v. 4, n. 7, 2024

Journal of
Engineering
Research

ASSESSMENT OF SOME HYDROPHYSICAL PROPERTIES OF THE SOIL UNDER THREE VEGETATION COVERS IN AN ORGANIC AGRICULTURE CONTEXT IN THE MUNICIPALITY OF ZIPACÓN, COLOMBIA

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The effect of vegetation cover of coffee (Coffea arabica) plus alder (Alnus acuminata) (T1), coffee (Coffea arabica) (T2) and managed pastures (cover dominated by Digitaria decumbens) (T3) on some physical and hydrological tests of the soil of the "La Libertad" farm, in the municipality of Zipacón, established 14 years ago under exclusively organic nutritional management. The variables evaluated were depth of the A horizon, resistance to penetration, apparent density, gravimetric humidity, total porosity, organic matter and infiltration capacity. The results showed greater resistance to penetration in the coffee cover, while the greatest depth of the A horizon and the highest organic matter content and total porosity were found for the grass cover. The infiltration capacity was moderately fast for the coffee plus alder agroforestry system and moderate for coffee and managed pastures. In general, these results suggest that variables such as organic matter, penetration resistance and apparent density are being affected, to a greater extent by the effect of coverings than by local soil topography conditions, where concave areas, such as those found only for the treatment of grasses, would be favoring a greater content of organic matter, greater thickness of the A horizon, greater porosity and greater gravimetric moisture content. However, this greater porosity (considering that the treatments are on soils with a similar clay-loam texture) is not showing a greater infiltration capacity, due to higher moisture levels favored by the location of the grass cover in an area that tends to become flooded. due to its concave morphometry. These results make it possible to identify water conditions that are more favorable to the recharge of aquifers under agroforestry covers, such as coffee plus alder, and to identify water conditions that are more favorable to coffee agricultural productivity.

INTRODUCTION

The study area, located three kilometers from the most important city in the municipality of Cachipay (municipality of Zipacón), has witnessed in the last fifteen years an important change in land use motivated by the proliferation of enterprises focused on the production of ornamental flowers, whose Agronomic management tends to be intensive in the use of agricultural machinery, pesticides and other aspects that have displaced traditional coffee and livestock activities from the territory. Some producers have opted for differentiated management of their resources, with an agroforestry and organic approach to coffee cultivation, establishing, among other measures, different coverages that accompany the main crop. In this sense, it is important to study the effect of establishing different coverings on some of the hydrophysical properties of the soil. For this, the farm "La Libertad" was selected, which has different coverings and has been established for 14 years. The study aims to contribute to the knowledge of the behavior of several edaphic variables that determine the productivity of the coffee growing system in the coffee producing zone of the eastern mountain range dominated by sedimentary materials from the Cundiboyacense region, in particular the ecotope 314 A, from the Bogotá river basin, under the influence of forest cover such as alder, in addition to evaluating the behavior of variables that, such as infiltration capacity, facilitate the recharge of the region's aquifers and the water regulation of the basin (Gómez, L.; Caballero, A.; Baldión, J .; 1991). (García-Olmos, C.F., 2007).

MATERIALS AND METHODS

The work was carried out on the "La Libertad" farm, Laguna Verde village, in the municipality of Zipacón, with geographic coordinates 4.721679 N and -74.415902 W and at an altitude of 1,700 meters above sea level. The average temperature is in the range of 18 to 24°C, average precipitation of 1,507 mm per year and relative humidity of 76% on average (Molina N. and Romero N., 2016). These conditions allow the study area to be located in the premontane humid forest (bh-PM) life zone, according to Holdridge.

According to the information available in a preliminary analysis, the soil had a medium clay-loam-FAr texture (24.5% of A, 42.8 of L and 32.6 of Ar), pH of 4.9, saturation aluminum content of 38.73%, carbon monoxide, C.O, and 3.6% (Walkley-Black), cationic exchange capacity, CIC, of 32.6 cmol/kg, base saturation of 19.13% and phosphorus, P, of1.63 ppm. The agronomic management of all covers in the study has been the same for 14 continuous years, starting the transition to organic production with the establishment of forage peanuts (Arachis pintoi) and then, eight years ago, with the planting of coffee (variety Castilla) and alder (Alnus acuminata L) and is characterized by the non-use of chemically synthesized fertilizers, but only organic fertilizer from curi excrement (Cavia porcellus) twice a year and supplemented with a periodic sickle each time the weeds of Coverage between the paths grows large enough to interfere with the regular course required for normal cultivation operations (approximately once a month).

The coffee is established 1.5 meters between rows and between plants in a staggered manner and the plot with agroforestry arrangement has alder shade, established every 9 meters, also in a staggered manner, and they were assigned the identification of treatment 1, coffee more alder, and only coffee vegetation cover as treatment 2, and reference treatment 3, managed pasture. According to the producer's statement (García V, C. 2023), the agroforestry system made it possible to substantially improve the quality of the coffee (measured by flavor and aroma characteristics).

To determine the study variables, the depth of the A horizon was measured directly using the drill hole and Dutch flexometer (see Figure 1), the penetration resistance was performed using the Eijkelkamp type cone penetrometer, sampling with 10 repetitions in each cover up to a depth of 50 cm, the apparent density was determined using the volume cylinder method (5 cm in height and 5 cm in diameter approx.), collecting three samples at two depths (0-15 cm and 15-30 cm) for each cover. Each sample had its gravimetric humidity determined (oven drying method at 105°C) and its real density (pycnometer method) in the soil laboratory facilities at the Vivero campus of the Distrital University (LSVUD). With the real density data, it was possible to calculate the total porosity in all samples according to the relationship:

PorTot = (DR/DR-DA), where:

PorT is the total porosity

DR, it is the real density, and:

Figure 1: Drill hole sampling to determine A horizon depth

Total organic matter was evaluated using the specialized muffle furnace calcination method at 650 °C for three hours in samples previously dried in a drying oven, also at LSVUD. The infiltration capacity was determined in the field for each cover using the concentric ring methodology (Montenegro, 1990), and the use of the Kostiakov-Lewis model for processing the data obtained and modeling the infiltration curves and determining the basic infiltration. The significance of the differences observed between coverages was analyzed using the F test and the "Mean Significant Difference" (DMS) statistic (Mendoza, 2002) with a probability of 95%. Likewise, the correlation analysis between the test variables (depth of horizon A, organic matter, apparent density, gravimetric humidity and porosity) was used using Pearson's correlation coefficient (University of Seville, n.d.). The presence or absence of volcanic ash as source material was tested by NaF tests on hand samples at 15 and 30 cm depth.

RESULTS AND DISCUSSION

Penetration resistance shows that the coffee coating (T2) presents the highest values (hereinafter, different letters represent significant differences) with an average of 13.87 kg/cm2, compared to 9.89-9.99 kg/ cm2 for other coverings:

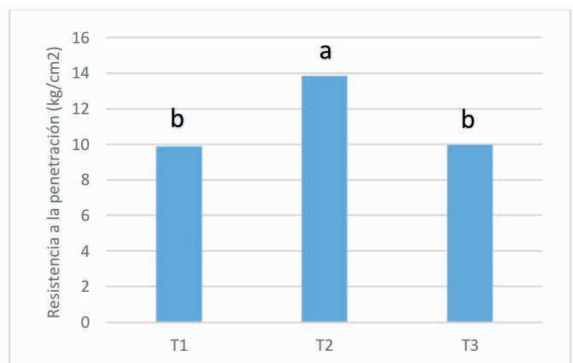

Figure 2: Average Penetration Resistance Values. "a" and "b" represent the categories of 10 and 14 kg/cm2

Considering the range of values found (0.97-1.36 Mpa), the literature reports that there is no reason to believe that these conditions are limiting for the growth of the crop's roots, since authors such as Forsythe (1986), report that from a value of 2.96 Mpa, problems and limitations may occur for normal root growth, something that, according to what was observed in the field and documented in the producer's production records, does not occur in the test performed. In relation to the higher value obtained for T2, there is a precedent by (Cardona D. and Sadhegian S., 2005) who found that resistance to penetration was greater in the coffee crop under free exposure than in the coffee plant associated with guamo (Inga spp), commenting that this behavior indicated soil compaction in this cover. Although it is true that the range of values found by them (0-4 kg/cm2) was lower than that of the present study, this would show the beneficial effect of having covers associated with main coffee crop, and also a non-harmful effect due to greater compaction in this crop for the values found in this study.

The higher penetration resistance values found here in relation to the study by D. Cardona & S. Sadhegian (2005) and Lince S. & Sadeghian K (2019) in coffee soils in Colombia, must be explained by differences attributable to pedogenic factors, such as the predominance of soils originating from igneous-intrusive or pyroclastic materials (volcanic ash) that generate textures less coarse than those found in this study, which are related to the influence of sedimentary materials from geological formations that, in the studied sector, tend to generate fine-grained soils (Molina N. & Romero N., 2016), which is also confirmed by the presence of the clay loam texture determined for the soil in this test. In this regard, it is important to mention that the NaF test was negative in the analyzed samples, confirming the absence of volcanic ash as a soil-forming material on the studied farm.

In relation to the depth of the A horizon, the grass cover (T3) presented the highest values in relation to the other covers:

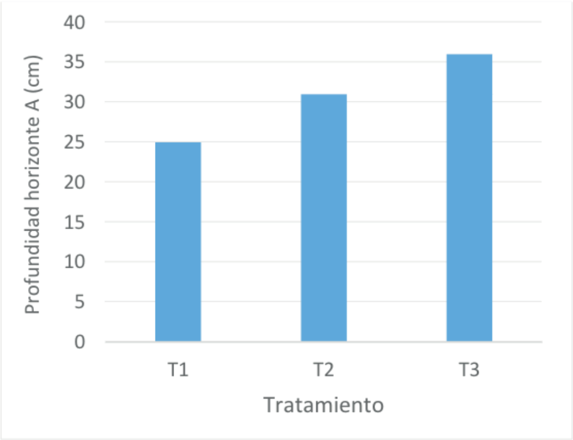

Figure 3: Average depth of the A horizon (cm) in the different treatments.

In pastures, the depth of horizon A had an average depth of 36 cm, different from the coverage of T1 (25 cm) and coffee alone (31 cm) (Figure 2), although there were no significant differences. However, the trend found would indicate, in some way, that the covers and their agronomic management are not leaving a pedogenetic footprint in the soil, since it is assumed that 14 years after the establishment of peanut, coffee and alder covers, at least non-significant differences must be observed between the covers if it is considered that biomass production is greater in forest covers (T1 and T2). Therefore, these results must be explained based on the occurrence of other factors, such as topography, where a concavity associated with lower levels of contour lines is seen, as it can be seen in the following illustration, and which was also complemented with the direct observation of the tendency to flood in that area, as observed by the authors.

In relation to total organic matter, the results indicate that, although no significant differences were found between the treatment averages (see graph below), it is observed that, consistently, pasture coverage is the one that presents high values of organic matter at the two depths analyzed:

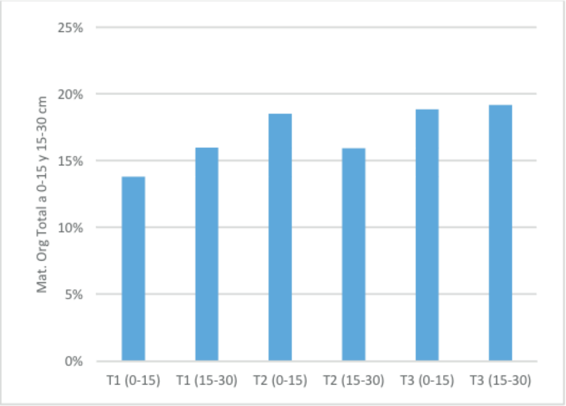

Figure 4: Total organic matter at two depths in the evaluated covers

Relating these results with what was found in the previous variable, it is observed that a greater depth of the A horizon would be related to factors that favor a greater accumulation of organic matter, which, in this case, is not explained by a greater production of biomass which, in principle, it must occur in coffee with alder coatings, but in others that have been observed in the field, such as a concave topography that favors, on the one hand, greater water saturation and, on the other, greater values of organic accumulation.

Regarding the gravimetric moisture content, it was found that the grass cover is where the highest moisture content was observed at a depth of 0 to 15 cm:

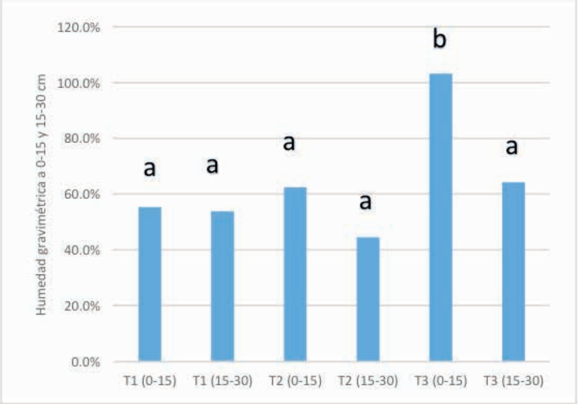

Figure 5. Gravimetric humidity at two depths in the evaluated roofs

Journal of Engineering Research ISSN 2764-1317 DOI: https://doi.org/10.22533/at.ed.317472426027

As it can be seen in Figure 5, there is statistical significance in the average humidity at the lowest depth of 0 to 15 cm in favor of pasture cover (103.4%) and, in addition, a higher humidity value for this same treatment at a depth of 15 to 30 cm (64.4%), although this difference was not significant. Soil moisture, of course, is variable depending on the textural, environmental and topographic conditions that also condition the formation and evolution of the soil, especially precipitation. Although soil moisture varies, at the time this assessment was carried out, it is clear that the soil in the sector where the pastures are located presents intrinsic conditions that favor a higher water content, not due to textural or environmental properties, as these are very similar between treatments. Furthermore, this content would also favor a higher percentage of total organic matter, as seen in the previous variable. In this sense, authors such as Jaramillo (2002) report that organic soils "are formed independently of climate and lithology, as long as there are topographic conditions that favor the accumulation of organic matter in hydromorphic conditions, that is, saturated with water deficient in oxygen, almost permanently" (p. 619). It is clear that the soil analyzed here is not organic in the taxonomic sense of the word (Soil Survey Staff, 2022), but it would be meeting the requirements for the concave topographic influence to leave its mark in a greater content of organic matter and a greater thickness in the horizon A, favoring greater water and organic accumulation.

In relation to total porosity, again the treatment or coverage of pastures presents significant differences in depth from 0 to 15 cm in relation to the coverage of T1 (72.8% vs. 53.4%), but not in relation to T2 (68.7%):

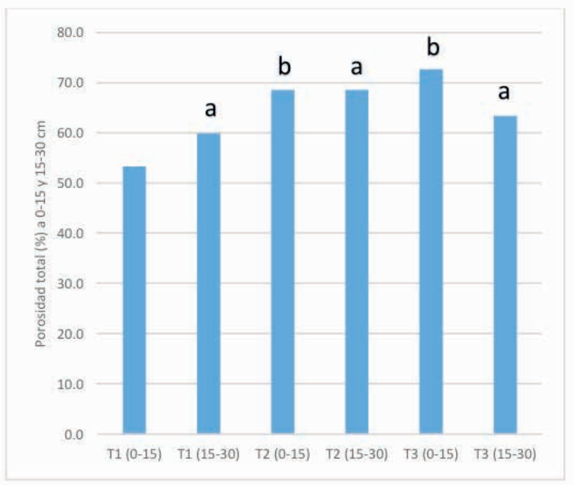

Figure 6. Total porosity at two depths in the evaluated coverings

No differences were found in this variable for the depth of 15-30 cm. Differences in porosity from 0 to 15 cm are significantly present in favor of simple coffee and grass mulches. It is considered that this behavior is due to intrinsic soil conditions that do not reflect the effect of the cover at the level of detail of the study, that is, the alder cover would not be exerting a significant control over the porosity of the soil as such. However, on a larger scale, the effect of coverage is clearer on the behavior of infiltration capacity, as will be seen below. The highest porosity found for T3 at a depth of 0-15 cm coincides with the highest gravimetric humidity found there, as discussed in the previous variable, which would be showing soil location conditions that favor greater saturation.

Regarding soil density, significant differences were found between T1 and T3 (coffee + alder with 0.93 g/cc and grasses with 0.65 g/cc):

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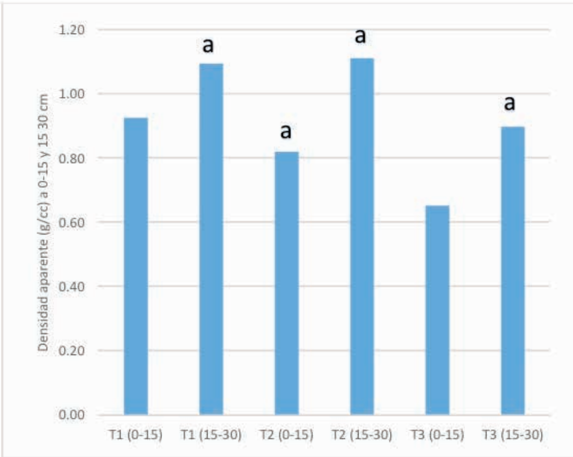

Figure 7. Bulk density (g/cc) at two depths in the evaluated coverings.

The differences between the apparent density coverages at a depth of 15-30 cm were not significant. The low density found for T3 in the range of 0-15 cm correlates well with the greater total porosity and gravimetric humidity found in this coverage. On the other hand, and as mentioned for the previous variable, densities that increase with increasing depth, a logical and expected behavior with thickening in deeper sectors of the soil, were consistently found in all treatments. Furthermore, the higher bulk density found for T1 and T2 is well related to the higher penetration resistance found for T2 (coffee only), although this is not true for the T1 coffee alder coating. It is possible, therefore, that the alder is generating some type of "loosening" of the soil, in addition to the action of the coffee roots alone, which would explain a lower resistance to penetration, but not a clear effect on soil density, which, as will be recalled, it is determined on relatively small, undisturbed soil samples that are not affected by alder root growth (this analysis can also be applied to total porosity).

Finally, relating the values above with studies carried out in other coffee growing areas with the presence of volcanic ash (Paz & Sánchez, 2007), (Lince & Sadhegian, 2019), it appears that the values found here are higher than those found by these researchers, configuring a situation in which a predominant typology of higher soil density is confirmed in coffee growing regions with soil origin materials other than volcanic ash, as is the case in this case.

The behavior of the infiltration capacity is shown in the following figures:

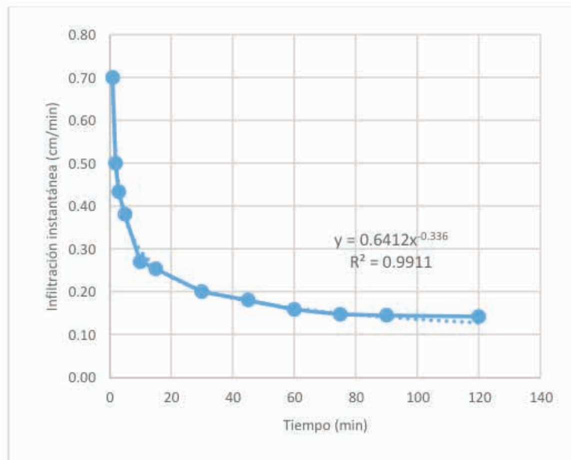

Figure 8: Infiltration Capacity for T1 Coverage (Café Mais Amieiro)

With the model obtained from the infiltration capacity, the basic infiltration was calculated at 6.47 cm/h, qualifying this soil as "moderately rapid" infiltration, according to IGAC, 2006.

The infiltration rate behavior for T2 (coffee only) is shown below:

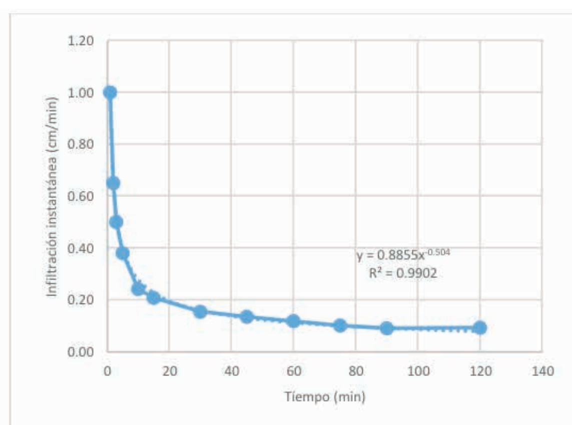

Figure 9. Instant Infiltration Capacity for T2 Coverage (Cafe)

In this case, the calculation of the basic infiltration capacity resulted in a value of 2.98 cm/h, which was classified as "moderate" according to IGAC (2006).

The behavior of the infiltration capacity for T3 (grass) is shown below:

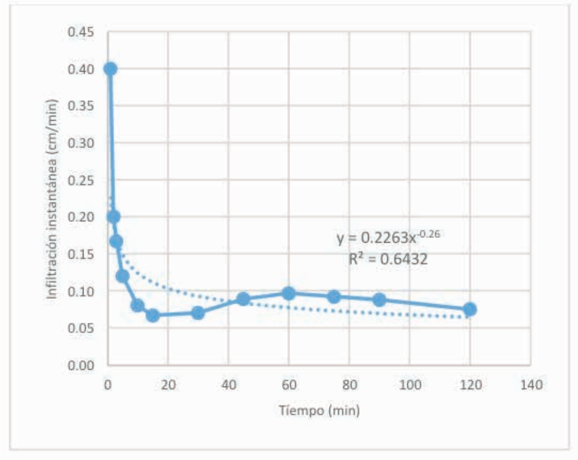

Figure 10. Infiltration capacity for T3 coverage (pastures)

In this case, the infiltration model obtained allows us to calculate a basic infiltration capacity of 3.65 cm/h, which qualifies this soil as having "moderate" infiltration. A summary of the above results is shown in the following table:

Treatment	Basic infiltration capacity (cm/h)	Qualification
T1	6,47	Moderately rapid
E2	2,98	Moderate
E3	3,65	Moderate

Table 1. Basic infiltration capacity between treatments

According to these results, it can be stated that the highest basic infiltration capacity was obtained in the T1 coverage, while the T2 and T3 coverages have a slower infiltration capacity compared to T1, but are similar to each other. This would indicate the effect of the alder cover which would be contributing to increasing the structural porosity of the soil by generating soil loosening due to the additional growth of alder roots in the field. Apparently, this is counterintuitive if we consider that the total porosity variable in T1 was the lowest of the three coverages. However, it must be remembered that a) the samples to determine total porosity were taken in small cylinders and this does not reflect the existence of fissures and other structural spaces that were evidenced in the field and b) infiltration does not depend only on the conditions inherent to the soil that facilitate (or hinder) the entry of water into the soil such as porosity, but also initial moisture content, surface permeability, degree of hydration of expandable soil colloids and organic matter content (Kramer, 1974). In this sense, it is evident, from the gravimetric humidity data, that the T1 coverage is the one with the lowest value in this study (at the lowest depth), which may explain the highest value of infiltration capacity found. It is clear that, in turn, this low moisture content for T1 is also related to the location of the lot in a convex zone, which allows better water drainage (something that can also be said for T2).

Thus, in this study, we found the behavior of several edaphic variables that are more affected by the local topography of the lot and by agronomic management (by allowing the growth of alder between the coffee trees) than by the conditions of biomass production and, therefore, of organic matter from this cover. In this regard, Barrezueta (2021) found important effects of surface runoff and topographic humidity index that end up strongly influencing the differences found in soil organic carbon accumulation in a study that also found differences due to coverage of bananas, young cocoa, ripe and old on a farm in the Oro province of Ecuador, located 500 meters above sea level.

The correlation analysis between the variables is presented below:

	MO 0-15 cm	M.O 15-30 cm	D.A 0-15 cm	D.A. 15-30 cm	H 0-15 cm	H 15-30 cm	PT 0-15 cm	PT 15-30 cm
Horizon depth A, PA	0,25	0,19	-0,59	-0,31	0,66	0,18	0,67*	0,26
Organic matter, MO, (0-15cm deep)			-0,47		0,25		0,40	
Organic matter, MO, (15-30 cm deep)				-0,70*		0,67*		0,25
Bulk density, DA, (0-15 cm deep)					-0,87**		-0,68*	
Bulk density, DA, (15-30 cm deep)						-0,90**		0,26
Moisture (0-15 cm deep)							0,70*	
Moisture (15-30 cm deep)								-0,38

Table 2. Pearson correlation coefficients (r) between the different soil physical variables (coefficients that presented statistical significance at the level of 5%* or higher** are shown

The correlation coefficients obtained indicate, in general, that there are different degrees of linear correlation between the edaphophysical variables evaluated, which are at least low to moderate. A high to very high correlation was found between the variables apparent density and humidity; total porosity and humidity; apparent density and total porosity; organic matter and apparent density (in addition to this case, an inverse correlation was found), indicating that high levels of organic matter tend to be associated with low values of apparent density (Montenegro, 1990); organic matter and moisture (between 15 and 30 cm); apparent density and total porosity (between 15 and 30 cm). Likewise, moderate to low correlation values were found between humidity and total porosity (between 0-15 cm), density and total porosity (between 15 and 30 cm), organic matter and humidity (0-15 cm) and total porosity -organic matter (0-15 cm), with a low level of significance. In relation to the depth of the A horizon, its high level of relationship with total porosity stands out (at a depth of 0-15 cm), but the low level of relationship with the other variables must also be observed, especially at a depth of 15 to 30 cm. In this case, it must be noted that the formation of the A horizon also depends on other factors not directly studied in this work, such as topography and the dynamics of organic matter accumulation. However, the tendency that greater surface humidity may be contributing to the thickness of this horizon appears to be relevant.

In general, it is considered that, although there is no greater strength in the correlations found, they mark a trend that supports the analyzes of the significance of the differences found between the variables with the F and DMS tests. This may be due, on the one hand, to the need to have a greater number of data and, on the other, to the presence of expandable clays, which was evidenced when drying the samples, since in all cases there was an appreciable decrease in the volume of samples obtained after oven drying and this may be affecting the correlations, especially at a depth of 15-30 cm (due to a greater presence of clays at deeper soil levels). See the following illustration:

Figure 11. Samples from the drying oven showing a decrease in original volume, a clear indication of the presence of expandable clays.

This presence affects the normal behavior of the trends found here, affecting the pore space and introducing "noise" in the behavior of the variables evaluated here.

Regarding the typology of the coffee ecotope 314º, located in the Bogotá River Basin and in which the site of this study is located, it can be stated that the results found here suggest, in general, that the taxonomic components of fine-grained soils originating of colluvium derived mainly from the formations of the Villeta group will have greater resistance to penetration and greater density than ecotopes or regions with the presence of volcanic ash. Furthermore, it can be indicated that for this ecotope and others like it, relatively high values of gravimetric moisture and organic matter can be expected, while total porosity is in the range of 53 to 70% and infiltration is considered moderate to moderately rapid. .

CONCLUSIONS

In general, it can be stated that greater resistance to penetration in coffee-only coverage does not seem to be generating negative effects on the crop, although the values found in all coverages evaluated here exceed those reported in other coffee-growing areas of the country, which, most often, are influenced by volcanic ash. This behavior is confirmed by the highest apparent density values found for coffee and alder coverings.

There was a tendency towards greater thickness in the A horizon, greater total organic matter content, greater total porosity and greater moisture content in the pasture cover (these last two variables being significant at the depth of 0-15 cm), which seems to indicate that there are different conditions for biomass production. This is attributed to the location of the lot where this cover is located in a concave area that favors the accumulation of water and organic material.

Significant correlations were found between soil density, humidity and total porosity, although not in all study variables, a behavior that can be explained, among other factors, by the presence of expandable clays in this sector of the 314th ecotope and which, to date, it had not been reported in soils in the coffee growing zone.

The highest value of infiltration capacity was found for the agroforestry cover with more alder, which would indicate the concrete beneficial effect of having a cover like this on the plot, substantially improving the entry of water into the deeper areas of the soil profile and enabling coffee production, mainly due to the impact that the producer attributes to the quality of his coffee.

Integrating the findings of this work, it can be stated that, under the organic agronomic management of the crop with the agroforestry cover of coffee and alder, it would be contributing to solving the difficulties that can be generated by the relatively high values of resistance to penetration, apparent density and clay-loam texture, characteristic of this sector of the ecotope and which, in principle, are not favorable to coffee growing.

RECOMMENDATION

It would be advisable to deepen the understanding of soil porosity by carrying out a texture or particle size distribution test using the traditional Bouyoucos test, or better yet, the pipette test, for each of the horizons sampled in the soils of each cover. Likewise, it would be advisable to implement tests that allow macro and microporosity to be discriminated, such as the equivalent humidity test (IGAC, 2006) or the Pla test, suggested by Jaramillo (2002) and tests that allow determining the COEL as a measure of volumetric expansion capacity of the soil.

THANKS

The authors would like to give very special recognition to Professor César Augusto García Valbuena, who facilitated the logistics of the field evaluation and clarified many aspects of the silvicultural management of the treatments, and to Professor Erick Giovanni Osorio, who provided us with invaluable statistical advisory support.

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