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Biomass Productivity and Physical Properties of the Soil after Cultivation of Cover Plant in the Autumn and Winter

Marcos Cesar Mottin[1]*, Edleusa Pereira Seidel[1], Emerson Fey[1], Jaqueline Vanelli[1], André Luiz Alves[1], Alfredo Richart[2], Jucenei Fernando Frandoloso[1], Katiely Aline Anschau[1], Marcio André Francziskowski[1]

[1]Center of Agrarian Sciences, State University of the West of Paraná-Unioeste, Campus of Marechal Cândido Rondon, Marechal Cândido Rondon, Paraná, Brazil
[2]School of Agrarian Sciences and Veterinary Medicine, Pontifical Catholic University of Paraná-PUCPR, Toledo Campus, Toledo, Paraná, Brazil

Email: *marcos.c.mottin@hotmail.com

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Abstract

The species that can be used as cover plants are many, which makes it difficult to make a choice, since there is no ideal plant, and it is necessary to make a survey of the most favorable species. The objective of this study was to evaluate the biomass productivity of cover crops in autumn and winter (*Poaceae*a and *Fabaceae*), and their effects on soil physical properties at different depths. The experimental design was of randomized blocks with subdivided plots, with six replications. The plots consisted of four cover crops in autumn and winter; two *Poaceae* (black oats and brachiaria) and two *Fabaceae* (fried pea and white lupine). The subplots were at different depths of evaluations; 0 - 0.05; 0.05 - 0.10 and 0.10 - 0.15 m to determine the pore volume and soil density; and 0 to 0.40 m to resistance to penetration. Were evaluated: dry mass yield; soil surface cover index; volume of macropores, micropores, total porosity; soil density; and soil resistance to penetration. It was verified that the family of plants *Fabaceae* showed higher dry matter yield (4400 $kg \cdot ha^{-1}$), however, the lower soil cover rate (68.71%). The highest volume of macropores (0.05 $m^3 \cdot m^{-3}$) and the lowest soil resistance to penetration were observed in the soil cultivated with *Poaceae* family cover plants, in the respective depths of 0 - 0.10 m and 0.05 - 0.20 m.

Keywords

Green Fertilizers, Soil Porosity, Soil Density, Resistance to Penetration

1. Introduction

Agricultural soils are considered a complex system, because they provide the favorable and necessary conditions so that the seeds of the plants can germinate, develop and reproduce their fruits. In view of this, a favorable physical environment for root growth and development is necessary and of fundamental importance in order to maximize the productivity of the implanted crops. Therefore, the use of managements that do not degrade and/or improve soil structure has received much attention [1]. In a productive system, only chemical properties should be prioritized, but attention must also be paid to the physical properties of the soil, such as: porosity, resistance to penetration, and soil density [2].

The no-tillage system is a technology that is mainly aimed at improving the soil, with objective of preserving the structures. However, this system, when inadequately managed, causes soil compaction. Compaction is characterized by reduced pore volume; reduction of oxygen diffusion rate; increased density; increase in the physical resistance and energy with which the water is trapped in the soil [3]. These factors directly affect root development, and consequently other plant structures, since compaction reduces the volume of soil to be harvested by the roots, as well as the amount of water, air and nutrients available, limiting crop productivity.

Several factors are factors that promote soil compaction, such as lack of crop rotation, reduction of soil organic matter input, intensive traffic of agricultural machines [4], inadequate use of agricultural tires [5], agricultural operations with inadequate soil water contents [6], as well as inadequate weighting of agricultural machines in each type of activity. Compaction is considered to be one of the main causes of degradation of agricultural soils [7].

Soil cover plants are considered an excellent alternative to decompress and improve soil structure, reaching a physical quality satisfactory [8]. The use of decompressing plants composes an important management strategy in intensive production systems [9]. However, the response is dependent on the cultivated plant [10]; because each root system presents a differentiated capacity of development in the soil. However, cover plants with good root development are able to act more uniformly in all soil depths when compared to mechanical systems, contributing more efficiently to the improvement of soil aggregation [11], thus presenting advantages over the use of agricultural implements, which can promote the disintegration of soil structures.

In addition, cover plants promote the removal of nutrients from the subsurface, gradually releasing them on the surface during the decomposition process [12]; formation of biopores with wide variation in size [13] functioning as alternative routes for the growth of the roots [14] and increase in the movement of water and the diffusion of gases in the soil [3]. Another advantage is the high density of roots and periodic renewal becomes this important for the quality and sustainability of the agricultural production system.

The species that can be used as cover plants are many, which makes difficult the best choice [15] because there is no ideal plant, and it is necessary before choosing to survey the most favorable species [16]. Information should be sought regarding its adaptation to the region's climate, sowing season, crop cycle, root system development and dry mass production. In this way, it is necessary to choose plant species that overcome physical constraints, as well as, promote the recovery of soil quality, especially when subjected to an intensive system of production.

The soil cover plants of the *Poaceae* Family are considered to be more efficient in promoting soil structuring in relation to *Fabaceae* [17]. However, for the first years of implantation of crop successions, the larger soil structuring occurs under the cultivation of *Fabaceae* [18] plants, which also promote the increase of nitrogen in the soil [19]. However, there is a need for [20]. In order to improve the soil structure, it is necessary to verify the real contribution of these plants in order to maintain or improve soil structure.

Thus, the objective of this work was to evaluate the biomass productivity of cover crops in autumn and winter (*Poaceae* and *Fabaceae*), and their effects on soil physical properties at different depths.

2. Material and Methods

2.1. Location, Climate and Soil of the Study Area

The work was carried out at the Experimental Station Professor Alcibíades Luiz Orlando belonging to the State University of the West of Paraná (UNIOESTE) in the municipality of Entre Rios do Oeste—PR, located at the geographical coordinates 24˚40'32.66" south latitude and 54˚16'50.46" longitude west, to 244 meters of altitude in relation to the level of the sea. According to the climatic classification of Köppen, the climate of the region is subtropical humid mesothermic (Cfa), with hot summers, with average temperatures above 22˚C and winters with average temperatures and below 18˚C and an average annual rainfall of 1600 - 1800 millimeters [21]. The soil of the experimental unit is classified as typical Red Eutrophic Oxisol, very clayey texture, smooth undulating relief [22]. Prior to the implantation of the experiment, the area was cultivated with oats in the winter period and corn in succession in the summer.

Prior to the implementation of the experiment, deformed soil samples were collected at the depth of 0 - 0.20 m for the determination of the chemical and granulometric characteristics. The chemical analyzes were performed according to the methodology of [23]. The results presented were: pH ($CaCl_2$) = 6.05; M.O. = 24.61 $g \cdot dm^{-3}$; P = 2.36 $mg \cdot dm^{-3}$; Ca^{2+} = 6.61 $cmol_c\ dm^{-3}$; Mg^{2+} = 1.77 $cmol_c\ dm^{-3}$; K^+ = 0.25 $cmol_c\ dm^{-3}$; Al^{3+} = 0.00 $cmol_c\ dm^{-3}$; $H^+ + Al^{3+}$ = 2.54 $cmol_c\ dm^{-3}$ e V (%) = 77.26. For the granulometric determination, the Bouyoucos densimeter method was used, according to [24]. The results were: 763 $g \cdot kg^{-1}$ of clay, 136 $g \cdot kg^{-1}$ of silt and 101 $g \cdot kg^{-1}$ of sand.

2.2. Experimental Design, Deployment and Data Collection

The experimental design was of randomized blocks with subdivided plots, with six replications. The plots consisted of four cover crops in autumn and winter; two *Poaceae* (black oats (T_1) and brachiaria (T_2)) and two *Fabaceae* (pea forage (T_3) and white lupine (T_4)). The subplots were at different depths of evaluations; 0 - 0.05 (P_1); 0.05 - 0.10 (P_2) and 0.10 - 0.15 (P_3) m to determine pore volume and soil density; and 0 to 0.40 m to resistance to penetration. Each plot was composed of 20.0 m in length and 5.40 m in width, totalizing 108 m^2. The useful area of each plot was calculated by discarding 1 m from each end and 0.45 m from each side, totaling 81.0 m^2.

Cultivation was carried out mechanically with a plotter on 09/05/2014, using 70 $kg \cdot ha^{-1}$ of black oats (*Avena strigosa* S.) grow crops IAPAR 61 Ibiporã; 8 $kg \cdot ha^{-1}$ of Brachiaria (*Urochloa ruziziensis*), with a cultural value of 73.06%; 60 $kg \cdot ha^{-1}$ of forage pea (*Pisum sativum* L.) grow crops IAPAR 83 and 50 $kg \cdot ha^{-1}$ of white lupine (*Lupinus albus* L.). The line spacing used was 0.20 m for the *Poaceae* and 0.40 m for the *Fabaceae*. No basal fertilization was used.

At 120 days after sowing, the dry mass productivity of the cover plants was evaluated. For this evaluation we used a square sample equivalent to 0.25 m^2 randomly placed in each plot, and the plants contained inside were cut close to the ground with pruning shears, and two samples were taken per plot. Samples from each treatment were placed in paper bags and taken to the forced air ventilation oven with a temperature of 65˚C for a period of 72 hours. When removing material made if the weighing determined the dry mass. Then the cover plants were managed using 3 $kg \cdot ha^{-1}$ of glyphosate acid equivalent.

After 25 days of management of the cover trees, the soil cover index was evaluated. For this purpose, a 10 m long tape was used, which was stretched on both diagonals of each plot. Thus, in each projection of 0.10 m on the soil surface, the presence or absence of the straw of the covering plants was evaluated [25], being that each point of the projection corresponded to the value of 1%. In each plot, the values of the two diagonals were summed and divided by two, thus obtaining the coverage index of the soil surface.

Also, undisturbed soil samples were collected at two points in each plot for the determination of macroporosity, microporosity, total porosity and soil density. A metal cylinder (Kopecky Ring) of known volume was used. Samples were collected at depths between 0 - 0.05; 0.05 - 0.10 and 0.10 - 0.15 m. After collecting the samples, they were placed for saturation in a tray with a water slide at 2/3 of the height of the metal cylinder for 24 hours.

The samples were then weighed and placed on the tension table with a potential of −0.006 MPa (light suction), draining the water contained in the macropores. The samples were again weighed and placed in an oven for drying, removing the water contained in the micropores, at 105˚C for 48 hours, being again weighed. The determinations of macroporosity, microporosity and total porosity were determined according to [24]. Soil density was obtained by the relationship between the dry soil mass and the total volume of the soil collected [24].

The soil penetration resistance was evaluated using the Falker digital penetrometer, model PenetroLOG-PGL 1020, with electronic capability for data acquisition, with four measurements per plot. The penetrometer was set to record readings every 0.01 m depth increment, working at constant penetration velocity. Data from the Falker penetrometer were extracted from the digital memory and analyzed every 0.05 m depth up to 0.40 m. PenetroLOG Software was used to process the penetration resistance data. At the time of sampling, a soil sample was collected in each plot in the depth of 0 - 0.20 and 0.20 - 0.40 m, for analysis of the moisture content, determined by the standard greenhouse method [24], which presented on average 0.20 $kg \cdot ka^{-1}$ of water.

2.3. Statistical Analyzes

The data were tabulated and submitted to analysis of variance considering a level of significance of 5% for the F test. When significant, the means were compared by the Scheffé test at 5% probability using the statistical software Sisvar [26]. The contrasts used in the comparison of the means of the treatments by the Scheffé test were: C_1: Comparison between families ($+1T_1$ $+1T_2$ $-1T_3$ $-1T_4$); C_2: Comparison within the family *Poaceae* ($-1T_1$ $+1T_2$) and C_3: Comparison within the family *Fabaceae* ($-1T_3$ $+1T_4$). As for the contrasts for the comparison of the depths of the evaluation depths, these were: C_4: Comparison between the depth of 0 - 0.05 m versus the depths of 0.05 - 0.10 and 0.10 - 0.15 m ($+2P_1$ $-1P_2$ $-1P_3$) and C_5: Comparison between depths of from 0.05 - 0.10 and 0.10 - 0.15 m depth ($+1P_2$ $-1P_3$).

3. Results and Discussion

3.1. Dry Mass Yield and Soil Surface Cover Index

Checked was a significant effect ($p < 0.05$) of cover crops on the dry mass productivity and the soil surface coverage ratio. Regarding the physical properties of the soil, there were significant differences ($p < 0.05$) for the isolated effect of the cover plants and depth of evaluation, as well as the interaction of these factors.

Table 1 shows the mean dry mass and soil cover index as a function of the cultivation of soil cover crops during the autumn and winter period.

Based on **Table 2**, which shows the values of the dry mass yield and soil cover indexes, it was verified that the highest dry mass yield was obtained under cover crops of the *Fabaceae* family (**Table 2**). Obtaining an average yield of 4400 $kg \cdot ha^{-1}$; while the *Poaceae* family showed an average productivity of 3038 $kg \cdot ha^{-1}$ (**Table 1**), that is, the *Poaceae* showed a productivity of 1361.50 $kg \cdot ha^{-1}$ less than the *Fabaceae* (**Table 2**). In this way, the plants of the family *Fabaceae* presented more than 44% of dry mass, when compared to plants of the family *Poaceae*.

When analyzing the results found in the literature, it found a contradiction. For [27] as *Poaceae* were the ones that obtained the highest productivity; while [28] did not obtain significant differences between these families of plants. These

Table 1. Average dry mass yield and soil cover index as a function of cover crop cultivation in autumn and winter.

Treatment	Dry mass	Coverage ratio
	——kg·ha^{-1}——	——%——
	Poaceae family	
Oats (T_1)	4966	87.83
Brachiaria (T_2)	1110	79.25
Average	3038	83.54
	Fabaceae family	
Pea (T_3)	4083	75.50
Lupine (T_4)	4716	61.92
Average	4400	68.71

Table 2. Values of dry matter yield contrasts and soil surface cover index as a function of cover crop cultivation in autumn and winter.

Contrast	Dry mass	Coverage ratio
	——kg·ha^{-1}——	——%——
C_1	−1361.5*	14.83*
C_2	−3856*	−8.58^{NS}
C_3	633^{NS}	−13.58*

Legend: C_1: ($+1T_1$ $+1T_2$ $-1T_3$ $-1T_4$); C_2: ($-1T_1$ $+1T_2$) and; C_3: ($-1T_3$ $+1T_4$). *: Significant by the Scheffé test at 5% probability, within each parameter evaluated; ^{NS}: Not significant by the Scheffé test at 5% probability, within each parameter evaluated.

fluctuations in productivity are due to phytotechnical, edaphic and climatic factors [29] [30].

In the evaluation of the dry mass productivity within the *Poaceae* family, it was verified that black oats presented a productivity superior to 347% (**Table 1**) in relation to brachiaria, with a difference of 3856 kg·ha^{-1} (**Table 2**). In the *Fabaceae* family, no significant differences were observed ($p > 0.05$) (**Table 2**). It is worth noting that sowing of the brachiaria was not carried out at the time most appropriate for its development, which affected its dry mass productivity [31].

The highest soil cover index was presented under the cultivation of plants of the *Poaceae* family (**Table 2**). A coverage index of 83.54% was observed; while the *Fabaceae* presented a coverage index of 68.71% (**Table 1**), a difference of approximately 15% in absolute terms (**Table 2**). This is explained by the higher C/N ratio that *Poaceae* family plants present when compared to *Fabaceae* [32]. *Poaceae* are considered to be plants with the highest potential for soil protection due to their lower rate of decomposition [28]. Contributing to the maintenance of soil moisture and protection against erosive effects [33].

The soil surface cover index within the *Poaceae* family did not present significant differences ($p > 0.05$), but for the *Fabaceae* family significant differences were observed ($p < 0.05$) (**Table 2**). The forage pea presented a coverage index 13.58% higher than white lupine in absolute terms; this is due to the growth habit of white lupine being more erect relative to forage pea [28].

3.2. Physical Properties of Soil

In **Table 3**, the average results of the physical properties of the soil at each of the evaluated depths are presented after the cultivation of cover plants of the families *Poaceae* and *Fabaceae*. The results of the soil physical properties contrast values are presented in **Table 4**, where it was verified a higher macroporosity in the soil under treatment with *Poaceae* (0.05 $m^3 \cdot m^{-3}$) and lower in the treatment with *Fabaceae*. Therefore, the areas cultivated with *Poaceae* presented 162.50% more macropores, when compared to the *Fabaceae* (**Table 3**).

Table 3. Mean results of soil physical properties at different evaluation depths as a function of cover crop cultivation in autumn and winter.

Treatment	Macropores			Micropores			Total porosity			Density		
	0 - 0.05	0.05 - 0.10	0.10 - 0.15	0 - 0.05	0.05 - 0.10	0.10 - 0.15	0 - 0.05	0.05 - 0.10	0.10 - 0.15	0 - 0.05	0.05 - 0.10	0.10 - 0.15
	$m^3 \cdot m^{-3}$									$Mg \cdot m^{-3}$		
					Poaceae family							
Oats (T_1)	0.18	0.12	0.08	0.40	0.40	0.42	0.57	0.53	0.51	1.13	1.22	1.30
Brachiaria (T_2)	0.19	0.12	0.08	0.37	0.41	0.43	0.57	0.55	0.50	1.17	1.30	1.37
Average		0.13			0.40			0.54			1.25	
					Fabaceae family							
Peas (T_3)	0.10	0.07	0.05	0.49	0.47	0.51	0.59	0.54	0.56	1.22	1.30	1.47
Lupine (T_4)	0.10	0.10	0.06	0.45	0.44	0.44	0.55	0.54	0.51	1.16	1.23	1.35
Average		0.08			0.47			0.55			1.30	

Table 4. Contrast values of soil physical properties at different depths of evaluation as a function of cover crop cultivation in autumn and winter.

Contrast	Macropores			Micropores			Total porosity			Density		
	0 - 0.05	0.05 - 0.10	0.10 - 0.15	0 - 0.05	0.05 - 0.10	0.10 - 0.15	0 - 0.05	0.05 - 0.10	0.10 - 0.15	0 - 0.05	0.05 - 0.10	0.10 - 0.15
	$m^3 \cdot m^{-3}$									$Mg \cdot m^{-3}$		
C_1	0.08*	0.03*	0.02^{NS}	−0.08*	-0.05^{NS}	−0.05*	0.00^{NS}	0.00^{NS}	-0.03^{NS}	-0.04^{NS}	0.00^{NS}	-0.07^{NS}
Average		0.05*			−0.07*			-0.01^{NS}			-0.05^{NS}	
C_2	0.01^{NS}	0.00^{NS}	0.00^{NS}	-0.03^{NS}	0.01^{NS}	0.01^{NS}	0.00^{NS}	0.02^{NS}	-0.01^{NS}	0.04^{NS}	0.08^{NS}	0.07^{NS}
Average		0.00^{NS}			-0.00^{NS}			0.00^{NS}			0.06^{NS}	
C_3	0.00^{NS}	0.03^{NS}	0.01^{NS}	-0.04^{NS}	-0.03^{NS}	-0.07^{NS}	-0.04^{NS}	0.00^{NS}	-0.05^{NS}	-0.06^{NS}	$-0{,}07^{NS}$	-0.12^{NS}
Average		0.02^{NS}			−0.05*			-0.03^{NS}			-0.08^{NS}	

Legend: C_1: ($+1T_1$ $+1T_2$ $-1T_3$ $-1T_4$); C_2: ($-1T_1$ $+1T_2$) and; C_3: ($-1T_3$ $+1T_4$). *: Significant by the Scheffé test at 5% probability, within each parameter evaluated; ^{NS}: Not significant by the Scheffé test at 5% probability, within each parameter evaluated.

Macroporosity values below 0.10 $m^3 \cdot m^{-3}$ can affect root growth of crops [34]. The highest microporosity of the soil (0.47 $m^3 \cdot m^{-3}$) was observed in the treatment cultivated with the *Fabaceae*, while the lowest value (0.40 $m^3 \cdot m^{-3}$) was with the *Poaceae* (**Table 3**). This behavior was expected because this property is inversely proportional to the soil macroporosity [35].

The effects of the different cover plants on the macroporosity and microporosity of the soil can be attributed to the different forms of the root structures of one of the families. In the *Poaceae*the root system is of the fasciculate type and in the *Fabaceae* pivoting. Therefore, the fasciculate root system promoted a higher volume of macropores as a function of better soil aggregation [36]. Other resultswere reported by [37] that obtained higher macroporosity in the soil after the cultivation of *Fabaceae* in relation to *Poaceae*. The authors justify this result as a function of seed decomposition, and the highest volume of micropores in *Poaceae*by the production of very fine roots.

In the interaction between the families of cover plants and the evaluated depths, significant differences were observed ($p < 0.05$) (**Table 4**). Macroporosity in *Poaceae*, at depths of 0 - 0.10 m, presented superiority over the *Fabaceae*. Thus, it was verified that *Poaceae* present better results as soil aggregation and macropore formation, since these properties are directly related [38].

Regarding the evaluation of the physical properties of the soil within the families (**Table 4**), no significant differences ($p > 0.05$) were observed in the area cultivated with *Poaceae*. Probably, due to the greater homogeneity of the distribution of the root system of these plants. In *Fabaceae* the highest microporosity was in the area where there was forage pea cultivation (−0.05 $m^3 \cdot m^{-3}$).

The increase of microporosity when associated to the reduction of macroporosity may be an indication of soil compaction [15]; that is, defragmentation soil aggregate [39]. However, in this study, the increase in microporosity was not accompanied by a reduction of macroporosity.

When assessing the physical properties of the soil at different depths, significant differences ($p < 0.05$) were observed for macroporosity, total porosity and soil density (**Table 5**). It was observed a higher volume of macropores (0.05 $m^3 \cdot m^{-3}$), total porosity (0.04 $m^3 \cdot m^{-3}$) and consequently lower soil density (−0.12 $Mg \cdot m^{-3}$) in depth 0 - 0.05 m, the lowest macroporosity and the highest density in the depth of 0.10 - 0.15 m (**Table 5**).

The highest volume of roots of the plants occurs at the soil surface, being also in this depth the greater deposition of organic material and greater microbial activity, providing greater aggregation and soil structuring [40]. The micropore values were similar at all depths evaluated (**Table 5**). In general, micropores are more resistant to deformation and little altered by management [41], especially in Oxisols [42].

The soil density above the values of 1.25 - 1.30 $Mg \cdot m^{-3}$ are considered critical for most crops in soils with more than 55% clay [43]. On the other hand, [44] consider as critical density to root growth values above 1.45 $Mg \cdot m^{-3}$. When the

Table 5. Contrast values of soil physical properties at different evaluation depths due to cover crop cultivation in autumn and winter.

Contrast	Macropores			Micropores			Total porosity			Density		
	Poaceae	*Fabaceae*	Average	*Poaceae*	*Fabaceae*	Average	*Poaceae*	*Fabaceae*	Average	*Poaceae*	*Fabaceae*	Average
					$m^3 \cdot m^{-3}$						$Mg \cdot m^{-3}$	
C_4	0.08*	0.03^{NS}	0.05*	-0.03^{NS}	0.00^{NS}	-0.01^{NS}	0.05^{NS}	0.03^{NS}	0.04*	−0.15*	−0.09*	−0.12*
C_5	0.04^{NS}	0.02^{NS}	0.03*	-0.02^{NS}	-0.02^{NS}	-0.02^{NS}	0.04^{NS}	0.00^{NS}	0.02^{NS}	-0.08^{NS}	−0.15*	−0.13*

Legend: C_4: $(+2P_1 -1P_2 -1P_3)$ and; C_5: $(+1P_2 -1P_3)$. *: Significant by the Scheffé test at 5% probability, within each parameter evaluated; ^{NS}: Not significant by the Scheffé test at 5% probability, within each parameter evaluated.

soil density is higher than 1.30 $Mg \cdot m^{-3}$, cultivation practices should be carried out to promote the growth of the root system and increase the aggregation [1], which will result in a reduction in soil density.

When assessing the physical properties of the soil at different depths in the families, significant differences were observed ($p < 0.05$) (**Table 5**). For the *Poaceae* family, higher macroporosity (0.08 $m^3 \cdot m^{-3}$) and lower soil density (−0.15 $Mg \cdot m^{-3}$) were found in the depth of 0 - 0.05 m. In the *Fabaceae* family, there were significant differences ($p < 0.05$) only in soil density. This variation was inversely proportional to depth.

These results are justified by the higher concentration of root volume on the surface, about 66% [45], which are responsible for the approximation of soil particles. During their growth the roots exert pressure on the soil particles [46]; and also by the constant absorption of water from the soil profile [47], besides promoting the release of organic exudates that act as cementing agents [48] that contribute in the formation and stabilization of the aggregates improving the physical properties of the soil.

When evaluating the physical properties of the soil at different depths within the families, it was verified that the *Poaceae* presented higher macroporosity and lower soil density in the depth of 0 - 0.05 m. At the same depth, the *Fabaceae* had the lowest soil density (**Table 5**).

The resistance of the soil to the penetration after the cultivation of different families of cover plants is shown in **Figure 1**. It was observed that in the area where the *Poaceae* was cultivated showed lower penetration resistance in relation to the *Fabaceae*, up to the depth of 0.20 m. Different root systems have different capacities/forms of soil penetration.

As *Poaceae* by the intense proliferation of roots fasciculate in the arable layer of the soil [36], condition more aggregation and less resistance to penetration. On the other hand, in *Fabaceae*, about 80% of the pivotal root system are capable of reaching up to 0.80 m depth [49], which contributes to the reduction of penetration resistance below 0.20 m.

In **Figure 2**, the influence on soil resistance to penetration after cultivation of cover plants within each of the evaluated families is presented. In the *Poaceae* family, black oats showed lower penetration resistance, differing significantly

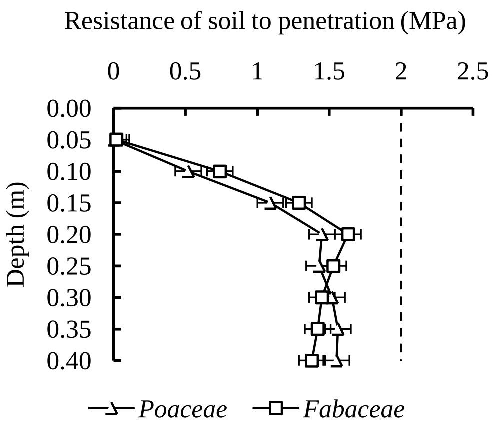
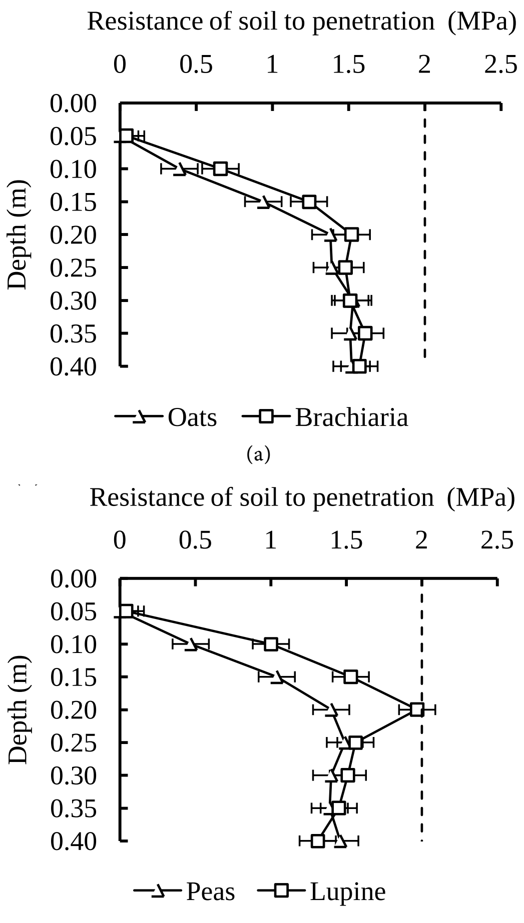


Figure 1. Average results for soil resistance to penetration in different families of cover plants and depths of evaluation.



(a)

(b)

Figure 2. Average results for soil resistance to penetration within the different families of cover plants and depths of evaluation.

($p < 0.05$) from the brachiaria to the depth of 0.15 m, below this depth there were no significant differences ($p < 0.05$) (**Figure 2(a)**).

This result indicates that the highest dry mass increase of black oats (4966 kg·ha^{-1}), associated to the most aggressive root system [50], was uniform and abundant throughout the soil volume [51], may have contributed to the increase in the stability of the larger diameter aggregates, improving soil structural quality [10], providing lower soil resistance to penetration.

For the *Fabaceae* (**Figure 2(b)**), soil resistance to penetration was found to be significantly different ($p < 0.05$) between forage pea and white lupine up to a depth of 0.20 m, with the lowest penetration resistance being evaluated in the cultivated area forage pea. However, in the treatment with white lupine at 0.20 m depth, the highest penetration resistance (1.93 MPa) was observed, being very close to the value considered critical for most cultures, 2.0 MPa [52], But this limit can vary between 2 - 3 MPa [53] as a function of soil moisture at the time of evaluation.

The physical properties evaluated in this experiment should be taken into consideration when choosing cover plants, especially when the purpose is to recover and/or improve the physical properties of the soil.

4. Conclusions

The *Fabaceae* family showed higher dry mass yield (4400 kg·ha^{-1}), however, the lower soil cover rate (68.71%).

The highest volume of macropores (0.05 m^3·m^{-3}) and the lowest soil resistance to penetration were observed in the soil cultivated with *Poaceae* family cover plants, at the respective 0 - 0.10 m depth and 0.05 - 0.20 m depth.

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