SOIL RESISTANCE TO PENETRATION IN AN OXISOL UNDER INTEGRATED AND NON-INTEGRATED GRAZING SYSTEMS IN SOUTHEAST BRAZIL

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ABSTRACT
In order to learn more about soil physical quality in integrated systems, this study proposed comparing soil penetration resistance in two different depths, 0 - 5 cm and 12.5 - 17.5 cm, in areas under different managements. The systems evaluated were continuous grazing (CONT), rotational grazing (ROT), integrated livestock-forest system (ICL), integrated crop-livestock system (ILF), integrated crop-livestock-forest system (ICLF), and native vegetation (NV). The study site was in an experimental unit in the Brazilian Agricultural Research Corporation located in São Carlos, Brazil, where the climate is humid subtropical, and the soil is classified as an Oxisol. Undisturbed soil samples were collected with four replicates in each system. Soil resistance to penetration (SRP) was assessed with a benchtop electronic penetrometer in which the water content was previously standardized to be equivalent to a tension of -6 kPa. Data were statistically analyzed with a two-way analysis of variance (ANOVA) followed by Tukey tests (significance level: α=0.05). Significant differences were found among the studied systems. NV presented the lowest SRP. All the agricultural systems had SRP means higher than the limit of 2 MPa.
Key words: soil mechanical resistance; integrated crop-livestock-forest systems; soil physical quality

INTRODUCTION

In recent times, the search for highly sustainable and productive agriculture systems has risen due to the challenge of feeding seven billion people and the pressure for environmental conservation (CARDOSO et al., 2013). Integrated crop-livestock-forest systems are considered prospects for sustainable agricultural intensification, combining crops, livestock, and forestry, which could be integrated into space using intercropping cultivation or in time by rotating systems (BALBINO et al., 2011). Several agronomic, environmental, and socio-economic benefits are expected from integrated systems, such as yield increase, mitigation of greenhouse gases, and a better physical, chemical, and biological soil quality (KICHEL et al., 2014).

Soil quality is a comprehensive concept related to physical, chemical, and biological soil properties or processes (CHERUBIN et al., 2015). It is generally inferred by assessing soil properties sensitive to land use and management changes (CARDOSO et al., 2013). Among soil properties, soil resistance to penetration (SRP) is an important physical indicator of soil quality, as it directly influences plant growth and crop production (LETEY, 1985).

Despite several benefits of integrated systems, there is a lack of studies investigating soil physical quality under these systems. A literature review (VALANI et al., 2021) showed that: i) only 9% of the published studies evaluated two integrated systems, and none of them compared three or more integrated systems, and ii) less than 20% of all the reviewed papers assessed integrated systems with the forest component. Therefore, there is a need to evaluate more diverse integrated systems, especially under experimental designs. This study may fill the gap in the literature about physical soil quality in integrated systems, especially in the systems with trees.

This study aimed to compare SRP in two soil layers of an Oxisol in three different integrated systems, as well as in two non-integrated grazing systems and a native vegetation area.

MATERIAL AND METHODS

The soil was sampled from an experimental unit in the Brazilian Agricultural Research Corporation located in São Carlos, Brazil. The region's climate is humid subtropical (ALVARES et al., 2013), with a mean annual temperature of 21 ºC and mean annual rainfall of 1420 mm. The soil in the area is an Oxisol (STAFF, 2014), with a clay content of about 300 g kg^{-1}, as previously described by Calderano Filho et al. (1998).

Six soil management systems were studied: continuous grazing (CONT), rotational grazing (ROT), integrated livestock-forest system (ICL), integrated crop-livestock system (ILF), integrated crop-livestock-forest system (ICLF), and native vegetation (NV). A summary of the study sites can be found in Table 1. The five agricultural systems were arranged in randomized blocks of 3 ha each, with two replicates covering a 30 ha area. Although the native vegetation was not part of the experimental design, it is essential to note that the soil type is the same as the experimental area (CALDERANO FILHO et al., 1998), and thus the native vegetation was studied as a reference for the agricultural sites.

Table 1. Summarized information about the studied sites.

ID	Establishment	Species grown	System description
CONT	< 1980	*Brachiaria decumbens*	No farm inputs, not degraded due to controlled animal stocking
ROT	2011	*Brachiaria brizantha* 'Piatã'	Liming and fertilizers are applied regularly. Rotational grazing.
ILF	2011	*Brachiaria brizantha* 'Piatã' *Eucaliptys urograndis* cl. GG100	Grass management as ROT. Trees with a spacing of 15 m x 4 m.
ICL	2011	*Brachiaria brizantha* 'Piatã' *Zea mays* 'DKR390PRO2'	Grass management as ROT. Corn was sown every three years under no-tillage with a spacing of de 0.25 m x 0.8 m, harvested for silage.
ICLF	2011	*Brachiaria brizantha* 'Piatã' *Zea mays* 'DKR390PRO2'	Grass management as ROT. Trees management as ILF and corn management as ICL.
NV	<1975	Semideciduous forest with 146 cataloged species (Silva and Soares, 2003)	Shannon-Wiener diversity index of 3.45 (Silva and Soares, 2003)

CONT: continuous grazing, ROT: rotational grazing, ILF: integrated livestock-forest system, ICL: integrated crop-livestock system, ICLF: integrated crop-livestock-forest system.

Undisturbed soil samples were taken with soil cores (5 cm of height, 97 cm^3 of volume) at two soil depths: 0 – 5 cm (topsoil) and 12.5 – 17.5 cm (subsoil) which were sampled with four replicates in each studied site. Soil resistance to penetration was assessed with a benchtop electronic penetrometer (CT3 Texture Analyzer, Brookfield, Middlebore, MA, EUA) in which the water content was previously standardized to be equivalent to a tension of -6 kPa. The equipment had a metallic rod with a cone at its end, set to penetrate the soil at a speed of 20 mm sec^{-1} down to 480 mm, with a data acquisition rate of 40 points per second, totaling 960 values for resistance to penetration in each sample. The data were filtered to include only the 600 values from the central portion of each sample.

The resulting dataset, average means and standard deviations were calculated for each system and soil depth was assessed. As the data were normally distributed as determined by the Shapiro-Wilk test ($p > 0.05$), a two-way analysis of variance (ANOVA) was performed, considering studied systems and soil depth as the two factors. The means were therefore compared by the Tukey test ($p < 0.05$). The data was analyzed by Statistica for Windows (Statsoft, Tulsa, USA).

RESULTS AND DISCUSSIONS

Considering the two-way ANOVA, significant differences ($p < 0.01$) were found between the studied systems. No differences were found between soil depths ($p = 0.92$) or interaction between studied systems and soil depths ($p = 0.29$). The lowest means for SRP was found in the topsoil of NV (0.77 MPa), while the highest mean was found in the subsoil of ICL.

Table 2. Average means and standard errors for soil resistance to penetration in two soil layers and subsoil of studied systems.

System	**Soil resistance to penetration (MPa)**		**Homogeneous subsets**
	Topsoil (0 – 5 cm)	**Subsoil (12.5 – 17.5 cm)**	
CONT	2.87 ± 0.79	2.18 ± 0.71	b
ROT	3.16 ± 1.55	2.87 ± 1.11	b
ILF	3.52 ± 1.04	3.00 ± 0.72	b
ICL	3.10 ± 0.68	4.36 ± 1.04	b
ICLF	3.47 ± 1.14	3.01 ± 0.72	b
NV	0.77 ± 0.50	1.07 ± 0.18	a

CONT: continuous grazing, ROT: rotational grazing, ILF: integrated livestock-forest system, ICL: integrated crop-livestock system, ICLF: integrated crop-livestock-forest system. The same letter in the last column does not differ by the Tukey test ($p < 0.05$).

No difference was found between the topsoil and subsoil in any of the studied systems concerning both soil depths studied. This result may be related to the soil type, an Oxisol, a soil order known as deep soils due to weathering (BIRKELAND, 1984), and therefore assessments in deeper soil layers may be needed to investigate SPR in these systems. Nevertheless, considering only absolute values, SRP was lower in the topsoil compared to the subsoil for all systems, except the integrated crop-livestock system.

No differences were found within agricultural systems (Table 2). Considering the critical limit for SPR widely suggested of 2 MPa (TORMENA et al., 1998; SILVA et al., 2008; DE LIMA et al., 2012), all systems should need amelioration to limited plant growth and development. However, considering the studied systems under no-tillage (ICL and ICLF) and the suggested critical limit for SPR in no-tillage systems of 3.5 MPa (MORAES et al., 2014), SRP in the ICLF may be considered as not limitingfor plant growth and development. The higher critical value for SRP in no-tillage systems is related to the presence of continuous and biological pores, which favor root growth even in areas with low SPR (TORMENA et al., 2007; BETIOLI JÚNIOR et al., 2012).

CONCLUSIONS

Soil resistance to penetration did not differ between the topsoil (0 – 5 cm) and the subsoil (12.5 – 17.5 cm) in the studied systems. SRP in the native vegetation was lower than all other systems. No differences were found between agricultural systems, in which SRP was always higher than the suggested critical limit of 2 MPa. Considering the critical limit of 3.5 MPa for no-tillage systems, the integrated crop-livestock-forest system may be suggested as the only agricultural system in which SRP is not limiting for plant growth and development in both assessed soil depths.

Further studies should assess different physical indicators of soil quality to contribute to the understanding of soil functioning in integrated and non-integrated grazing systems, including assessments in greater depths.

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