in the laboratory. **Results.** Deficiencies in crop structure, organic matter, soil cover, biota, and low availability of nitrogen, zinc, and boron were observed in the soil of La Guajira. **Implicaciones**. These results evidence the possibility to be used as low cost and high impact strategies for edaphic monitoring of common bean fields in the dry Caribbean region. **Conclusion**. The *in situ* techniques evaluated can be integrated to conventional techniques of edaphic characterization as a starting point in the identification of variables that require deterioration mitigation actions.
Keywords: ecological indicators; *Phaseolus vulgaris*; soil quality criteria.

RESUMEN

Antecedentes. Colombia se propone incrementar su producción alimentaria mediante nuevas alternativas en áreas poco utilizadas, como los suelos del Caribe seco, donde se requieren métodos prácticos de valoración de suelos cultivados. **Objetivo**. El objetivo de este estudio fue evaluar la asociación y confiabilidad del método *in situ* para medir indicadores de calidad del suelo respecto a análisis en laboratorio. **Metodología**. Se determinó la calidad de suelos cultivados con frijol común en presiembra y pos floración en seis localidades ubicadas en los departamentos del Cesar y La Guajira. Se correlacionaron metodologías organosensoriales de los indicadores estructura, profundidad efectiva, materia orgánica superficial, cobertura, aireación, control de la erosión, velocidad de infiltración y biota, con variables químicas y microbiológicas, medidas en laboratorio. **Resultados**. Se observaron deficiencias en estructura, materia orgánica, cobertura, biota, baja disponibilidad de nitrógeno, zinc y boro en suelo de Guajira. **Implicaciones**. Estos resultados evidencian la posibilidad de utilizar estos indicadores como estrategias de bajo costo y alto impacto, para el monitoreo edáfico en cultivos de frijol en el Caribe seco. **Conclusiones**. Las técnicas *In situ* evaluadas, pueden integrarse a las técnicas convencionales de caracterización edáfica, como puntos de partida en la identificación de variables que requieren acciones de mitigación frente al deterioro.
Palabras clave: criterios de calidad del suelo; indicadores ecológicos; *Phaseolus vulgaris*.

INTRODUCTION

Common bean is one of the most consumed grains per capita in developing countries. Colombia is one of such countries of great social importance, belonging to what is referred to as peasant economy, i.e. smallholdings with an average planting area of a hectare, using austere technological resources, under topographic conditions that make it difficult to reach high technical levels. Even if this translates into low productivity, farming is an activity that can potentially generate a large number of jobs (Tofiño *et al.,* 2016).

As part of the leguminous family, common bean favors soil renovation. The endosymbiotic association between the plant's roots and the Rhizobium bacteria contributes to biological nitrogen fixation that ranges from 60% to 80%, allowing for reduced doses of nitrogen fertilizers

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(Sánchez 2007; Tajini *et al.*, 2011); reactivation of poor soils such as those in the dry Colombian Caribbean region; (Melo *et al.*, 2015; Shisanya 2002; Tofiño *et al.*, 2016). Another effect is the mitigation of the local desertification that generates ground cover and biodiversity loss, as well as low crop productions – which, in turn, result in poor nutrition for rural populations and in the worst cases, forced migration (Piguet, 2011).

Therefore, it is necessary to advance in management programs for production systems so that these include an assessment of the impact of crops on soil conservation, productivity and quality, on the basis of initial conditions. It is also relevant to establish a regular monitoring method to identify changes, in order to take preventive rather than corrective measures (Pérez, 2012).

Nowadays, the few monitoring projects performed in soils destined to common bean crops in dry Caribbean minifundia, have focused on physical, chemical and biological aspects (Tofiño *et al.*, 2011; Tofiño *et al.*, 2012), measured exclusively by laboratory techniques. This results in long periods of time between sampling and analysis and delayed actions by farmers in the face of a particular situation. Such aspect has a negative impact, particularly on crops that have a short phenological cycle – e.g. common bean – which can reach 88 days after sowing, with 44 days for flowering under the agroecological conditions of the areas studied; consequently, any untimely culture action will cause a negative impact on the crop yield (Tofiño *et al.*, 2016).

However, the use of sensory tests to determine pedologic characteristics *in situ* has not yet been mass-applied within the area. Studies by Altieri and Nicholls (2002) show the importance of socializing this type of low-cost strategies, which allow the observation of the impact of productive models in amoeba charts.

The main objective of this study was to establish edaphic indicators for conventional common bean crops through an *in situ* strategy for assessment, with the use of sensory tests compared to laboratory analyses of chemical and microbiological indicators, in order to establish soil response variables that could be used by small and medium producers in Cesar and La Guajira departments for the fast monitoring and practical development of a baseline soil quality.

MATERIALS AND METHODS

Description of the study area

This study was conducted in the second semester of 2013, in five municipalities of the Cesar department: Valledupar (10°27′37″N 73°15′35″W), Manaure (11°46′30″N 72°26′40″W), Agustín Codazzi (10°02′12″N 73°14′13″W), La Jagua de Ibirico (DI) (9°33′40″N 73°20′11″W), Tamalameque (8°51′32″N 73°48′50″W), and in one municipality of La Guajira department: San Juan del Cesar (DC) (10°46′15″N 73°00′11″W), located at an altitude of 131; 900; 150; 50 to 150; 168 and 213m MSL, respectively, with an annual average temperature of 28°C, rainfall of 1360 mm and 68% relative humidity.

Crops

Black bush bean of a traditional variety was sown in plots, 0.6 m between furrows and 0.2 m between plants, with a density of approximately 28,750 plants/hectare. Fertilization was applied at sowing, following reposition criteria based on the extraction of macronutrients and an expected production of 1 t ha^{-1} with additional foliar applications, according to Tofiño *et al.* (2016). Weed control was performed by manual and chemically directed (with fluazifop-p-butyl 12.5 g L^{-1}) methods. For pest and disease control, insecticides (thiamethoxam 350g L^{-1} for the commercial product, 3 mL kg^{-1} for seed) and fungicides (fludioxonil 13,2 g L^{-1}, Metalaxyl-M 19,2 g L^{-1}) were applied in seeds, while carbendazim and tiabendazole were applied in the lots. A shift to systemic insecticides – bifenthrin (50 g L^{-1}) + imidacloprid (250 g L^{-1}), nonylphenol ethoxylate, and mancozeb – was made in the post-flowering stage.

In situ analysis of soil indicators

Physical variables were analyzed *in situ* by sampling in X shape at 13 points and 30 cm depth during the pre-planting and post-flowering stages, according to the methodology described by Perez (2012). Such variables were 1) soil structure analysis, according to the formation or absence of soil aggregates and their consistence; 2) effective rooting depth, measured by resistance to penetration by iron rod, stoniness, and humidity; 3) status of superficial organic matter according to odor, origin and size of organic residue particles; 4) soil cover , per quantity and permanence; 5) soil aeration, according to the filtration time of several droplets of solution of calcium carbonate (1:5 ml) in water on a "portion of soil"; 6) erosion control, through observation of soil channels and A-horizon loss; 7) infiltration rate of 1 L of water through a 12.5 cm diameter and 20 cm long PVC tube. The evaluated biological indicators *in situ* were 1) biota, through the observation of earthworms and invertebrates, and indirect microbial activity, measured through hydrogen peroxide levels, according to Perez’s scale (2012), during pre-planting and post-flowering stages; 2) identification of functional radical legume nodules during post-flowering stage only (Tajini *et al.*, 2011). All indicators were ranked on a ten-point scale, from the negative (1) to the most positive (10) (Altieri and Nicholls, 2002).

Laboratory analysis of soil indicators

In order to establish the relationship between variables analyzed *in situ* and variables analyzed in a laboratory, chemical and microbiological indicators were evaluated under controlled conditions. A sampling of 1.5 Kg ha^{-1} of soil was performed in X shape, at 5 points in each location, during the pre-planting and post-flowering stages of bean crops. The method was aimed at obtaining a composite sample (Tofiño *et al.,* 2016), which was then packed in airtight bags and preserved in refrigeration at 4ºC to be taken to the microbiology laboratory of the Santander University in Valledupar for a microbiology analysis. The total number of colony forming units (CFU) was evaluated for the presence of bacteria, fungus, and actinobacteria; also, functional groups of phosphate solubilizing bacteria (PSB) and rhizobia group bacteria were evaluated in Pikovskaya agar with tricalcium phosphate and yeast-mannitol agar with Congo red for rhizobia (YMA-CR), respectively (Corrales *et al.,* 2014; Morell and Hernández, 2008). The mycorrhiza-forming fungi (MFF) count was performed through Gerdemann and Nicolson's method, as described by Barriga *et al.* (2011). For chemical analyses, soil samples were sent to AGROSVIA Laboratory, at the Tibaitatá Research Center; pH indicators (soil-moisture relation, potentiometer method), organic matter content (OM) (Walkley-Black method, modified), available phosphorus (Bray II), and available potassium (Olsen method) in soil, as well as Fe, Mn, Cu, Ca, B and Zn, were evaluated (Fernández *et al.,* 2006).

Agronomic yield measuring

In order to measure crop production at each location, 20 plants were sampled at each plot, and with the use of an electronic balance, yield was estimated in t ha^{-1} on three occasions.

Statistic analysis

Descriptive statistics tests estimating average were used for all variables. Pearson correlation coefficient tests were used for variables from two phenological stages. A regression analysis was performed for the *in situ* and laboratory variables with the highest rate of correlation and, finally, a analysis of main components was used for analyzing soil quality variables during the post-flowering stage, using both *in situ* and laboratory methods, in relation to yield at each location. SPSS Software version 2.0 was used for all analyses.

RESULTS AND DISCUSSION

Pedologic indicators *in situ* for bean crops pre-planting and post-flowering stages

Variables analyzed *in situ* during the pre-planting stage with no fertilization for agronomic management are shown in the radar chart below (Figure 1). They evidence levels between 1 and 7 (measuring scale, 1-10), with the best pedologic characteristics at Manaure, particularly related to aspects such as crop structure, soil cover, organic matter, and biota. However, San Juan DC shows levels lower than 5 with the same characteristics, which places it in the most internal part of the chart. Levels from medium to high were seen for the soil aeration variable at all locations. Jagua DI evidenced deficiencies for two indicators: biota and soil cover (3/10). In contrast, the radar chart that summarizes the organic matter (0.00), erosion control (0.02), and biota (0.04) variables show a strong trend to symmetric distribution for the post-flowering stage and a better performance in San Juan municipality. During the pre-planting stage, no symmetric distribution was observed with any variable (Figure 2). However, in Tamalameque, a positive change was observed in biota and soil cover under pre-planting conditions.

During the monitoring activities of the pre-planting stage in Valledupar, Manaure y Agustín Codazzi, edaphic characteristics observed *in situ* were generally considered adequate in relation to bean crops establishment by Sánchez *et al.* (2010) and Altieri & Nicholls (2002), as their indicators show medium levels at most of the variables, except soil cover, which shows a high level at all three locations, assessed by Perez's scale (2012). The data obtained suggest that bean crops may adapt to highly variable environments, under different bioclimate and soil quality conditions. Tamalameque and La Jagua DI showed medium to low-quality levels and, in San Juan DC, lower indicators were mainly observed, as assessed through *in situ* methods and laboratory methods (Pedroza *et al.,* 2016; Tofiño *et al.,* 2016).

In samples taken during the post-flowering stage, an improvement was observed at all municipalities, mainly due to increasing levels in biota, formed by worms/invertebrates and microorganisms with dehydrogenase activity, as well as the restoring effect of soil cover. Sánchez *et al.* (2010) point to the benefit of soil cover in soil properties and bean crops yield, and also emphasize its potential and efficiency for restoring degraded soils. Likewise, these results support the phytoremediation activity observed in relation with bean crops, which are involved in nitrogen fixation and soil extraction of metal chemicals (Sánchez, 2007; Shisanya, 2002; Tajini *et al.,* 2011). They also acted as a useful cover that reduces the impact of rain droplets, preventing destruction of the surface soil structure, promoting water filtration and reducing soil particles leaching (Ruiz and Molina 2014); this is demonstrated through higher levels and a greater symmetry (0.02) *in situ* indicators such as control of erosion and infiltration rate during the post-flowering stage, as was observed in most of the studied locations.

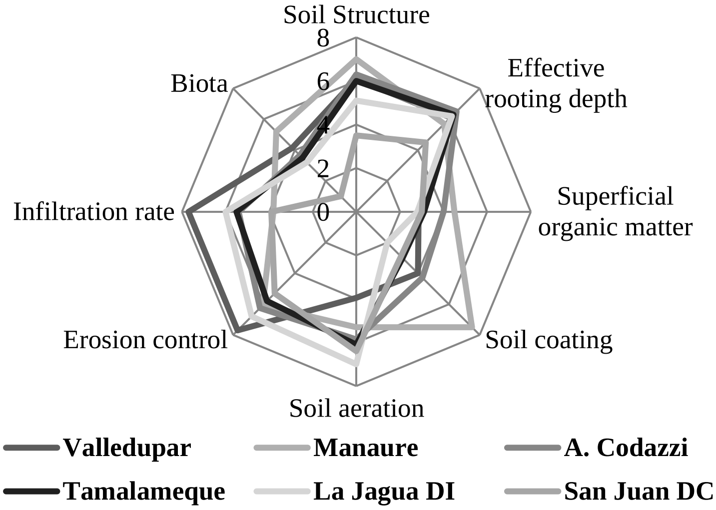

Figure 1 – Pedologic characteristics evaluated *in situ* for bean crops pre-planting stage.

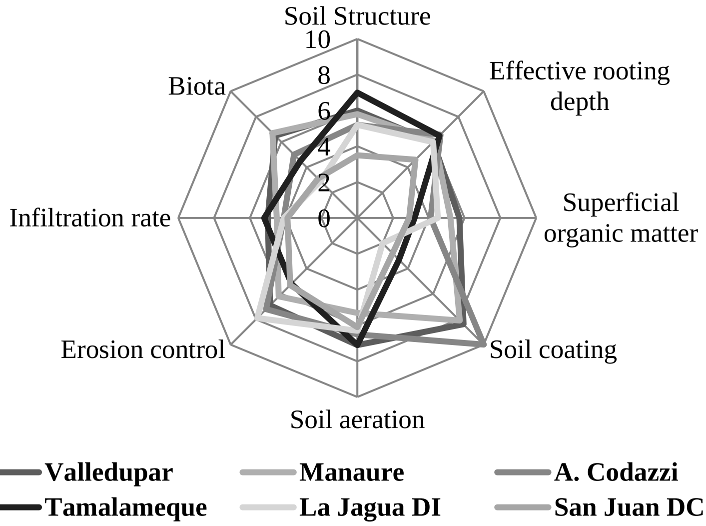

Figure 2 – Pedologic characteristics evaluated *in situ* for bean crops post-flowering stage.

Pedologic indicators analyzed by laboratory methods for bean crops pre-planting and post-flowering stages

At all locations, according to chemical indicators measured in laboratory (Table 1), moderately acid and non saline soils were identified (Quintana *et al.*, 2016; Rojas *et al.*, 2015), as well as a low level of organic matter, ranging between 0.81% to 1.51%, except in Manaure and Agustin Codazzi, where organic matter level was medium, 3.64%, and 2.3%, respectively. A high level of phosphorus content was observed (> 30 mg kg^{-1}) in Valledupar, Codazzi, and San Juan DC municipalities, but it was within an adequate range of tolerability for bean crops (Guerrero 2009; Tofiño *et al.*, 2016). Base exchange of calcium, magnesium, and potassium was moderated in nature, with lower levels observed in Tamalameque and La Jagua DI. Low levels of zinc and boron micronutrients were found at these locations (Guerrero, 2009). All indicators during the post-flowering stage were found to be similar during the study.

The total count of microbial populations, such as bacteria, fungi, and actinobacteria (Table 2) was found to be within the recorded levels range for tropical soil (Table 2) at all locations during the pre-planting stage (Melo *et al.*, 2015). However, during the post-flowering stage, a reduction in the total count of bacteria and fungi was observed in municipalities with lower physical and chemical indicators, such as Tamalameque, San Juan y La Jagua DI. This could be associated to agronomic management with the use of agricultural chemicals in this stage (Melo *et al.*, 2015), as well as other factors, such as slightly acid pH, low content of organic matter and low cover level (3/10). Soil cover has been reported as an indicator that strongly influences microbial colonization, due to highly available carbon, used as a source of energy (Ferreras *et al.*, 2009).

Table 1 - Chemical soil indicators evaluated in 6 municipalities before planting and during bean crops development.

Indicator	Valledupar		Manaure		Agustín Codazzi		Tamala-meque		La Jagua DI		San Juan DC	
	PP	PF	PP	PF	PP	PF	PP	PF	PP	PF	PP	PF
pH	6.43	5.28	6.08	5.71	5.8	6.07	5.58	5.95	5.45	4.39	5.3	6.11
CE	0.26	1.59	0.18	0.35	0.27	1.08	0.17	0.07	0.13	0.35	1.09	0.22
OM	1.13	0.83	3.64	2.66	2.3	2.27	1.07	1.59	0.81	1	1.07	1.51
Phosphorus	29.77	203	11.88	16.7	176	170.9	28.3	1.41	7.23	7.11	97.85	171
Sulphur	2.83	57.5	5.26	9.35	3.11	8.02	1.39	4.05	1.39	4.16	74.27	4.26
Calcium	4.94	5.17	7.3	8.27	6.48	7.49	1.32	4.61	2.43	1.04	4.98	8.19
Magnesium	1.21	0.82	1.38	1.39	1.19	1.54	0.26	2.16	0.21	0.31	1.91	2.22
Potasium	0.26	0.66	0.2	0.17	0.43	0.56	0.08	0.06	0.03	0.04	0.3	0.22
Sodium	0.11	0.04	0.04	0.03	0.05	0.04	0.05	0.1	0.05	0.02	0.16	0.04
Iron	46.4	283	137	221	179	163	251	190	99.2	100	82.3	214
Manganese	5.8	35.2	9.2	18.9	6.7	6.7	2	1.7	2.4	42.2	11.5	10.1
Zinc	1.9	3.7	2.7	3	4.4	3.3	1.6	1	1.6	1.8	2.2	6.1
Copper	2.7	3.4	5.2	5.1	4	2.9	1.2	2.2	0.8	1.8	3	10.1
Boron	0.14	0.22	0.3	0.15	0.12	0.37	0.24	0.14	0.38	0.12	0.2	0.17

*****PP: pre-planting; PF: Post-flowering; CE, electrical conductivity in dS m^{-1}; OM, Organic Matter %; Phosphorus in mg Kg^{-1}; Sulphur in mg Kg^{-1}; Calcium in cmol (+) Kg^{-1}

Concerning functional PSB groups, only Valledupar, Manaure and Agustín Codazzi municipalities could be isolated; Manaure and San Juan DC showed an increase during the post-flowering stage. Also, during this stage, a reduction in Rhizobia group bacteria colonies was seen at all municipalities, except La Jagua DI. This trend may be associated with soil nutrients content since N fixation activity by rhizobia bacteria could have been stimulated as a result of an excess or a deficit of N in soil (Gutiérrez and Martinez, 2001). A higher presence of PSB was found in Manaure (3.5x103 to 3.5x104 CFU g-1 in soil) (Table 2), which could be possibly related to an increase of soluble phosphorus in soil (Table 1) during the post-flowering stage. This process can be demonstrated with the reduction in soil pH during the post-flowering stage, which could be potentially related to some organic components produced by bacteria, particularly organic acids, which in turn are one of the various mechanisms of solubilization (Corrales *et al.,* 2014).

A similar phenomenon occurs in San Juan DC during the post-flowering stage, as phosphorus content in soil increases to a 75% (171.13 mg Kg^{-1}) versus the pre-planting stage. Even though there was no reduction in soil pH, this shows that phosphatase or phytase enzymatic activity occurred at this stage (Corrales *et al.,* 2014). Furthermore, Gutiérrez & Martinez (2001) point out that plants establish a symbiotic relationship with such microorganisms when nutrients content levels in soil are low, otherwise, when nutrients availability is high, as seen in other locations, there is a lower possibility for interaction to occur.

However, interactions for symbiotic fixation of nitrogen are complex and involve an exchange of multiple signals between the host plant and symbiont bacteria, and also are influenced by environmental and edaphic factors, e.g. acidity and phosphorus availability (Martínez *et al.*, 2016). This explains the behaviour of rhizobia bacteria indicators and the presence of active nodules in locations with a different level of soil quality, such as La Jagua DI and Manaure; the first showing an increase in rhizobia bacteria during the post-flowering stage, which indicates an inverse relation between the adequate nutrition of crops and beneficial microorganisms colonization. On the other hand, in Manaure, which shows better edaphic characteristics, nodules presence and a reduction in rhizobia bacteria were observed during the post-flowering stage; which could be associated to a process of roots colonization. During the pre-planting stage, a greater number of rhizobia bacteria acted as a successful inoculum, considering that a nodulation peak occurs between 30 and 50 days after inoculation of material (Saraiva *et al.,* 2008).

MFF was scarcely found, considering the range reported for tropical soils with an acid pH and low fertility (Barriga *et al.,* 2011), associated with symbiosis dependent plants and soil degradation caused by intensive farming in the zone. Nevertheless, this demonstrates the efficiency of mycorrhiza inoculation applied to bean crops in order to increase yield and adaptability of plants (Grajeda *et al.,* 2012; Morell and Hernández 2008; Terry *et al.,* 2013). Manaure was the only municipality where an appropriate quantity of radical nodules formation was seen (28 active nodules per plant) (Altieri and Nicholls, 2002; Tajini *et al.,* 2011).

Table 2 – Microbial count averages in all municipalities, during pre-planting and post-flowering stages.

Municipality /Stage	Bacteria CFU g^{-1} (10^5)		Fungi CFU g^{-1} (10^4)		Actinobacteria CFU g^{-1} (10^4)		PSB CFU g^{-1} (10^4)		Rhizobia group bacteria CFU g^{-1} (10^3)		MFF g^{-1} soil	
	PP	PF	PP	PF	PP	PF	PP	PF	PP	PF	PP	PF
Valledupar	440	0.2	14	34	27	20	0.2	0	1.4	0	1.2	0.4
Manaure	3.5	55	1.3	12	1.5	10	0.4	350	2.4	0.5	0.9	1.0
Agustín C	90	0.5	19	200	18	20	0.1	0	1	0	0.8	0.5
Tamalameque	110	2.0	1.3	0.5	2.2	0.2	0	0	3	1.5	0.3	0.5
La Jagua DI	190	25	1.1	0.1	1.7	0.2	0	0	0.7	2.5	0.5	0.6
San Juan DC	11	1.2	1.5	0.1	25	0.2	0	0.4	0.5	0	0.4	0.3

***PP**: pre-planting; PF: post-flowering

Yield of bean crops in 6 locations

The yield of bean crops was low in most of the studied locations: 0.8 t ha^{-1}, compared to the average of yield in the region (Tofiño *et al.*, 2016). The highest yield was obtained in Valledupar, with 0.8 t ha^{-1}, followed by La Jagua DI, with 0.7 t ha^{-1}, Codazzi, with 0.67 t ha^{-1}, and San Juan DC and Tamalameque, with 0.6 t ha^{-1}. Conversely, in Manaure, although it showed the best pedologic conditions, the lowest yield was obtained, counting 0.53 t ha^{-1}. This demonstrates that crop production within the zone is influenced by various factors, which also include climatological characteristics and agronomic management (Tofiño *et al.*, 2016).

Correlations of soil quality levels indicators analyzed *in situ* and in the laboratory

Variables analyzed *in situ* during the pre-planting stage showed a significant correlation (<0.05) with chemical and microbiological features measured in the laboratory (Table 3). Soil cover was the characteristic with the highest number of associated variables: organic matter (r = 0.95), phosphate solubilizing bacteria (r = 0.91) and copper (r = 0.88). This shows the importance of the estimation of this indicator as a visible physical characteristic, which also influences the biological, physicochemical dynamics of soil (Sánchez *et al.,* 2010). Ferreras *et al.,* (2009), identified higher levels of microbial biomass carbon and a higher activity of dehydrogenase and urease in soils with the cover. On the other hand, Lozano *et al.* (2010) found that cover influenced physical soil properties: bulk density, saturated hydraulic conductivity, absolute porosity and mechanical resistance. Additionally, it is important to emphasize the relation between organic matter measured *in situ* and in the laboratory (r = 0.98) (Figure 3), which highlights the usefulness of this indicator as a variable to be evaluated in order to estimate soil requirements of this component. It is possible to establish this relationship, as *in situ* analysis allows the observation of organic residues, which provide nutrients such as nitrogen and organic carbon to the soil when adequately degraded; these variables can be measured in laboratory subsequently.

Concerning variables analyzed *in situ* during the post-flowering stage, only soil structure, rooting depth and erosion control showed a significant relation (< 0.05) with elements measured in a laboratory, such as Zinc (-0.834), copper (0.899) and magnesium (-0.900), respectively; soil cover, on the other hand, was correlated with actins presence (0.948).

***In situ* analyzed variables and variables analyzed in a laboratory, relating to bean crops yield in 6 locations**

Seventy-nine point three percent (79.3%) of the variance was explained by two components. In the first component, with a 48.5% of the variance in the study, boron, potassium, and rhizobia bacteria are found. On the other hand, the most important variables in the second component, with a 30.8% of the variance, were superficial organic matter, electrical conductivity levels, and soil structure.

Table 3 – Correlation of variables analyzed *in situ* and variables analyzed in a laboratory for the bean crop pre-planting stage.

In situ indicators	Laboratory indicators *
Aeration	pH(-0.94); MFF (-0.86)
Structure	CE (-0.82)
Rooting depth	OM_{Lab}(-0.88)
Superficial OM	OM_{Lab} (0.98)
Soil cover	Copper (0.88); PSB (0.91)
Infiltration rate	Bacteria (0.96)
Erosion control	Bacteria (0.91)
Biota	CE (-0.84); Sulphur (-0.84)

*Significant correlation <0.05

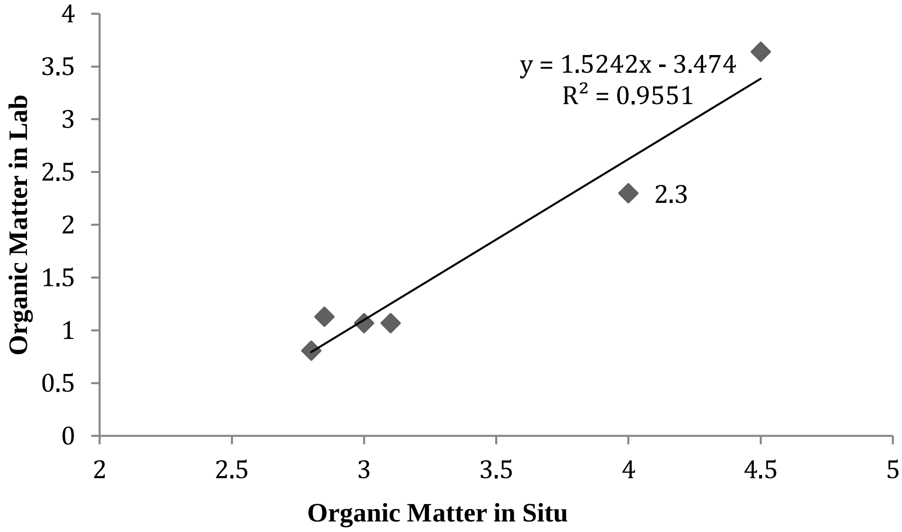

Figure 3 – Relation between organic matter indicators* measured *in situ* and in a laboratory. * status of superficial organic matter according to odor, origin and size of organic residue particles (Perez, 2012). All In situ indicators were ranked on a ten-point scale, from the negative (1) to the most positive (10)

The analysis of the main components shows the sensibility of *in situ* variables under favorable conditions for growing, which promote a high yield, as it was seen in Valledupar. However, in extreme conditions, corrective actions should be established to complement laboratory analyses. Likewise, Campitelli *et al.* (2010) highlight the sensibility and usefulness of *in situ* soil indicators such as calcium carbonate depth and A-horizon measuring, and other variables obtained by analyzing the main components in several locations that have an agricultural management.

According to the analysis of *in situ* indicators and laboratory indicators, the use of organic fertilizers in the case of locations with a lower fertility level is advised, particularly in San Juan DC, where the mean levels of effective rooting depth and soil aeration observed may promote the development of aerobic microorganisms, which allow for a higher mineralization and humification of organic matter than anaerobic microorganisms (Beltrán *et al.,* 2017). Additionally, microorganisms populations stimulate soil microstructure and promote assimilation of nutrients from fertilizers added during a period of at least 30 days in arid and semi-arid areas, which is the maximum period for nutrients absorption by bean crops. Even if fertilizers are not completely absorbed during the present bean crop cycle (Celaya and Castellanos, 2011), they will improve the edaphic properties of locations with lower levels in quality indicators. This will lead to sustainable production in locations with medium to high levels in quality indicators. Also, it is important to implement soil cover (Sánchez *et al.*, 2010), since it was a variable that had a strong influence on the study.

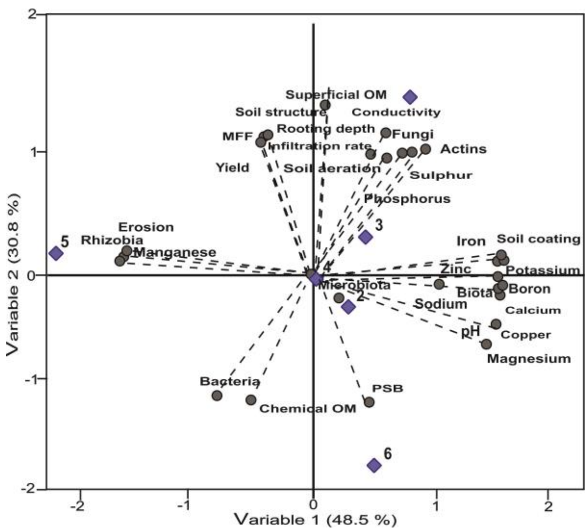

Figure 4 - Biplot for variables evaluated *in situ* and chemical, biological variables analyzed in laboratory, related to bean crop yield in 6 locations: 1- Valledupar, 2- Manaure, 3- Agustín Codazzi, 4- Tamalameque, 5- La Jagua DI and 6- San Juan DC.

CONCLUSIONS

Superficial organic matter and soil cover are the indicators measured *in situ* that show the greatest sensibility and the highest correlation with chemical and microbiological variables analyzed in a laboratory, mainly during the pre-planting stage.

During the post-flowering stage of bean crops, variables such as agronomic management affect the behavior of the indicators analyzed in this study.

Sensory in situ methods usage is a feasible and useful strategy that generates low costs and has a high impact. It allows for a better knowledge of soil before planting and enhances monitoring of soils where bean crops are grown in dry Caribbean regions. However, it should be complemented with laboratory analyses for greater accuracy.

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Compliance with ethical standards. This research complies with the ethical standards required of research in Colombia in relation to the handling of biological material

Data avaliability. Data are available with Mario Zapata-Tamayo, mazapata@agrosavia.co upon reasonable request.

REFERENCES

Altieri, M.A., and Nicholls, C.I., 2002. Un método agroecológico rápido para la evaluación de la sostenibilidad de cafetales. Manejo Integrado de plagas y agroecología (Costa Rica). 64: 17-24.

Barriga, J., Visbal, M., and Acero, J., 2011. Relación entre los caracteres de las micorrizas arbusculares nativas con las propiedades físico-químicas del suelo y bromatología del pasto estrella en en ganadería de carne. Revista Científica UDO Agrícola. 11(1): 134-141.

Beltrán, M.E., Rocha, Z.E., Bernal, A.A., and Pita, L.A., 2017. Microorganismos funcionales en suelos con y sin revegetalización en el municipio de Villa de Leyva, Boyacá. Colombia Forestal. 20(2): 158-170.

Campitelli, P., Aoki, A., Gudelj, O., Rubenacker, A., and Sereno, R., 2010. Selección de indicadores de calidad de suelo para determinar los efectos del uso y prácticas agrícolas en un área piloto de la región central de Córdoba. Ciencia del Suelo (Argentina). 28(2): 223-231.

Celaya, H., and Castellanos, A. 2011. Mineralización de nitrógeno en el suelo de zonas áridas y semiáridas. Terra Latinoamericana. 29(3): 343-356.

Corrales, L., Arevalo, Z., and Moreno, V., 2014. Solubilización de fosfatos: una función microbiana importante en el desarrollo vegetal. NOVA. Publicación en Ciencias Biomédicas. 12(21): 67-79. DOI https://doi.org/10.22490/24629448.997

Fernández, L.C., Rojas, N.G., Roldán, T.G., Ramirez, M.E., Zegarra, H.G., Uribe, R., Reyes, J., Flores, D., and Arce, J.M., 2006. Manual de técnicas de análisis suelos aplicadas a la remediación de sitios contaminados. Instituto Mexicano del Petróleo. Secretaria de Medio Ambiente y Recursos Naturales e Instituto Nacional de Ecología, México D.F.

Ferreras, L., Toresani, S., Bonel, B., Fernández, E., Bacigaluppo, S., Faggioli, V., and Beltran, C., 2009. Parámetros químicos y biológicos como indicadores de calidad del suelo en diferentes manejos. Ciencia del Suelo (argentina). 27(1):103-114.

Grajeda, O.A., Diaz, F., Peña, J., and Vera, J.A., 2012. Impacto de los biofertilizantes en la agricultura. Revista Mexicana de Ciencias Agrícolas. 3(6): 1261-1274.

Guerrero, R., 2009. Fertilización de cultivos en clima cálido. Monómeros colombo venezolanos, Bogotá.

Gutierrez, A., and Martinez, E., 2001. Natural endophytic association between Rhizobium etli and maize (Zea mays L.). Journal of Biotechnology. 91(1): 117-126. DOI https://doi.org/10.1016/S0168-1656(01)00332-7

Lozano, Z., Romero, H., and Bravo, C., 2010. Influencia de los cultivos de cobertura y el pastoreo sobre las propiedades físicas de un suelo de sabana. Agrociencia. 44(1): 135-146.

Martínez, I., Reyes, Y., Falcón, A., Nápoles, M.C., and Núñez, M., 2016. Efecto de productos bioactivos en plantas de frijol (Phaseolus vulgaris L.) biofertilizadas. Cultivos Tropicales. 37(3): 165-171. DOI http://dx.doi.org/10.13140/RG.2.1.1077.0165

Melo, A., Ariza, P., Lissbrant, S., and Tofiño, A., 2015. Evaluation of agrochemicals and bioinputs for sustainable bean management on the Caribbean coast of Colombia. Agronomía Colombiana. 33(2): 203-211. DOI http://dx.doi.org/10.15446/agron.colomb.v33n2.49858

Morell, F., and Hernandez, A., 2008. Degradación de las propiedades agrobiológicas de los suelos Ferralíticos Rojos Lixiviados por la influencia antrópica y su respuesta agroproductiva al mejoramiento. Agronomía Tropical. 58(4): 335-343, 2008.

Pedroza, A., Trejo, R., Sánchez, I., Samaniego, J., and Yáñez, L., 2016. Evaluation of three pinto bean varieties under drought and irrigation in Durango, Mexico. Agronomía Mesoamericana. 27(1); 167-176. http://dx.doi.org/10.15517/am.v27i1.21896

Pérez, M.A., 2012. Aportes Metodologícos al "Sistema Agroecológico Rápido de evaluación de calidad de suelo y salud de cultivos". Universidad Internacional de Andalucia, España.

Piguet, E., Pécoud, A., and Guchteneire, P., 2011. Migración y cambio climático. Migraciones. 30: 161-196.

Quintana, W., Pinzón, E., and Torres, F., 2016. Evaluación del crecimiento de fríjol (Phaseolus vulgaris l.) cv ICA cerinza, bajo estrés salino. Revista U.D.C.A Actualidad & Divulgación Científica. 19(1): 87-95. DOI https://doi.org/10.31910/rudca.v19.n1.2016.113

Rojas, J., Guerra, A., Arevalo, J., Guerrero, L., and Leiva, F., 2015. Sensor de conductividad eléctrica aparente para definir zonas homogéneas de manejo en suelos salinos. Revista Colombiana de Ciencias Hortícolas. 9(1): 86-96. DOI https://doi.org/10.17584/rcch.2015v9i1.3748

Ruiz, E., and Molina, D., 2014. Beneficios asociados al uso de coberturas leguminosas en palma de aceite y otros cultivos permanentes: una revisión de literatura. Revista Palmas. 35(1): 53-64.

Sánchez, M., 2007. Las endomicorrizas: expresión bioedáfica de importancia en el trópico. Universidad Nacional de Colombia, Facultad de Ciencias Agropecuarias, Palmira.

Sanchez-Saenz, C.M., Souza, Z.M., Matsura. E., and Freitas, N.R., 2010. Efecto de la cobertura en las propiedades del suelo y en la producción de fríjol irrigado. Revista U.D.C.A Actualidad & Divulgación Científica. 13(2): 41-50. Doi https://doi.org/10.31910/rudca.v13.n2.2010.728

Saraiva, C., Lira, M.A., Pereira, N., Galvão, F., and Albuquerque, M., 2008. Nodulação e produção do caupi (Vigna unguiculata L. WALP) sob efeito de plantas de cobertura e inoculação. Revista Brasileira de Ciência do Solo. 32(2): 579-587. DOI https://doi.org/10.1590/S0100-06832008000200013

Shisanya, C., 2002. Improvement of drought adapted tepary bean (Phaseolus acutifolius A. Gray var. latifolius) yield through biological nitrogen fixation in semi-arid SE-Kenya. European Journal of Agronomy. 16(1): 13-24. DOI https://doi.org/10.1016/S1161-0301(01)00117-4

Tajini, F., Trabelsi, M., and Drevon, J.J., 2011. Combined inoculation with Glomus intraradices and Rhizobium tropici CIAT899 increases phosphorus use efficiency for symbiotic nitrogen fixation in common bean (Phaseolus vulgaris L.). Saudi Journal of Biological Sciences, 19: 157–163. DOI https://doi.org/10.1016/j.sjbs.2011.11.003

Terry, E., Padrón, J., Tejeda, T., and Díaz, M., 2013. Respuesta del cultivo de la habichuela (*Phaseolus vulgaris* L. var. Verlili.) a la aplicación de diferentes bioproductos. *Cultivos tropicales, 34(3)*: 5-10.

Tofiño, A., Tofiño, R., Cabal, D., Melo, A., Camarillo, W., and Pachón, H., 2011. Evaluación sensorial de fríjol (*Phaseolus vulgaris* L.) mejorado nutricionalmente en el norte del departamento del Cesar, Colombia. *Perspectivas Nutrición Humana, 13*: 161-177.

Tofiño, A., Tofiño, R., and Jiménez, H., 2012. Determinación del potencial productivo y nutricional de un fríjol biofortificado mesoamericano en el Cesar Colombia. *Vitae, 19(1)*: 297-299.

Tofiño, A., Pastrana, I., Melo, A., Beebe, S., and Tofiño, R., 2016. Rendimiento, estabilidad fenotípica y contenido de micronutrientes de genotipos de fríjol biofortificado en el Caribe seco colombiano. Corpoica Ciencia y Tecnologia Agropecuaria, 17(3): 309-329. DOI https://doi.org/10.21930/rcta.vol17_num3_art:511