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SOIL PHYSICAL QUALITY INFLUENCED BY WINTER PLANTS

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ABSTRACT - The biomass production by cover plants provides soil protection against erosion and weed control in the winter period, while the effect of cover crops on the parameters of physical soil quality helps in root growth and water storage. The objectives of the present study were to evaluate the influence of winter plants on the physical quality of the soil. The experiment consisted of unifactorial treatments, composed of different winter plants: vetch (*Vica sativa* L.), forage radish (*Raphanus sativus* L.), black oat (*Avena strigosa* Schreb.), rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.) and control treatment. The experimental design was randomized blocks, with four replications per treatment. The parcels consisted of 34 lines implanted with a disc seeder and spaced 17 cm and 10 m long, comprising an area of 57,80 m^2 per parcel. Sowing densities were 40 kg ha^{-1} for vetch, 20 kg ha^{-1} for forage radish, 60 kg ha^{-1} for rye, 150 kg ha^{-1} for wheat and 90 kg ha^{-1} for black oat. The control treatment consisted of the vegetation that emerged spontaneously. The parameters evaluated were plant green mass, weed occurrence, apparent density, gravimetric moisture and soil penetration resistance. With the vetch cultivation there was a reduction in the density of the soil in its surface layer, compared to the control treatment and the other cover crops. Wheat increased gravimetric soil moisture retention. Forage radish was superior to the other cover crops in terms of biomass production, totaling 59.91 t ha^{-1}, as well as being the only cover crop that reduced soil penetration resistance, in the layer from 0 to 40 cm of ground. Vetch reduced the density of the soil in its surface layer, and also the resistance to penetration, from 21 cm of depth. Compared to the control treatment, cover crops were efficient in suppressing weed growth.
Keywords: Cover plants, soil resistance to penetration, soil density, gravimetric moisture.

QUALIDADE FÍSICA DO SOLO INFLUENCIADA POR PLANTAS HIBERNAIS

RESUMO - A produção de biomassa por plantas de cobertura propicia a proteção do solo contra a erosão e o controle de plantas daninhas no período invernal, enquanto o efeito das plantas de cobertura sobre os parâmetros de qualidade física do solo auxilia no crescimento radicular e armazenamento de água no solo. Diante do exposto, objetivou-se com o presente trabalho avaliar a influência de plantas hibernais sobre a qualidade física do solo. O experimento foi constituído por tratamentos unifatoriais, compostos por diferentes plantas hibernais: ervilhaca (*Vica sativa* L.), nabo forrageiro (*Raphanus sativus* L.), aveia preta (*Avena strigosa* Schreb.), centeio (*Secale cereale* L.), trigo (*Triticum aestivum* L.) e testemunha. O delineamento experimental foi o blocos ao acaso, contendo quatro repetições por tratamento. As parcelas foram constituídas por 34 linhas implantadas com semeadora de discos e espaçadas por 17 cm e 10 m de comprimento, compondo uma área de 57,80 m^2 por parcela. As densidades de semeadura foram 40 kg ha^{-1} para a ervilhaca, 20 kg ha^{-1} para o nabo, 60 kg ha^{-1} para o centeio, 150 kg ha^{-1} para o trigo e 90 kg ha^{-1} para a aveia-preta. O tratamento testemunha foi composto pela vegetação que emergiu espontaneamente. Os parâmetros avaliados foram massa verde de plantas, ocorrência de plantas daninhas, densidade aparente, umidade gravimétrica e resistência do solo à penetração. Com o cultivo da ervilhaca, obteve-se redução na densidade do solo em sua camada superficial, comparativamente ao tratamento testemunha e às demais plantas de cobertura. O trigo aumentou a retenção de umidade gravimétrica do solo. O nabo forrageiro foi superior às demais plantas de cobertura quanto à produção de biomassa, totalizando 59,91 t ha^{-1}, bem como foi a única planta de cobertura que reduziu a resistência do solo à penetração, na camada de 0 a 40 cm de solo. A ervilhaca reduziu a densidade do solo em sua camada superficial, e também a resistência à penetração, a partir de 21 cm de profundidade. Comparativamente à área de pousio, as plantas de cobertura foram eficientes em suprimir o crescimento de invasoras.
Palavras-chave: Plantas de cobertura, resistência do solo, densidade do solo, umidade gravimétrica.

INTRODUCTION

In a crop rotation system, the aim is to obtain a favorable environment for water infiltration into the soil and root growth. The construction and maintenance of soil pores, as well as the cycling of nutrients, is achieved by cultivating plants that produce deep roots and have an aggressive growth habit. The benefits are extended to all plants cultivated in the crop rotation system, including those with less root growth. According to Franchini et al. (2009), the presence of compacted layers restricts soybean root development on the soil surface, limiting the crop's water demand. Thus, for soybean farmers in southern Brazil, the use of winter crops is recommended, contributing to the

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improvement of compaction indicators, such as soil density and penetration resistance.

The soil may have compacted layers due to inadequate management, such as the use of heavy machinery (ESPÍNDOLA et al., 1997). Lopes et al. (2011) report that soil management with increasing moisture contents changes its physical properties. As a consequence, compaction can reduce soil water storage and increase soil resistance to root penetration to levels detrimental to crop yields. In this sense, knowledge of soil resistance to penetration is essential, as it allows identifying the conditions in which root growth may be impeded by plants (LIMA et al., 2013).

Soil resistance to penetration is quantified using a penetrometer equipment to report higher penetration resistances in deeper soil layers (CAMPOS et al., 2012). According to Andrade et al. (2013), penetration resistances equal to or greater than 1900 kPa, determined by the soil water content equivalent to field capacity, can be considered indicators of compacted soils.

With crop rotation, the soil is populated by roots with different root habits and the production of great green mass. The rotting of the roots forms channels that help in the conduction of water in depth (KLEIN; KLEIN, 2014), interfering with the efficiency in the use of water and nitrogen fertilizers (PIERCE; RICE, 1988). According to Azevedo et al. (1999), soil moisture conservation is related to reduced water evaporation, reduced rainwater runoff, increased organic matter, and water infiltration rate into the soil. In this sense, cover plants, in addition to contributing to the suppression of weeds (BORGES et al., 2014; LAMEGO et al., 2015), also mitigate erosive processes and provide for the conservation of soil moisture.

Miyata et al. (2009) found a reduction in surface water flow and soil erosion due to vegetation cover. Yan et al. (2013) also reports the importance of vegetation cover to protect fine soil particles against wind erosion, preserving soil nutrients. In addition to suppressing weed development, winter cover crops can improve the root environment for successor crops by making the soil less dense and improving the edaphic environment for the root growth of successor plants. In this sense, the objective of the present study was to evaluate the influence of winter plants on the physical quality of the soil.

MATERIAL AND METHODS

The present study was carried out in 2019 and carried out in an experimental area located in Não-Me-Toque/RS, under geographic coordinates of -28.442147º latitude, -52.817970º longitude, and an average altitude of 514 m in Tipic Eutrophic Oxisol, with texture clayey to very clayey, according to the Soil Survey Staff (1999). The experimental area has been conducted with the cultivation of annual crops in a no-tillage system. The experimental area has been conducted with the cultivation of annual crops in a no-tillage farming system. In the winter of 2017, the culture of wheat (*Triticum aestivum* L.) was implemented. Then, in the summer of the 2017/18 crop, the soybean crop (*Glycine max* (L.) Merr.) and in the winter of 2018, the black oat (*Avena strigosa* Schreb. cv. Comum) was planted as cover. Finally, in the summer of the 2018/19 crop, corn (*Zea mays* L.) was also planted as cover.

The experiment consisted of one-factor treatments for different winter plants: vetch (*Vicia sativa* L.) cv. Common, fodder turnip (Raphanus sativus L.) cv. IPR116, black oat (*Avena strigosa* Schreb.) cv. Common, rye (Secale cereale L.) cv. BRS Serrano, wheat (*Triticum aestivum* L.) cv. Celebrate and witness, made up of the fallow. The experimental design was randomized blocks, with four replications per treatment.

Sowing densities were 40 kg ha^{-1} for vetch, 20 kg ha^{-1} for turnip, 60 kg ha^{-1} for rye, 150 kg ha^{-1} for wheat, and 90 kg ha^{-1} for black oat. The implantation of the cover plants was done with a disc seeder. The plots consisted of 34 lines spaced 17 cm and 10 m long, comprising an area of 57.80 m^2 per plot. Fertilization of the treatment plants was performed according to the recommendations of SBCS (2016), with base fertilization carried out with 350 kg ha^{-1} of formulated (16-16-16) at the time of planting the crops. At 65 days after emergence, nitrogen fertilizer was applied as a top dressing in ammonium nitrate [27% nitrogen (N)]. The applications were carried out according to the organic matter levels in the different blocks of the experiment. In blocks 1, 2, and 3, Medium class for a percentage of soil organic matter, according to SBCS (2016), 266 kg ha^{-1} were applied, totaling 71.82 kg ha^{-1} of N, while in block 4, Low class, according to SBCS (2016), 333 kg ha^{-1} were applied, totaling 89.91 kg ha^{-1} of N.

At 62 days after sowing, the surface layer of soil from 0 to 4.7 cm deep was sampled, by collecting undisturbed soil samples positioned between the planting rows, according to the methodology adapted from Almeida et al. (2017). Volumetric rings with a diameter of 9.6 cm, a height of 4.7 cm, with a volume of 340 cm³ were used. The samples were weighed on a precision balance immediately after collection and dried in an oven for 24 h at 105°C. After drying, the samples were weighed again to obtain the dry soil mass, soil density, and determination of the gravimetric soil moisture content (ALMEIDA et al., 2017). Ten random samplings were performed 104 days after sowing to verify the effect of the cover crops on soil resistance to penetration. Each EU was sampled using a hydraulic penetrometer (Falker brand, model Solo Star), equipped with an automated system for inserting metal cones in the soil. The readings of penetration resistance were expressed in kilopascals (kPa) at depths of 0 to 40 cm.

The quantification of the green biomass of plants and weeds in each treatment was performed 100 days after sowing. In each treatment, a 0.50 x 0.50 m frame was sampled per plot with the help of a set square. After collecting the plant samples, the cultivated and invasive plants were separated from each plot, and the samples were immediately weighed to determine the green mass. Weeds were classified according to Lorenzi et al. (2014). Values were converted to ton ha^{-1}.

The data were submitted to analysis of variance and, later, the Scott-Knott test was performed at 5% error probability. Finally, statistical comparisons were performed using the Sisvar 5.7 program (FERREIRA, 2011).

RESULTS AND DISCUSSION

Table 1 shows the values of shoot green mass and weed green mass. The turnip treatment was the most efficient in producing green mass (59.91-ton ha^{-1}). The other treatments were inferior to turnip, obtaining yields equivalent to 21.80; 25.98; 23.16- and 31.54-ton ha^{-1} of green mass of plants, with the treatment's vetch, rye, wheat, and black oat, respectively, with no difference between them (Table 1). The production of green mass obtained with cover crops is of great importance in crop rotation systems. Through it, it is possible to protect the soil against the impact of raindrops, reducing soil and nutrient losses by erosion. The present study results regarding the production of turnip green mass were higher than other values found by Azevedo et al. (2012) and Wolschick et al. (2016), who obtained up to 29.65-ton ha^{-1}- and 30.46-ton ha^{-1} of forage radish green mass, respectively. In addition to the abundant production of green mass and the consequent ability to protect soil throughout its production cycle, the turnip crop has also been characterized as a vital nutrient cycler due to the rapid release of macronutrients when managed in the pre-flowering stage (CRUSCIOL et al., 2005).

TABLE 1 - Green biomass of cover crops and green mass of weeds, at 100 days after sowing.

Treatments	Green biomass	
	Cover plants	Weeds
	---------- ton ha^{-1} ----------	
Vetch	21.80 b*	3.97 b
Rye	25.98 b	1.18 b
Wheat	23.16 b	0.66 b
Control	0.00 c	23.85 a
Turnip	59.91 a	0.35 b
Black oat	31.54 b	0.85 b
CV(%)	37.95	113.05

*Different letters in the column indicate statistically significant differences according to the Scott-Knott test, at 5% probability of error.

In the plots with the presence of weeds, the species ryegrass (*Lolium multiflorum*), horseweed (*Conyza sumatrensis*), mistletoe (*Stellaria media*), and milkweed (*Sonchus oleraceus*) were identified. It is observed that all cover crops were able to mitigate the development of weeds compared to the control treatment, composed of fallow. According to Siqueira et al. (2014), vegetation cover can be one of the weed control methods. In the same sense, Lima et al. (2014) also observed weed suppression in plots with cover crops, indicating that dry mass production and weed suppression are influenced by the cover crop cycle and the persistence of mulch on the soil. Therefore, by mitigating the development of weeds, cover crops provide an economy to the rural producer. It is so because the absence of these species reduces the costs of desiccation prior to the implementation of summer crops, especially for those species that are resistant to herbicides, such as *Lolium multiflorum* (MARIANI et al., 2015), *Conyza sumatrensis* (SCHNEIDER et al., 2020) and *Sonchus oleraceus* (MOBLI et al., 2019).

Table 2 shows the soil density and gravimetric moisture in the first 4,7 cm of depth. In the vetch treatment, the lowest values of soil density were observed, indicating optimization of root growth conditions in the surface layer of soil, compared to the other treatments. Additionally, vetch provides the crop rotation system with two very desirable characteristics: nitrogen supply and soil structuring. The higher N content and the lower C/N ratio of vetch provide a higher rate of waste decomposition, not showing net immobilization and releasing 50% of the N accumulated in the plant mass in the first 30 days, which can provide amounts of more than 100 kg ha^{-1} of N (ACOSTA et al., 2014). In this sense, in addition to being an important fixer of atmospheric nitrogen, vetch also plays an essential role in soil structuring.

In the rye, wheat, and control treatments, the values of 1.41, 1.43, and 1.44 g cm^3 were observed, respectively, and between them, there were no differences in the apparent density of the soil. Higher soil density values were observed in the plots with turnip and black oat at the evaluated depth from 0 to 4.7 cm: 1.59 and 1.65 g cm^3, respectively. According to Reichert et al. (2003), clayey soils have critical density values between 1.30 and 1.40 g cm^3. Higher gravimetric moisture was observed in the wheat treatment compared to the control and the other treatments. These results are possibly associated with infiltration and retention of soil moisture, as well as the promotion of structuring and stability of soil aggregates by the fasciculate roots of grasses. The overall development of the grass root system is the primary aggregating agent of particles in tropical soils, contributing to more excellent erosion resistance, good aeration, and greater capacity for water infiltration into the soil (SALTON; TOMAZI, 2014).

TABLE 2 - Soil apparent density and soil gravimetric moisture at 62 days after sowing cover crops, at a depth of 0 to 4.7 cm.

Treatments	Soil apparent density (g cm^{-3})	Soil gravimetric moisture (g g)
Vetch	1.178 a*	17.388 b
Rye	1.418 b	15.725 b
Wheat	1.435 b	23.115 a
Control	1.440 b	16.468 b
Turnip	1.595 c	18.125 b
Black oat	1.653 c	15.700 b
CV(%)	9.98	25.19

*Different letters in the column indicate statistically significant differences according to the Scott-Knott test, at 5% error probability.

Figure 1 and Table 3 show the penetration resistance observed in treatments with cover crops. In the turnip treatment, lower penetration resistance was observed at all depths compared to the control treatment, while in the wheat crop, lower penetration resistance was observed at a depth of 3 to 15 cm (Table 3). There was less resistance to penetration from 21 to 40 cm of depth in the vetch treatment than in control (Figure 1). With the present results, it was possible to infer that turnip, vetch, and wheat are crops that contribute to the reduction of soil penetration resistance at different depths. Turnip provided lower penetration resistance throughout the evaluated depth. These effects are desirable since, as reported by Costa et al. (2012), lower values of soil penetration resistance contribute to root production. Silva et al. (2012) found some effect of the nature of cover crops on the values of soil resistance to mechanical penetration, while Genro Junior et al. (2004) and Assis et al. (2014) did not observe the effect of different cultures.

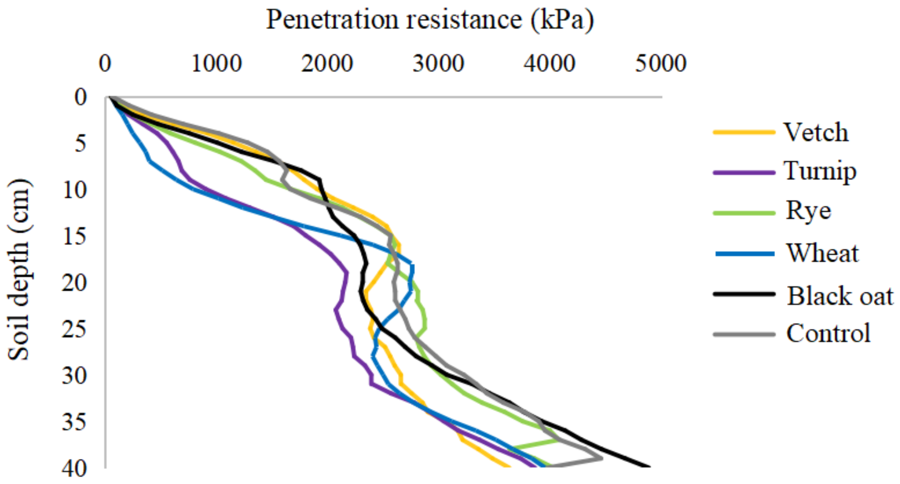

FIGURE 1 - Resistance to soil penetration between treatments of cover crops, from 0 to 40 cm depth.

TABLE 3 - Effect of cover crops on soil penetration resistance, from 0 to 40 cm depth.

Layer	Penetration resistance (kPa)					
(cm)	Wheat	Turnip	Rye	Black oat	Vetch	Control
0 to 5	206.8 Eb*	340.0 Fb	441.8 Fb	522.8 Ga	636.0 Ea	732.4 Ga
5.1 to 10	545.6 Dc	728.2 Ec	1348.2 Eb	1679.4 Fa	1661.4 Da	1586.2 Fa
10.1 to 15	1536.0 Cc	1483.0 Dc	2273.8 Da	2084.6 Eb	2360.0 Ca	2249.8 Ea
15.1 to 20	2656.6 Ba	2080.6 Cb	2624.8 Ca	2322.6 Db	2541.6 Ca	2601.6 Da
20.1 to 25	2619.0 Ba	2117.0 Cb	2844.4 Ca	2381.2 Db	2377.0 Cb	2661,8 Da
225.1 to 30	2445.8 Bb	2283.8 Cb	2890.0 Ca	2825.2 Ca	2553.2 Cb	2988.4 Ca
30.1 to 35	2805.0 Bc	2745.6 Bc	3418.8 Bb	3618.6 Ba	2850.4 Bc	3606.0 Ba
35.1 to 40	3662.4 Ab	3536.6 Ab	3922.6 Ab	4490.0 Aa	3372.8 Ab	4159.4 Aa

*Means followed by the same lowercase letters in the row and uppercase in the column, do not differ from each other by the Scott Knott test, at 5% error probability, CV = 9.13%.

In all treatments, more excellent resistance to penetration was observed in the deeper layers (Table 3). These results agree with Costa et al. (2012), who related the increase in soil resistance to penetration to the reduction in root production. Excessive values of soil penetration resistance can impair root growth in length and diameter (MEROTTO; MUNDSTOCK, 1999), so the value of 2000 kPa is the critical limit suggested by Tormena et al. (1998) in Oxisol.

CONCLUSIONS

Forage radish was superior to the other cover crops in terms of biomass production, totaling 59.91 t ha^{-1}, as well as being the only cover crop that reduced soil penetration resistance in the layer from 0 to 40 cm of the ground.

The vetch is notable for the reduction in soil density in its surface layer, as well as for the reduction in penetration resistance, starting at a depth of 21 cm.

Compared to the fallow area, cover crops efficiently suppressed weed growth.

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