Hydric Soil Properties of Agroforestry Coffee Plantations in Peru

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Abstract

Suitable hydric and aerial soil properties of the habitat are very important for its stable and sustainable development and significantly determine the state of current and future natural ecosystems. These are characteristics that can be modelled into a more desirable and favourable state through the appropriate application of management practices and overall management settings. Agroforestry systems combining the aim of balanced production while maintaining favourable microclimatic conditions appear to be a proper way of nature-friendly farming and a suitable adaptation of intensive agriculture to ongoing climate change. The aim of the research was to evaluate the soil properties in different depths of three landuse types in Peru. The research plots were in natural forest stands, pasture areas and agroforestry coffee plantations. Soil samples were collected and subsequently processed in the form of Kopecky physical cylinders for evaluation of hydrostatic soil properties. The evaluated soil hydrolimits were compared with the actual soil moisture state determined by a moisture sensor. Based on the evaluated results, the most favourable soil hydrophysical properties were found in the soil environment of natural forest ecosystems. Soil environments of pasture and agroforestry coffee plantations were comparable according to the mostly unfavourable results of the evaluated properties. Thus, the result of the conducted research clearly demonstrated the influence of landuse type on the state of hydrophysical soil properties. Similarly, the influence of landuse type on the amount of soil carbon content and its positive effect on the state of hydrophysical soil properties has been confirmed.

Keywords: *soil environment, physical soil properties, landuse, agroforestry coffee plantation, pasture, forest stand, soil carbon content*

1 Introduction

The soil environment of natural ecosystems can be characterised as a sequence of superimposed layers of different physical and chemical properties, which is formed by a very long-term process under the influence of biotic and abiotic factors (Van Breemen, Buurman, 2002; Vavříček, Kučera, 2017). Soil properties have a very significant influence on the growing conditions of the tree species or in some cases also of other crops (Onwuka, Mang, 2018; Zanella, *et al.*, 2011). One of the soil properties that is very important for the proper development of the ecosystem grown is hydric regime, i.e. in particular the soil water content (Ritchie, 1981).

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Enough water available to the roots of a plant is necessary to cover all its physiological needs and life processes, of which the process of photosynthesis is a typical example (Porporato *et al.*, 2004; Špinlerová, 2014). The soil water content is primarily influenced by the physical and chemical properties of the soil itself, but it is possible to optimise the water content to a very high degree by appropriate cultivation interventions and methods of habitat use that are gentle and close to the natural ecosystem development processes (De Frenne *et al.*, 2021; Bonan, 2008). The overall character of the natural ecosystem, and particularly the degree of canopy cover, indicates the prevailing microclimatic conditions such as temperature, airflow, total precipitation falling on the soil surface or evapotranspiration rates (Von Arx, *et al.*, 2012; Avila, 2001).

Inside of the forest stands and agroforestry systems, it is the presence of tree cover layer and the influence of the physiological processes of the trees present that leads to the creation of a specific microclimate (Maclean, Klinges; 2021). The microclimate of these systems is typically characterized by a more favourable and balanced temperature with limited occurrence of temperature extremes, a significant reduction in evaporation or limitation and consequent total solar radiation penetrating the stand canopy (Shankar, Garkoti, 2023; Wojkowski *et al.*; 2022; Wojkowski *et al.*, 2023). These microclimatic conditions are generally perceived as ecologically more favourable for the proper functioning and development of natural ecosystems and for maintaining their ecological stability and sustainability (Devi *et al.*, 2023). On the other hand, the removal of the cover layer leads to significant changes in the microclimatic conditions of the habitat, especially in the space just above the soil surface. This change in conditions is also associated with a subsequent increase in the effect of stress factors. The consequent microclimatic conditions lead to overheating of the uppermost layers of the soil environment. These changes lead to an increase in evaporation of water from the soil and thus to a disturbance of the water balance (Kovács *et al.*, 2020). The process of humification is also negatively affected (Pirastru *et al.*, 2013).

In the case of pasture areas, the character of herbaceous vegetation is also affected. In general, species-poorer ecosystems of lower plants are created and these areas are characterised by lower cover (Alaoui *et al.*, 2011). In addition to the effect of grazing on the character of the vegetation, there is also a marked effect on the soil environment itself, where the mechanical soil compaction process occurs due to the movement of cattle over the area (Teague *et al.*, 2011).

The presence of trees on agricultural land in agroforestry systems has generally rather positive effects on soil properties (Houška, 2022). The influence of trees is mainly through an increase in organic matter and the activity of root systems. Both effects of the trees presence lead to more favourable values of the physical properties of the soil, better infiltration of water into the soil environment and also significantly eliminate soil compaction (Ghestem, *et al.*, 2011). With a balanced density of trees and their appropriate spacing, an ideal ratio between evaporation, transpiration and surface runoff is also achieved, which generally has a positive effect on soil hydric properties and the water cycle (Alkmade *et al.*, 2009).

2 Material and Methods

Totally nine transects of the research plots (three transects per each of three different landuse types) were located at agroforestry coffee plantations, pasture areas and nature forest stands around the town of Oxapampa, Pasco region, Peru (10.5744336S, 75.4044786W).

The climate of Oxapampa surrounding area is characterized by a warm and temperate climate. According to the Köppen and Geiger classification, this type of climate is referred to as Cfb. Average annual temperatures range from 14–15 °C. Annual rainfall often exceeds 3500 mm, the rainiest months being January and February with monthly rainfall between 450–500 mm (Aronson, 2022).

2.1 Soil sampling and laboratory analysing

Soil samples were taken during January and February of year 2024 in the form of 100 cm^3 volume Kopecky physical cylinders from depths of 0–5 cm, 5–15 cm, 15–25 cm and 25–35 cm. The evaluation of selected soil hydrolimits is based on the analysing processes presented in the literature Lesnická pedologie by Klement Rejšek (1999). During the laboratory analysing of the soil samples the values of field capacity (FC), water retention capacity (WRC), wilting point (WP), maximum capillary water retention capacity (MCR), utilisable water content (UWC) and minimum air capacity (MAC) were determined according to the above-mentioned methodology. The soil texture was determined according to the pipetting method described in the literature Analýza půd I by Jiří Zbíral (2002).

2.2 Data analysing

Soil retention curves were constructed for all soil samples using ROSETTA, a module of RETC version 6.0, and the SSCBD+water content at 33 kPa (TH33) module was used for evaluation. This calculation module takes as input the percentages of sand, silt and clay determined by the pipetting method. This evaluating process is based on the methodology presented in Schaap *et al.* (2001) and van Genuchten *et al.* (1991).

The amount of soil carbon was determined using a CHNS vario MACRO cube elemental analyzer. The soil sample was analyzed by the CNS module. The analysis of the total elemental abundance was carried out on the principle of "dry burning", where the soil sample is burnt at a temperature of at least 1200 °C.

Statistical evaluation of the results was performed by using Statistica analytical software, version 14.00.15, from TIBCO Software Inc, using basic statistical tests such as the Shapir-Wilk test for data normality and the Kruskal-Wallis Anova and median test. The confidence level of results was set at value of 0–0.05.

3 Results

In all cases of above-mentioned selected soil hydrolimits, the most favourable values were found for soil samples sampled from the soil environment of forest ecosystems at all investigated depths. Comparing the other two landuse types, comparably unfavourable values of physical soil properties were found. In some cases, the pasture areas appeared to be more favourable soil environment according to the evaluated results. Thus, in general, in most cases the soil environment of agroforestry coffee plantations was the least favourable. Generally higher values of soil hydrolimits can be inferred from the depicted soil retention curves in the soil environment of forest stands (FS) and, in some depths, also in pasture areas (P). The higher soil water holding capacity is based on the retention curve course also evident in the case of forest stand and pasture soils. These soils are still characterised by stable soil moisture values over a longer period, even at higher values of suction pressure. On the other hand, the lowest soil moisture values and the least favourable curve shape indicating low soil water holding capacity can be seen in the case of soil samples from the agroforestry coffee plantation (CP) (Figure 1).

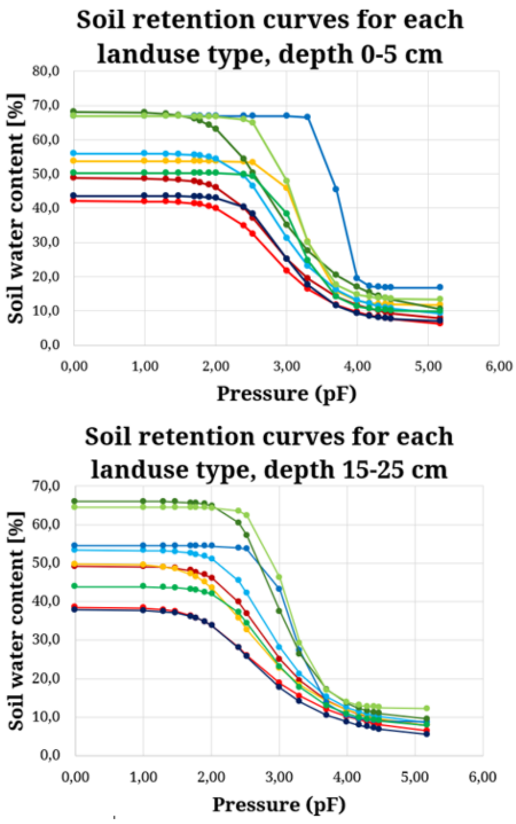

Fig. 1: *Soil retention curves for each landuse type and all depths*

Similar results were also found for the assessment of soil porosity. The most favourable soil porosity values at all evaluated soil profile depths were found in the natural forest stands. In contrast, the lowest soil porosity values were typical for the soil environment of agroforestry coffee plantations in all depths. The Figure 2 below shows the values of utilisable water content (UWC) at each evaluated depth.

The research also included an assessment of the total carbon content (TCC) in the soil environment of each landuse type. The carbon content values were found, then compared with the corresponding values of the other soil properties assessed and, in all cases, positive correlations were found. Thus, it is true that higher soil carbon content has a positive effect on the increase of soil physical properties values and with increasing soil carbon content, the values of the soil parameters under consideration also increase. A statistically significant relationship was found for the relationship between total carbon content and full water capacity, maximum capillary water capacity, water retention capacity and utilisable water capacity. In the case of the relationship of wilting point and minimum air capacity with total soil carbon content, a positive correlation was found, and higher carbon content also had a positive effect on the values of these soil properties. However, in these two cases the relationship was not statistically significant. According to this result, more favourable soil properties can be expected in soils with higher carbon content. During the research evaluation, higher values of TCC at all assessed depths were found in the soil environment of forest stands (Figure 3).

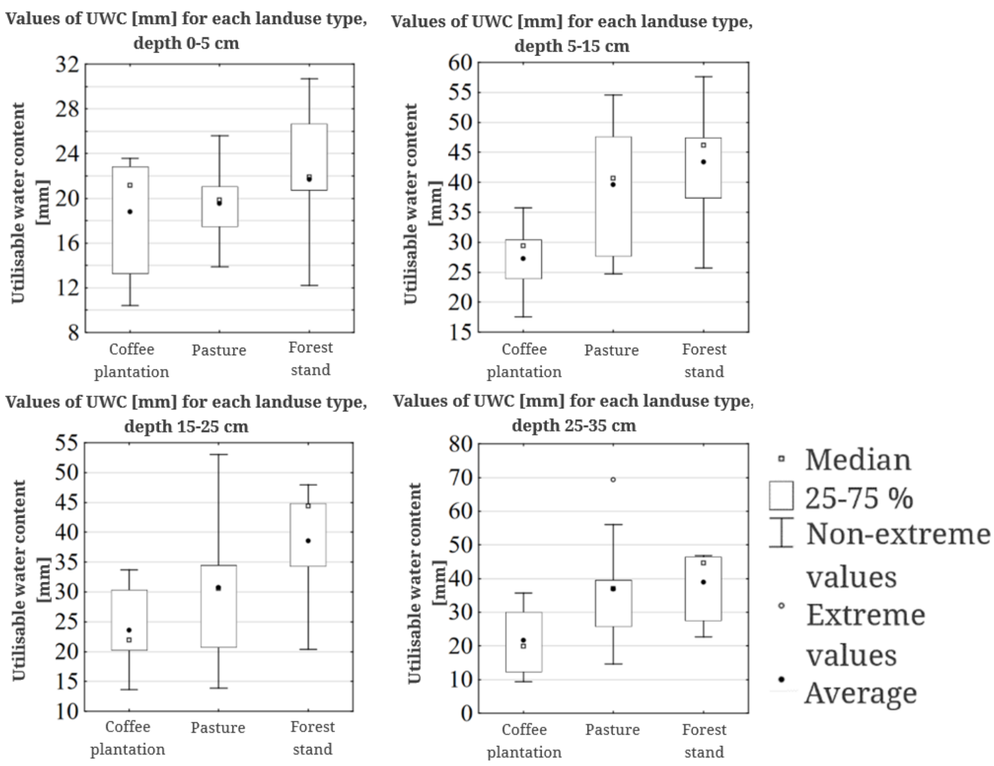

Fig. 2: *Values of UWC [mm] for each landuse type and all depths*

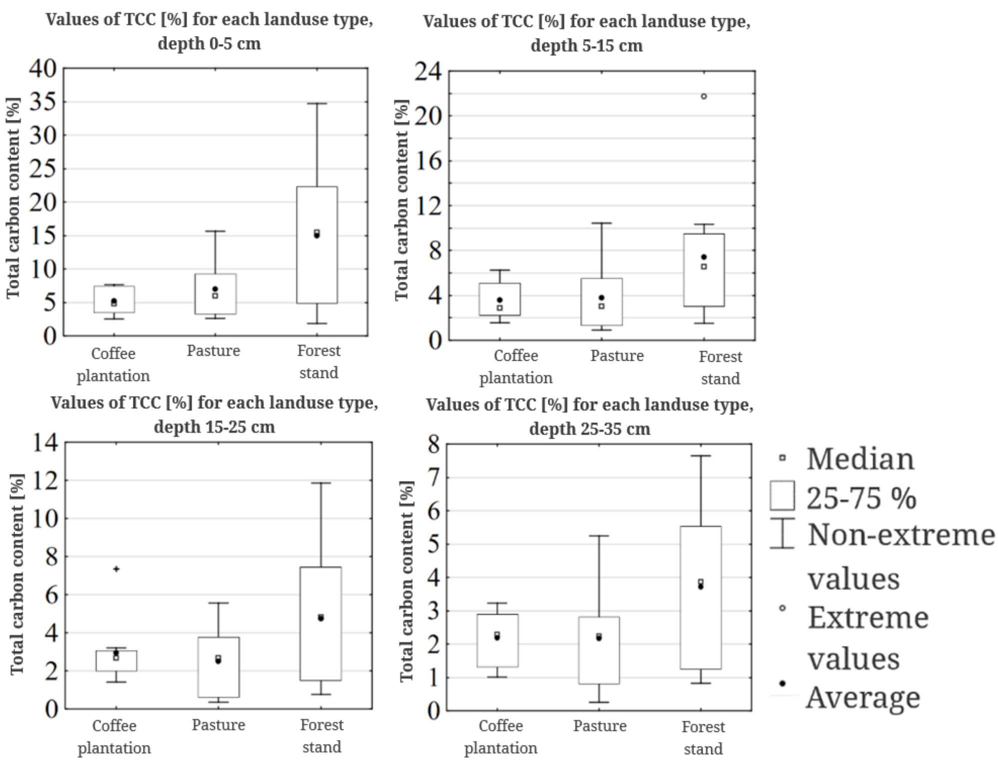

Fig. 3: *Values of TCC [%] for each landuse type and all depths*

4 Discussion

The management of natural ecosystems brings many specificities and the need for an individual approach, based mainly on the high degree of variability of natural conditions that must be dealt with. In particular, the overall topography of the terrain and the associated skeletal content or specific species and spatial composition of the habitat must be considered. All these mentioned factors also had an influence on the individual ecosystem's characteristics of the individual research plots.

Considering the topography of the terrain, the importance of slope sites is particularly evident in relation to material erosion, water runoff, and therefore the overall character of the soil environment (Fu *et al.*, 2011; Kinnell, 2000). Otherwise, the effect of soil compaction on the flat terrain of pasture areas is further enhanced by compaction caused by cattle movement (Šarapatka, Niggli, 2008).

In general, a negative influence of higher skeletal content on hydrophysical soil properties can also be confirmed (Rejšek, Vácha, 2018; Vavříček, Kučera, 2017). On the other hand, a higher skeleton content in the soil environment should result in more favourable values of soil air properties (Danalatos *et al.*, 1995), but this was not proven in the research.

From a forestry point of view, the significant influence of the tree composition of the habitat on its soil properties cannot be overlooked. Each woody species influences the conditions of the soil environment through its litterfall and its subsequent decomposition (Augusto *et al.*, 2002). In general, the litterfall of broadleaf species is perceived as more favourable (Kacálek *et al.*, 2017). In the case of the research carried out, it is possible to assess the influence of two different tree cover types on a general scale in relation to agroforestry systems, namely the influence of Pinus tecunumanii with Pinus oocarpa and then the influence of Inga edulis, which is generally known for its good ameliorative function and is often used as a shade tree in agroforestry plantations (Siles *et al.*, 2010; Cannavo *et al.*, 2011). When evaluating the surface soil layers up to a depth of 5 cm, in all cases the most favourable values of physical soil properties were evaluated in the areas of agroforestry plantations shaded by the broadleaved tree Inga edulis. Thus, the positive effect of broadleaved trees can be confirmed according to the results obtained in the soil humus layers (Wahl *et al.*, 2003; Hajnos *et al.*, 2003).

Another very important factor in the evaluation of soil environmental properties is the considerable long-term nature ecosystem forming process over which the soil environment is significantly affected (Perry *et al.*, 2008). This fact is particularly evident in physical soil properties, which change much more slowly than chemical properties (Rejšek, Vácha, 2018). This fact can also be demonstrated in a model on the example of selected research sites. The agroforestry coffee plantations were established on areas historically used for cattle grazing. The change in the management of the area occurred between 15 to 20 years ago. Since then, in the context of the long-term effects of the management type on the soil environment, this is a very short period for the current land use type to have a significant impact. In fact, the achieved results of the soil conditions of the agroforestry plantation presented in this paper, when compared to the very intensive management of pastures, which is quite different from the sustainable management of natural resources and the systematic care of the conditions of not only soil ecosystems (Tubiello *et al.*, 2007), do not show more favourable results than might be expected, and in many cases the conditions found for agroforestry sites were even less favourable than those of the pasture areas. A similar situation occurred in the case of research plots located in forest stands. Two research sites were in the old-grown natural forest of the national park. One plot was established at site previously used as a coffee plantation. Young age and different vertical and horizontal structure of this forest stand may explain the least favourable values of soil properties of this research site compared to just the sites in the national park, which are typical natural forest stands (Sellan *et al.*, 2019).

5 Summary

As a result of the research, it was found that the type of landuse and management applied has a significant influence on the state of physical soil properties. In general, more favourable values of soil properties were found in the soil environment of the forest ecosystem at all assessed soil depths. On the other hand, in the case of soil samples collected in agroforestry plantation and pasture areas, unfavourable values were found for all these assessed soil parameters. It is necessary to note that the unfavourable conditions of these two landuse types were very often similar in their values. In addition, a positive effect of higher carbon content on physical soil properties has also been confirmed, and since higher carbon content has generally been found in the soil environment of forest stands, a more favourable state of soil properties can be expected on forest sites. This evaluated results therefore provide very interesting information on the effect of landuse type on soil physical properties. The implication of the results should therefore clearly be, especially in the current global climate change, to strive for the conservation of forest stands and to strive for their favourable nature resources development.

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