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Soil Electrochemical and Physical Properties in Coffee Crops in the State of Paraná, Brazil

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Abstract

In aerated soils, pH is considered to control available nutrients to plants. Also, pH is related to soil charges and is a key property expanding double layers of colloids. These electrochemical properties are affected by soil management and are related to soil physical properties like water-dispersible clay, aggregation indexes, and infiltration rate. Water-dispersible colloids are the fraction of clay that disperse in water and are affected by nature of soil including mineralogy of clay fraction, soil management in terms of crop sequence, application of organic manures, field traffic, and mechanical stress by time of shaking for the analysis. Traffic of machines, soil tillage, and weed control methods are the main causes of change in soil physical properties in coffee crop. However, management of soil acidity with limestone and use of gypsum also can change soil physical and electrochemical properties, which are related with dynamic processes like soil air and hydraulic permeability into soil which are essential to root development and growth. Therefore, soil management in coffee crops requires comprehension of the effects of changes in soils caused by addition of amendments like limestone and gypsum, traffic of machines, and weed control methods on behavior of soil properties for better management.

Keywords: *Coffea arabica* L., point of zero charge (PZC), water-dispersible clay, soil-water retention, soil structure, weed management

1. Introduction

Crop production is more problematic in tropical and subtropical climatic conditions than in temperate humid climates [1]. These authors highlighted that many cultivated plants derive from regions which are ecologically different from their present region of production. When competing with weeds which have become properly adapted to their habitat, these crops cannot survive without protection and assistance from the farmer.

Brazil is the greatest exporter of coffee and second consumer of the product in the world. Currently, the land area cultivated with coffee is 1.84 million of hectares,

the total 1.47 million of hectare ($\approx 80\%$) being cultivated with *Coffea arabica* L. species and 373.33 mil hectares ($\approx 20\%$) with *Coffea canephora* Pierre (Secretary of Agricultural Policy in the Ministry of Agriculture, Livestock and Food Supply—MAPA, 2019).

In the state of Paraná, most coffee plants are cultivated in high coffee population density system (>5000 plants per hectare) which guarantees the coffee farmers higher productivity by hectare [2] in soils derived from basalt with high iron content (Fe_2O_3 higher than 18 dag kg^{-1}). In these soils, the workability is easier, and the drainage is usually very good [3]. On the other hand, in the high coffee population density, spacing between coffee rows is $2\text{--}3.2 \text{ m}$ and $0.5\text{--}0.75 \text{ m}$ between the plants in the lines, which compromises the mechanization of operations to management and harvest.

Soil slope is another important factor that compromises the mechanical operations and coffee management besides coffee planting spacing. In a previous study done in the climatic zoning of the State of Paraná for the cultivation of coffee (Figure 1), Höfig and Araujo-Junior [3] showed that 89% of the land area are not limited to mechanization by the criterion of soil slope classes.

Considering mesoregions of the State of Paraná, the northwest has the smallest area with a slope higher than 20% and therefore the greatest potential for mechanization of coffee plantations. On the other hand, in the Pioneer

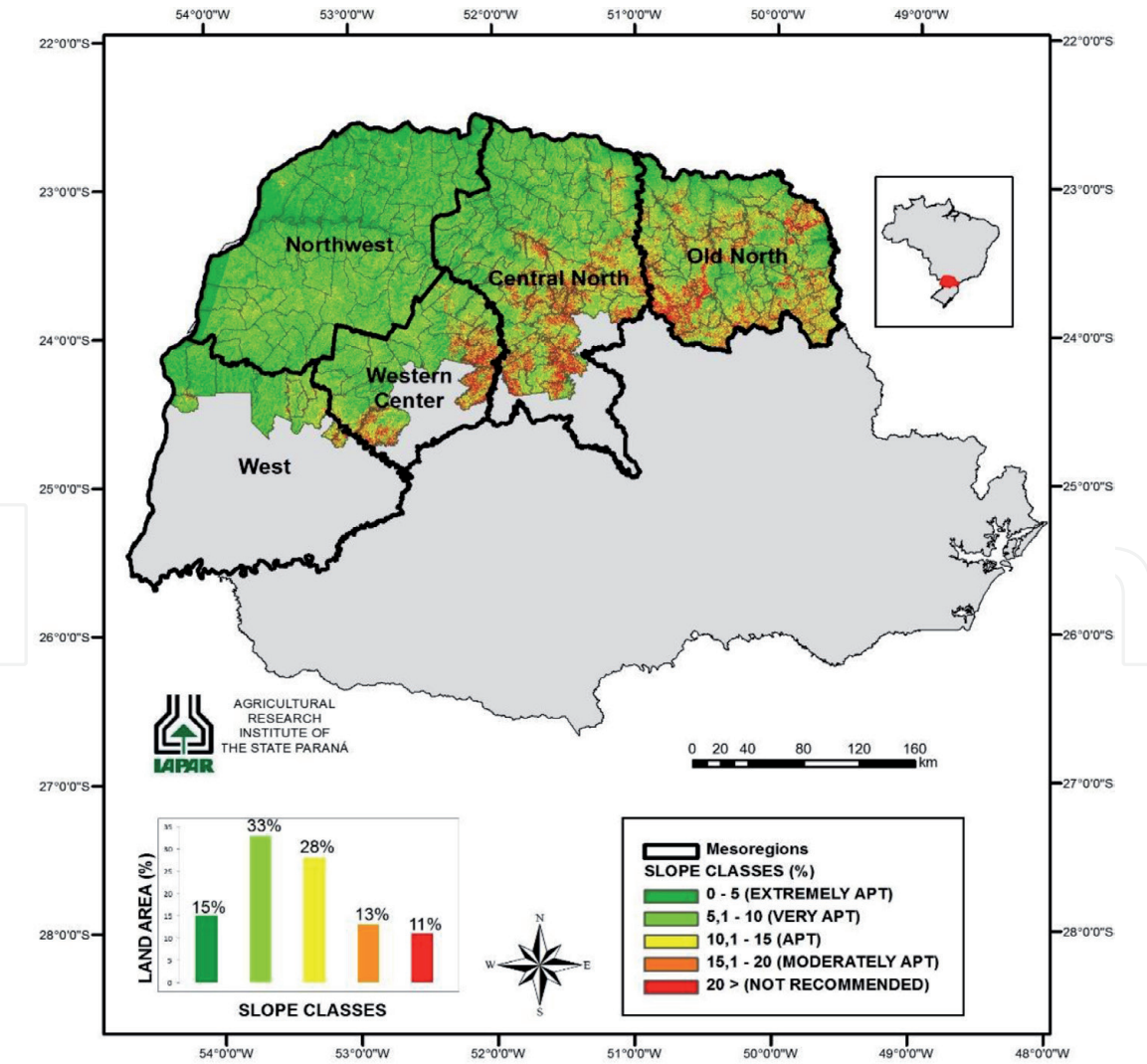


Figure 1. Map of the State of Paraná with slope classes and potential for mechanization in the area with climatic zoning to cultivate coffee. Source: Höfig and Araujo-Junior [3].

Northern mesoregion, which currently has about 37% of coffee plantations in the State of Paraná and has great technological potential due to edaphoclimatic characteristics for coffee cultivation, 10% of the area is not recommended for mechanization based on soil slope classes, which represents an area of 160,000 hectares.

Besides mechanization, the addition of soil amendments like limestone and gypsum and weed control methods affects the behavior of soil properties. In long-term experiments conducted in different coffee regions of Brazil, the effects of weed control methods on soil attributes have been proven.

Weeds when properly managed in both row and interrow areas can become allied with the coffee farmer without compromising crop yield. On the other hand, when the weed is constantly controlled with pre-emergence herbicide, soil surface is exposed to direct raindrop impact which can form soil crusting that makes water infiltration more difficult. As a consequence of surface soil crusting, runoff is increased, and hydric soil erosion must be a problem.

Research results have shown that weed management modifies soil resistance to compaction and can minimize damage caused by machine traffic on the soil as well as assisting soil and water management and conservation by providing benefits for accelerated water erosion.

In this chapter of the book, we presented that soil physical and mechanical properties are essential to the assessment of the effect of anthropogenic activities on natural resources and may help coffee farmers to obtain an optimum soil environment for plant growth. Due to that, this chapter characterizes the soil physical properties in coffee crops in the State of Paraná, Southern Brazil.

2. Soil electrochemical and physical properties in coffee crops

Soil physical properties are essential to comprehension of the behavior of the soil when submitted to mechanization. Among the physical properties, the water content in the soil profile determines the reaction to tillage, and soil moisture is the most important for soil-machine interactions, since it controls the consistency of the soil [4] and governs the amount of soil deformation when subjected to external pressure [5].

In aerated soils, pH is considered to control available nutrients to plants. Also, pH is related to soil charges and is a key property expanding double layers of colloids. Points of zero charge (PZC) are pH values associated with specific conditions imposed on one or more surface charge densities of an electrified interfacial region between a soil solution and soil solid phase [6]. Point of zero charge indicates the pH at which the net surface charge on variable charge surface is zero [7].

The surface charge density is the most important physical characteristic of an electrified interface. It can be defined as the number of coulombs per square meter borne by surface functional groups, and it depends in sign and magnitude on the composition of the soil solution and structure of the solid phase to which the functional groups are bound [6].

PZC was estimated from pH-H₂O and pH-KCl (1 mol L⁻¹) through Eq. (1). According to these authors, ΔpH is the electrochemical soil properties that most affect the dispersion. When ΔpH tends to zero, charges are balanced with less dispersion.

$$\text{PZC} = 2 \text{pH}_{\text{KCl}} - \text{pH}_{\text{H}_2\text{O}} \quad (1)$$

where PZC is the point of zero charge, dimensionless; pH_{KCl} is the hydrogenionic potential determined in potassium chloride solution (1 mol L^{-1}); pH_{H_2O} is the hydrogenionic potential determined in water.

$$\Delta pH = pH_{KCl} - pH_{H_2O} \quad (2)$$

These electrochemical properties are affected by soil management and are related to soil physical properties like water-dispersible clay, aggregation indexes, and infiltration rate.

Water-dispersible colloid (WDC) is generally recognized as the fraction of clay that disperses in water. Dispersion is the ultimate state of breakdown that results in release of clay particles as a consequence of expanding double layers and dominating repulsive forces [8]. WDC is affected by the nature of soil including mineralogy [9–11], clay content and application of sewage sludges [7], soil management [8] in terms of crop sequence, application of organic manures [12, 13], soil tillage, and traffic [14] which have been shown to affect dispersion-flocculation of clay in soil structural elements.

Besides liming and gypsum on coffee crop, soil organic matter may have a dispersive or aggregating effect according to the quantity and quality of the fertilizer [12]. These authors observed that the addition of manure at the doses of 23 g kg^{-1} and 30 g kg^{-1} provided dispersion of the clay fraction in electropositive *red-yellow* Latosol caused by negative electric charge balance.

3. Mechanization in crops with high coffee shrub population density

In coffee plantations, mechanization has emerged as an alternative in reducing production costs, operating income, and reducing labor hardness. However, for the preservation of natural resources (soil and water), soil and machinery management becomes essential to minimize the effects of anthropogenic actions on the soil. Within these aspects the coffee farmers can reduce the axle load and the contact pressure of the tires with the soil and use management systems that contribute to the deposition of organic matter, as soils with greater aggregation support more load and the organic matter relieves stress exercised by agricultural machinery.

Soil stress exerted by tires or tracks of machines on soil interface can be assessed according to machine characteristics and soil attributes [15]. These authors modelled soil stress through the software Tyres/Tracks and Soil Compaction (TASC) version 3.0 [16].

TASC version 1.0 was used for the first time in Brazil in a long-term weed control method experiment to assess the effects of weed control on soil load-bearing capacity and the impact of a coffee tractor on soil stresses [17]. In this study, a coffee tractor Valmet[®], model 68, with a power rating of 44.9 kW (61 hp), a total weight of 38,245 N (3900 kg), front tires of 6.16 at inflation pressure 172 kPa, wheel mass of 683 kg and rear tires of 12.4 R28 at inflation pressure 124 kPa, and wheel mass of 1.365 kg was used for coffee management and mechanical weed control.

The contact area at soil-tire interfaces ranged from 0.0381 m^2 for the front tire to 0.1328 m^2 for the rear tire 12.4 R28 [17]. The ground average contact pressure at soil-tire interface ranged from 101 kPa to 176 kPa, with the highest occurring for the front tires. As highlighted by Guimarães Júnnyor et al. [15], the ground average contact pressure depends on the tire type, tire structure, tire sizes, wheel load, inflation pressure, and soil stiffness.

The State of Paraná (**Figure 1**) is located between the coordinates 22°30' and 26°30' S latitude and 48° and 55°W longitude within a region of climatic transition, from north to south, with regional and local variation due to altitude and topography. However, the recommended area to coffee cultivation in the State of Paraná [18] is located between the coordinates of the southern latitudes 22°51'50", 24°76'70" west longitude, and 49°55'30" to 54°34'20" from Greenwich (**Figure 1**).

High coffee shrub population density system (higher than 5000 shrubs per hectare) was developed in the State of Paraná by the Agronomic Institute of Paraná (IAPAR) to improve coffee yields and to provide economic benefits to coffee farmers; soil and water conservation also helps coffee shrubs after frost damage.

In Londrina in the State of Paraná, in an experiment conducted between 1976 and 1981 to determine the effects of spacing between plants in the row (4 m × 1 m and 4 m × 2 m), Siqueira et al. [19] concluded that irrespective of coffee cultivars (Catuaí Vermelho LCH 2077-2-5-81 and Acaíá LCP 474-4) or hybrid Icatu H 4782-7 AMBR (*Coffea arabica* vs *Coffea canephora* Pierre) the coffee yields per area increased with decreases of spacing between plants 2 m and 1 m [19].

In addition to crop response, coffee shrub population density system promotes improvements in chemical, physical, and biological soil attributes [20].

4. Liming and gypsum on clay fraction flocculation and soil particle aggregation

Soil correction by liming and/or gypsum has a significant influence on the soil physical and water properties [9, 21–26].

Liming by applying limestone–calcium carbonate [$\text{Ca}(\text{CO}_3)_2$] or magnesium carbonate [$\text{Mg}(\text{CO}_3)_2$] is the soil management practice used to correct excessive soil acidity. In addition to correcting acidity, lime application in soils is able to provide calcium and magnesium, provide nutrients, and neutralize excess aluminum and soil manganese that are toxic to plants [20, 22].

Gypsum applied on the surface of soil columns with dimensions of 0.6 m in height by 0.3 m in diameter provided increases in Ca contents and decrease in exchangeable Al contents, consequently favoring the root growth of deep coffee seedlings [27]. These authors also pointed out that the superficial application of the gypsum– CaSO_4 –was more efficient than CaCO_3 incorporated at 0.3 m depth due to the higher root growth in depth as a result of the exchangeable calcium increase and aluminum reduction in the subsurface ground.

In the long term, both liming and gypsum can contribute to reducing the risks of erosion in coffee-cultivated LVdf, especially under conditions without green cover between rows and with uncovered soil. In a typical Distroferric Red Latosol (LVdf) (Rhodic Hapludox), very clayey texture cultivated with coffee shrubs in Londrina, Northern State of Paraná, liming and gypsum had positive effects on soil aggregation and consequently on the water infiltration rate in the soil profile 2 years after corrective application [21].

On the other hand, the short-term incubation studies (3 months after limestone application), using samples from an LVdf from Londrina, Castro Filho and Logan [9], found that the aggregates were stable in water up to the pH value in CaCl_2 equal to 5.7. On the other hand, when pH values exceeded 5.7, they reduced the stability of the aggregates in water.

5. Electrochemical properties of an Oxisol cultivated with coffee crop and its relationship with flocculation-dispersion of colloids and aggregates

5.1 Water-dispersible clay

Water-dispersible clay is the fraction of clay that disperses in water, and dispersive soils are common problematic soils in many parts of the world [14]. Due to fact that dispersible clay blocked soil porous system and compromise the water and gas movement, this soil property has been used in studies of hydric erosion and soil management.

In a long-term experiment conducted at experimental station of the IAPAR in Londrina, PR submitted to seven different weed management in the interrow area (between coffee row), weed managements in the interrow area did not affect the point of zero charge. The experiment was installed in randomized complete block design, seven treatments with four replicates. The soil in the experiment site is classified as Typical Dystroferic Red Latosol, very clayey texture (80 dag kg⁻¹ clay) with kaolinitic mineralogy derived from the saprolites from basaltic rocks. The weed management were as follows: T1, hand-hoe weeding (HAW); T2, portable mechanical mower (PMOW); T3, herbicides (HERB); T4, cover crop peanut horse (CCPH); T5, cover crop dwarf mucuna (CCDM); T6, no-weeding control in the interrow area (SCAP); and T7, weed check (CHECK) (no-weed control in the row and interrow area). Soil samples were collected at 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm depths. Soil electrochemical properties were determined: pH in relation 1:2.5 soil/solution in a 0.01 mol L⁻¹ CaCl₂, KCl, and water and point of zero charge (PZC). Water-dispersible clay was determined by pipette method without chemical dispersion shaker for 2 h.

However, the estimated point of zero charge changed among the soil sample depths (**Figure 2**). The estimated PCZ values were 4.2 (StDv. 0.54), 3.6 (0.54), 3.7 (0.29), and 3.7 (0.37) lower than the pH in all depths which contribute to excess in negative charge. When soil pH is higher than PZC, there were electrostatic repulsion and drop in clay flocculation [7].

For soil samples collected at county Londrina, Northern Paraná in Native Forest at 0–20 cm depth of a Red Latosol with very clayey texture (72 dag kg⁻¹), incubated with limed sludge with doses 1.5–24 g kg⁻¹, Tavares Filho et al. [7] observed after 180 days incubation in pots in the greenhouse PZC 4.8–5.03; delta pH –0.22 to –0.15; and water-dispersible clay 66–128 dag kg⁻¹; soil samples were shaken in an orbital shaker at 300 rpm for 3 h.

Weed management in the interrow area of coffee crop changes delta pH ($p < 0.001$) for a Dystroferic Red Latosol, very clayey at 0–10 cm depth. The highest values were found for T6 no-weed control between coffee rows ($\Delta\text{pH} = -0.57$) = T1 hand weeding ($\Delta\text{pH} = -0.68$) = T7 weed check ($\Delta\text{pH} = -0.72$) and lowest for T2 portable mechanical mower ($\Delta\text{pH} = -0.80$) = T3 herbicides ($\Delta\text{pH} = -0.93$) = T4 cover crop peanut horse ($\Delta\text{pH} = -0.80$) = T5 cover crop dwarf mucuna ($\Delta\text{pH} = -0.78$).

Changes in ΔpH affected the water-dispersible clay (**Figure 3**).

With the aim of to investigate the effect of liming on chemical and physical properties of three very fine, ferruginous, isothermic Rhodic Hapludox with different levels of organic carbon, Castro Filho [6] observed that pH affects positively the aggregate stability indexes. This author also suggested that aggregate stability depends on the soil mineralogical composition and the highest aggregation occurred nearly 100% of Al neutralization.

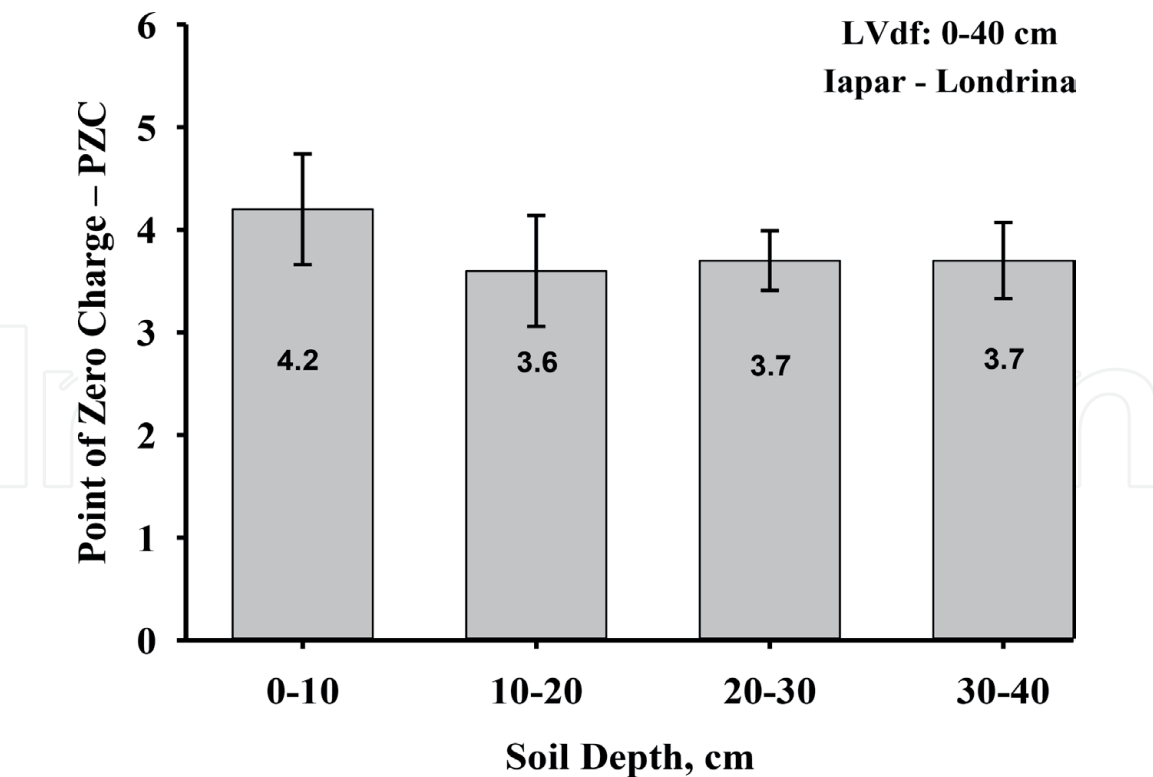


Figure 2.
Point of zero charge (PZC) in four layers of a Red Latosol cultivate coffee.

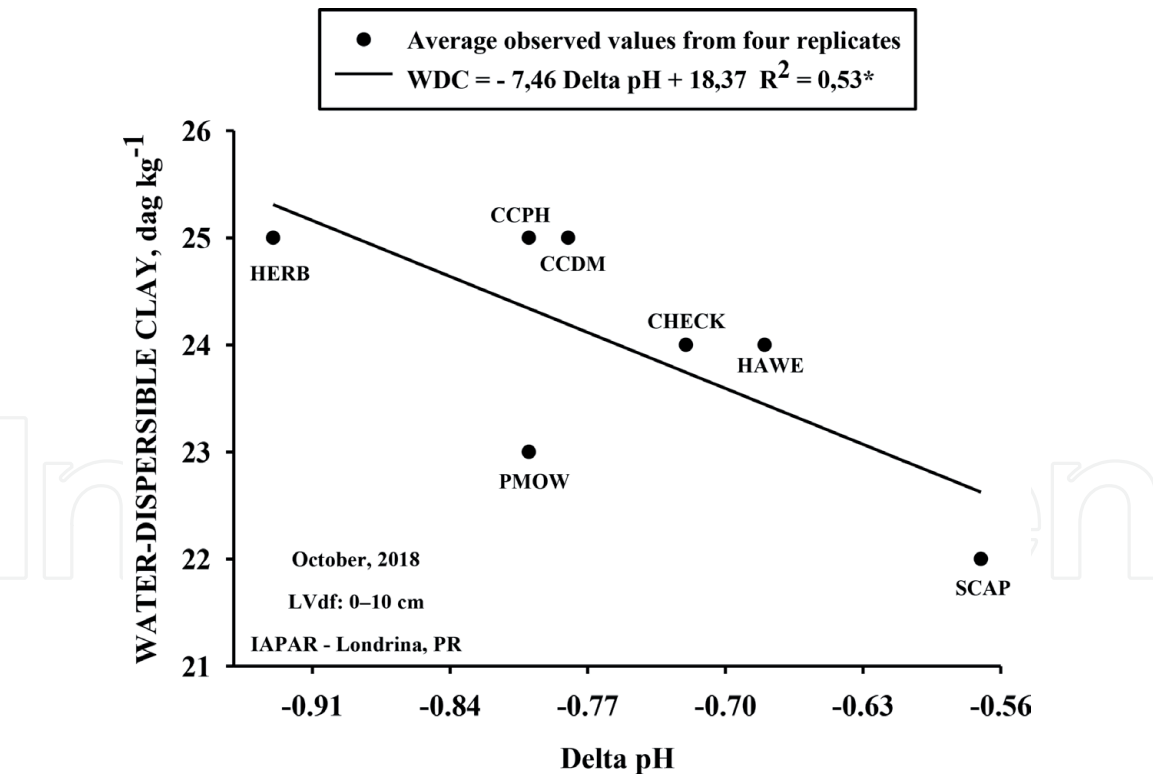


Figure 3.
Water-dispersible clay in relation to delta pH of a Dystroferric Red Latosol cultivated with coffee crop submitted to weed management in the interrow area. HAWE, hand weeding; PMOW, portable mechanical mower; HERB, herbicides; CCPH, cover crop peanut horse; CCDM, cover crop dwarf mucuna; SCAP, no-weed between coffee rows; CHECK, no-weeding in the interrow and row areas.

As can be observed in **Figure 4**, mean weight diameter increased as soil pH. Mean weight diameter (MWD) is large if the soil has a high percentage of large aggregates [6].

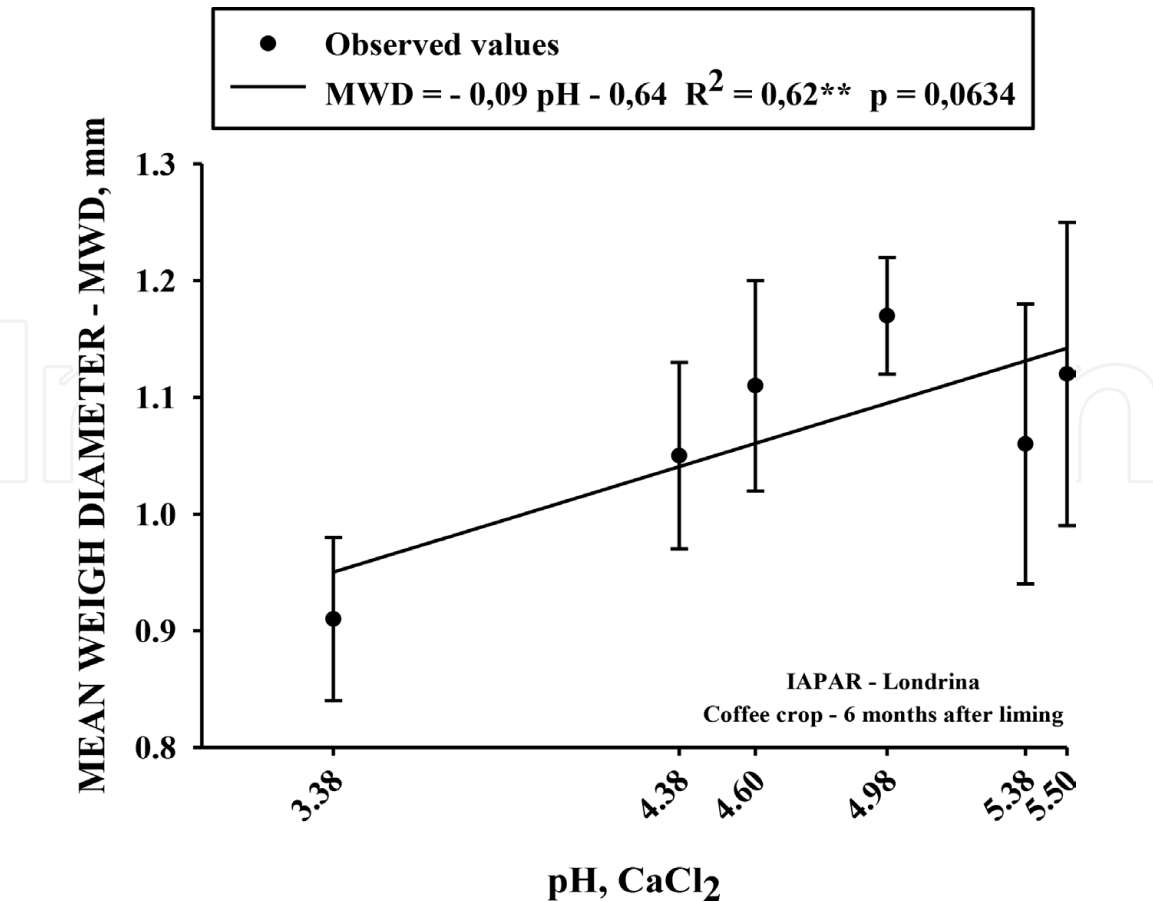


Figure 4.
Mean weight diameter (MWD) of the aggregates of a Red Latosol cultivate coffee 6 months after liming.
Source: From Roth et al. [21].

Soil organic matter and soil pH (**Figure 3**), whose mechanisms involved depend on the substitution of aluminum by calcium in the sortive complex, participate in the soil aggregation whose formation and stabilization of the different classes of soil aggregate sizes will allow more or less lower aggregation, resulting in greater or lesser soil loss [9].

In a field experiment conducted in a Rhodic Hapludox cultivated with coffee, 2 years after the surface liming, Roth et al. [21] highlighted that the aggregation of solid particles exerts a significant action on soil susceptibility to accelerated water erosion for uncovered soil conditions. This study showed that after 60 min of simulated rainfall at an intensity of 60 mm per hour, soil maintained without soil correction with pH = 5.2 provided total infiltration of 56% of the total precipitation [21]. On the other hand, the authors observed that the best liming treatment to increase pH 7.0 provided 83% of total infiltration. In soil with pH 6.0 and with the application of plaster, the total infiltration was 67% of the total precipitation.

6. Conclusions

Traffic of machines, soil tillage, and weed control methods are the main causes of change in soil physical properties in coffee crop. However, management of soil acidity with limestone and use of gypsum also can change soil physical and electrochemical properties, which are related with dynamic processes like soil air and hydraulic permeability into soil which are essential to root development and growth.

Weed management in the interrow area of coffee crop changes delta pH for a Dystroferric Red Latosol very clayey at 0–10 cm depth. Changes in Δ pH affected the water-dispersible clay.

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Conflict of interest

The authors declare that there is no conflict of interest anyway including that they are not members of the academic editors in Intech and members of an organization that could benefit financially or materially from the publication of their work.

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