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DRY MATTER PRODUCTIVITY AND SOIL PHYSICAL PROPERTIES AFTER WINTER COVER CROPS CULTIVATION

Katiely Aline Anschau Deimling[1*], Edleusa Pereira Seidel[2], Jean Sérgio Rosset[3], Marcos Cesar Mottin[4], Daniela da Rocha Herrmann[4], Amanda Cecato Favorito[5]

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ABSTRACT - The present study aimed to evaluate the dry matter yield of cover crops cultivated in monoculture and intercropped in a no-till system and its effects on the soil physical properties. The experimental design was of randomized blocks, with four replicates. Treatments used were black oat, black oat + forage radish, forage radish, black oat + field pea, field pea and the control (fallow). After 100 days after sowing the cover crops, the dry matter yield was evaluated, with the highest values found in the intercropped crops. After desiccation, undeformed soil samples were collected for the determination of macroporosity, microporosity, total porosity and soil bulk density in the 0 - 0,10; 0,10 - 0,20; 0,20 - 0,30 and 0,30 - 0,40 m layers. Soil penetration resistance was evaluated with a digital penetrometer. The intercrop of black oat with field pea and with forage radish provided the highest dry matter yield, showing the potential of dry matter accumulation in relation to monoculture. The cover crops were capable of improving the macroporosity, bulk density and soil penetration resistance when compared to the fallow area (control); however, they had no influence in soil aggregation due to the high compaction degree in the area.
Keywords: green manure, penetration resistance, aggregate stability.

PRODUTIVIDADE DE MATÉRIA SECA E PROPRIEDADES FÍSICAS DO SOLO APÓS CULTIVO DE PLANTAS DE COBERTURA NO INVERNO

RESUMO - O presente estudo teve por objetivo avaliar a produtividade de matéria seca de plantas de cobertura no inverno cultivadas em monocultivo e consorciadas em sistema semeadura direta e seus efeitos nas propriedades físicas do solo. O delineamento experimental foi de blocos ao acaso, com quatro repetições. Os tratamentos utilizados foram: aveia-preta, aveia-preta + nabo forrageiro, nabo forrageiro, aveia-preta + ervilha forrageira, ervilha forrageira, e a testemunha (pousio). Após 100 dias da semeadura das plantas de cobertura, efetuou-se a avaliação da produtividade de matéria seca onde os maiores valores foram observados nos cultivos consorciados. Após a dessecação foram coletadas amostras de solo indeformadas para a determinação da macroporosidade, microporosidade, porosidade total, e densidade do solo nas camadas de 0 - 0,10; 0,10 - 0,20; 0,20 - 0,30 e 0,30 - 0,40 m. A resistência do solo à penetração, foi avaliada com a utilização do penetrômetro digital. Os consórcios de aveia com ervilha-forrageira e com nabo-forrageiro proporcionam maior produtividade de matéria seca ao solo, demonstrando potencial de acúmulo de matéria seca em relação aos monocultivos. As plantas de cobertura foram capazes de proporcionar melhorias na macroporosidade, densidade do solo e resistência do solo a penetração quando comparadas a área de pousio (testemunha); entretanto, não influenciaram na agregação do solo devido ao alto nível de compactação presente na área.
Palavras-chave: adubos verdes, resistência a penetração, estabilidade de agregados.

INTRODUCTION

Soil cultivation carried out unconsciously leads, over time, to changes in its physical structure, chemical and biological properties; because in this system, there are no practices to conserve it, it is just used the soil, extracting it to its maximum potential. In a crop system the soil physical properties are affected; mainly the bulk density and pores distribution, harming the commercial crop development. The modification in the physical properties is one of the major processes responsible for the reduction in the soil productive capacity (WOLSCHICK et al., 2016), because the losses in the structural quality are not capable of providing ideal conditions for the full development of the cultures implanted (SANCHEZ, 2012).

[1]Agrônoma (o), Mestre em Agronomia, Programa de Pós-Graduação em Agronomia (PPGA), Universidade Estadual do Oeste do Paraná (Unioeste), *Campus* Marechal Cândido Rondon, Paraná, Brasil. E-mail: katy_aline@hotmail.com. *Autora para correspondência.
[2]Professora Dra, Programa de Pós-Graduação em Agronomia (PPGA), Universidade Estadual do Oeste do Paraná (Unioeste), *Campus* Marechal Cândido Rondon, Paraná, Brasil. E-mail: edleusaseildel@yahoo.com.br.
[3]Professor Dr. Universidade Estadual do Mato Grosso do Sul, Mundo Novo, Mato Grosso do Sul, Brasil.
[4]Doutorando em Agronomia, Programa de Pós-Graduação em Agronomia (PPGA), Universidade Estadual do Oeste do Paraná (Unioeste), *Campus* Marechal Cândido Rondon, Paraná, Brasil
[5]Graduação em Agronomia, Centro de Ciências Agrárias (CCA), Universidade Estadual do Oeste do Paraná (Unioeste), *Campus* Marechal Cândido Rondon, Paraná, Brasil.

With the crescent preoccupation in reducing the agricultural area’s degradation, the use of different soil management forms that aim to improve the physical, chemical and biological properties of the edaphic environment are gaining space. Among these alternative managements the use of cover crops stands out, due to the benefits that these plants are capable of providing to the soil structure and for the following crops.

The cultivation of cover crops has as its main goal the formation of organic matter, that improves the soil chemical, physical and biological properties (HARASIM et al., 2016). Cover crops may be cultivated as monoculture or intercropped, and play a role in protecting the soil, while in the intercropping they tend to maximize significant benefits to the soil, and to the cropping system (GIACOMINI, 2001), favoring the processes of aggregate formation for the greater contribution of organic matter to the soil (TISDALL and OADES, 1982; OADES, 1984; SANCHEZ, 2012) and providing improvements mainly in bulk density and aeration (FERREIRA et al., 2000).

In no-till cropping systems, where the crop rotation is made keeping a large amount of plant biomass over the surface, it is possible to observe an expressive improvement in the bulk density and soil porosity, mostly in the subsurface layers after consecutive years of conservationist cultivation (WOLSCHICK et al., 2016).

In the southern region of Brazil, the existence of monoculture is what occurs in crops, which transforms the cropping system over time harmful to the soil due to the environmental impacts caused, principally by the lack of soil coverage. According to Wolschick et al. (2016), there is a need to publicize the benefits brought by the cover crops to the soil physical, chemical and biological properties and, consequently, the productivity increase, so then its use will expand in a way that favors the agriculture in a sustainable way. It is important to highlight that for each region there are more adequate plants, which will adapt satisfactorily, maximizing its effects to the system.

To analyze which is the best choice to be made, regarding the cover crop cultivation, some evaluations based on physical indicatives that allow the impacts caused by the management systems are made, standing out the soil bulk density (BD), soil penetration resistance (SPR), macroporosity (Ma), microporosity (Mi), total porosity (Tp) and aggregate stability (AS) (PEZARICO et al., 2013).

Given the above, the objective of this study was to evaluate the dry matter production left from the cover crops and if it will improve the soil physical properties (macroporosity, microporosity, total porosity, soil bulk density, soil penetration resistance and aggregate stability), when compared to the control (fallow).

MATERIAL AND METHODS

The study was carried on a private farm, located in Quatro Pontes (Paraná, Brazil). The geographical coordinates were 54°00’00.5”W and 24°34’12.3”S, with an altitude of 420 m and average declivity of 4%. The soil is classified as Oxisoil, with a clayey texture (SANTOS et al., 2013). The climate of the region is *Cfa* type, subtropical humid mesothermal, according to Köppen classification (CAVIGLIONE et al., 2000).

The site where the experiment was conduced has been cultivated since 2000 in the no-till system, with a crop succession of soybean and silage corn, first and second crop respectively. After the soybean being harvested (harvest 2015/2016), the area was cultivated with corn, which was used to produce silage in April/2016. After the corn was removed, the area remained in fallow until the experiment was implanted.

The experimental design use was of randomized blocks, with six treatments and four replicates. Treatments were black oat, black oat + forage radish, forage radish, black oat + field pea, field pea and control (fallow). The total area for the experiment was 1200 m², being that each plot had 50 m².

Before sowing the cover crops the whole area was desiccated using 2.75 kg ha^{-1} from the equivalent in glyphosate acid in 04/03/2016. The winter cover crops were mechanically sown on 05/05/2016 in the no-till system with a row spacing of 0.17 m. For the cover crops sowing were used 45, 15 and 80 kg ha^{-1} of seeds, for field pea (*Pisum sativum* L.) cultivar IAPAR 83, forage radish (*Raphanus sativus* L.) cultivar IPR 116 and black oat (*Avena strigosa* S.) cultivar EMBRAPA 139, respectively. For the intercrop of forage radish with black oat and of field pea with black oat, were used 5 and 30 kg ha^{-1}, 25 and 30 kg ha^{-1} of seeds, respectively (GIACOMINI et al., 2003). No base fertilization was made in the cover crops implementation.

At 100 days after sowing, the cover crops dry matter yield was determined, using a sampling square with 0.25 m², randomly thrown twice in each plot and the plants in its interior were cut close to the ground with pruning shears. Samples of each treatment were placed into kraft paper bags and taken to dry in an air forced circulation oven at 65ºC for 72 h. Next, the remaining plants were chemically managed using 2.75 kg ha^{-1} (glyphosate acid).

After the cover crops were managed undeformed soil samples were collected in each plot for the determination of macroporosity (Ma), microporosity (Mi), total porosity (TP) and soil bulk density (Bd). The Ma and Mi analysis were made in a tension table with a -0,001 MPa potential (Ma) and -0,006 MPa (Mi), and TP by adding the results from macroporosity and microporosity (Ma + Mi) and the Bd by the relation between the dry soil mass and the total volume collected (TEIXEIRA et al., 2017).

The soil penetration resistance was determined with a digital penetrometer Falker model PenetroLog-PGL 1020, being realized five readings per plot. At the sampling, in each plot were collected three soil samples from the 0 - 0.20 and 0.20 - 0.40 m layers, to determine the soil humidity, by the standard oven method (EMBRAPA, 2011), presenting an average of 0.22 kg kg^{-1} of water.

The stability of the wet aggregates was carried out according to the methodology described by Kiehl (1979) in the 0 - 0.20 and 0.20 - 0.40 m layers. Were determined, by means of equations, the weighted average diameter (WAD) (KIEHL, 1979), geometric mean diameter (GMD) (KEMPER and ROSENAU, 1986) and aggregate stability index (ASI) (SILVA and MIELNICZUK, 1997).

Data were submitted to variance analysis, considering the p>0.05 by the F test. When significant, the means were compared by the Tukey test, at 5% probability of error, using the Sisvar statistic software (FERREIRA, 2011).

RESULTS AND DISCUSSION

Table 1 shows the results for the cover crops dry matter yield. Higher dry matter yield was obtained in the intercropping of cover crops, with an average yield of 7.56 Mg ha^{-1}, not significantly differing from each other. There was a significant difference for the cover crops in monoculture, being the smallest yield obtained in the black oat crop (4.69 Mg ha^{-1}). The smallest dry matter productivity was obtained in the control (fallow) with 0.45 Mg ha^{-1}. The forage radish dry matter yield was 6.24 Mg ha^{-1}, being inferior to the one found by Doneda et al. (2012), which found a productivity of 8.30 Mg ha^{-1}, followed by field pea, in a study carried in an Oxisoil. In a similar study carried in Guarapuava city (PR), Sanchez (2012) obtained a 12.73 Mg ha^{-1} dry matter production for the forage radish and 9.12 Mg ha^{-1} for black oats.

TABLE 1 - Average results for dry matter productivity brought to the soil by winter cover crops.

Cover crops	Dry matter (mg ha^{-1})
Black oat	4.69 c*
Forage radish	6.24 b
Field Pea	6.01 b
Black oat + forage radish	7.81 a
Black oat + field pea	7.31 a
Control	0.45 d
CV (%)	7.22
MSD	0.89

*Means followed by the same lowercase letter in the column, do not differ by Tukey's test, at 5% probability of error.

The intercrops black oat + forage radish and black oat + field pea produced 41 and 35% more plant material to the soil, when compared to the black oat in monoculture. This result indicates that the intercrop of cover crops is a favorable alternative in relation to the monoculture, because by means of intercropping it is possible to increase the soil organic matter, leading to a better chemical, physical and biological condition, and as a consequence favoring the following crop. Silva et al. (2007) also observed higher mass production in the intercrop of forage radish and black oat, with a similar study carried in an Ultisol.

According to Heinrichs et al. (2001), when cover crops are intercropped, the C/N ratio obtained is intermediary to the ones in monoculture and, consequently, they provide a soil protection for a longer period, providing nutrients to the crop in succession in a more balanced way and diversity of root systems.

As for the soil physical properties, significant differences were observed for the cover crops in the different layers evaluated (Table 2). Significant differences were observed for macroporosity (Ma) and soil bulk density (Bd). A higher Ma was observed for the 0.0 - 0.10 m layer in the treatments which had forage radish and black oat in relation to fallow. For the 0.10 - 0.20 m and 0.30 - 0.40 m layers, the treatment with black oat in monoculture was equal to the control for Ma (Table 2).

Values of Ma inferior to 0.10 m^3 m^{-3} observed in the control in all layers can affect the crop root growth due to a limitation in the root development, by the reduced gas diffusion in the soil and the difficulty in draining excess rainwater (SEIDEL et al., 2015).

For the soil microporosity (Mi) and total porosity (Tp) no differences were observed between the treatments used. The Mi is little affected by short-term management (VIANA et al., 2011). Santos et al. (2009), in a similar study, observed that the plant coverage influenced significantly the Mi values, but had no influence in the other parameters tested (Bd, Ma and Tp), differing from the results found in this study (Table 2).

For the 0.20 - 0.30 m layer all treatments showed a smaller value for Bd in relation to the control (Table 2). The 0.10 - 0.30 m layer is the one with the highest Bd values, result similar to the observed in the soil penetration resistance evaluation (Figure 1), mainly in the control treatment.

Debiasi et al. (2010) showed that black oat and the intercrop of black oat + vetch had the smallest values for Bd and highest for Tp and Ma, similar to this study, in which the black oat + field pea intercrop had the smallest Bd values, differing from the control. For the Bd, Reichert et al. (2003) report that for soils with a clay content similar to the one in this study, the critical limit for plant development is in between 1.40 and 1.50 Mg m^{-3}. It is observed that the control presents values within the critical range (Table 2), which may be justified by the silage making process during 12 consecutive years, showing how important it is the use of cover crops, which help in the improvement of the soil physical properties.

The improvement caused in the soil structure by using the cover crops provides benefits to the soil porosity and aeration, as observed by Abreu et al. (2004). However, these improvements occur in a more expressive way after the cover crops have their roots fully decomposed, forming pores more stable and favoring the plant development due to a better soil physical condition (FERREIRA et al., 2000).

It is possible to affirm that despite the significant difference observed in relation to the soil physical properties, they are still not capable of promoting expressive benefits to the cultivation system, mainly regarding increases in the crop's yield, being necessary the continuity in the management with cover crops to promote even more improvements to the soil structure, consequently leading to an increase in the productivity of the implanted cultures.

TABLE 2 - Average results for the soil physical properties with different winter cover plants and soil evaluation layers.

Soil layer (m)	Macroporosity (m^3 m^{-3})					
	BO	FR	FP	BO + FR	BO + FP	C
0.00 – 0.10	0.1033 a*	0.1032 a	0.1004 ab	0.1057 a	0.1025 a	0.0916 b
0.10 – 0.20	0.0985 ab	0.0986 ab	0.0995 a	0.1053 a	0.1009 a	0.0842 b
0.20 – 0.30	0.0966 a	0.0978 a	0.0978 a	0.0999 a	0.0986 a	0.0841 b
0.30 – 0.40	0.0907 ab	0.0958 a	0.0947 a	0.0948 a	0.0953 a	0.0828 b
	Microporosity (m^3 m^{-3})					
0.00 – 0.10	0.4322 ^{ns}	0.4016 ^{ns}	0.4480 ^{ns}	0.4353 ^{ns}	0.4216 ^{ns}	0.3996 ^{ns}
0.10 – 0.20	0.4391	0.4444	0.4503	0.4224	0.4386	0.4713
0.20 – 0.30	0.4137	0.4235	0.4830	0.4371	0.4315	0.4644
0.30 – 0.40	0.4311	0.4551	0.4495	0.4479	0.4413	0.4604
	Total porosity (m^3 m^{-3})					
0.00 – 0.10	0.5355 ^{ns}	0.5048 ^{ns}	0.5484 ^{ns}	0.5907 ^{ns}	0.5240^{ns}	0.4912 ^{ns}
0.10 – 0.20	0.5673	0.5429	0.5498	0.5277	0.5395	0.5544
0.20 – 0.30	0.5103	0.5213	0.5808	0.5369	0.5301	0.5485
0.30 – 0.40	0.5218	0.5509	0.5443	0.5428	0.5366	0.5432
	Bulk density (mg m^{-3})					
0.00 – 0.10	1.23 ^{ns}	1.24 ^{ns}	1.30 ^{ns}	1.32 ^{ns}	1.34 ^{ns}	1.25 ^{ns}
0.10 – 0.20	1.23 b	1.38 ab	1.32 ab	1.32 ab	1.31 ab	1.46 a
0.20 – 0.30	1.37 b	1.37 b	1.35 b	1.32 b	1.30 b	1.57 a
0.30 – 0.40	1.27 b	1.43 b	1.35 ab	1.29 ab	1.32 ab	1.41 ab

*Means followed by the same lowercase letter on the line, do not differ by Tukey's test, at 5% probability of error. ^{ns} = not significant. BO = black oats, FR = forage radish, FP = field pea, C = control.

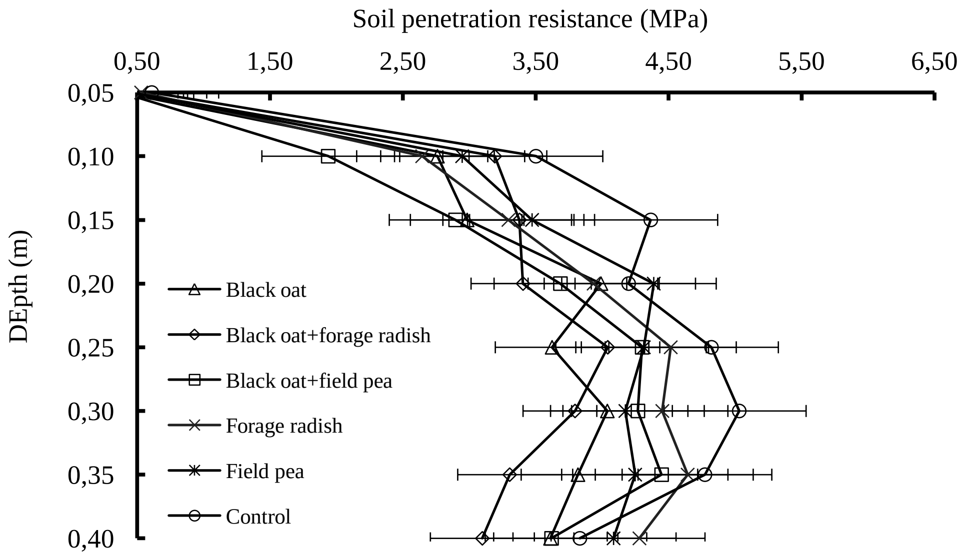

FIGURE 1 - Average results for soil penetration resistance with different cover crops.

For the soil penetration resistance (Pr) a significant difference was observed ($p<0.05$) between the treatments used only for the 0.15 m depth, where the intercrop of black oat + field pea was the only one that differed from the control. In the other depths evaluated the treatments presented no significant difference (Figure 1).

The Pr values observed were high, above the critical limit which is 2.0 MPa, which was expected, because this area has been used for silage production for many years. For the silage production the machinery traffic is constant, and it is worsened by the crop management being made in a condition when the soil humidity is above the friable consistency, allied to the higher clay content of the soil where the experiment was made (ROSSET et al., 2014).

In a study carried by Rosset et al. (2014), evaluating the soil physical properties in different conversion times from the tillage system to the no-tillage system, in the western Paraná, it was observed in the soil bulk density and penetration resistance, values superior to the critical limit, which suggests the occurrence of compacted subsurface layers that can negatively affect the crop development (DIMASSI et al., 2013).

Regarding the soil aggregation, no significant difference was observed (p>0.05) between the treatments used (Table 3). Among the factors that influence soil aggregation is the presence of iron (Fe) and aluminum (Al) oxides and hydroxides and organic matter (BASTOS et al., 2015), being that in more weathered soils, as the Oxisoil, the main agents responsible for the aggregates stabilization are the Fe and Al oxides and hydroxides (FERREIRA et al., 2007).

TABLE 3 - Weighted average diameter (WAD), geometric mean diameter (GMD) and aggregate stability index (ASI), after the cultivation of winter cover crops, at different evaluation depths.

Treatments	WAD (mm)	GMD (mm)	ASI (%)
		0.0 – 0.20 m	
Black oat	2.18 ns	1.25 ns	97.29 ns
Forage radish	2.44	1.44	96.04
Field pea	2.45	1.37	95.99
Oat + forage radish	2.23	1.17	95.95
Oat + field pea	2,44	1.36	96.04
Control	2,13	1.15	96.23
		0.20 – 0.40 m	
Black oat	2.04 ns	1.13 ns	97.01 ns
Forage radish	2.53	1.57	96.21
Field pea	2.40	1.40	96.36
Oat + forage radish	2.24	1.26	96.17
Oat + field pea	2.34	1.27	96.21
Control	2.11	1.08	95.59

ns = not significant.

The presence of Fe and Al oxides and hydroxides in Oxisoils can explain why the aggregate stability was not significantly influenced in the short period, because according to Tisdall and Oades (1982), Fe and Al oxides and hydroxides are linked to the presence of smaller, but very stable aggregates, which are difficult to change in a short period of time. According to Ambrosano et al. (2009), the use of cover crops favors the soil aggregation due to the root's activity, through the release of exudates that cement the particles, by the higher addition of mass and by the fastest plant decomposition, however, in order to observe significant changes, a longer period is necessary.

Besides, the adoption of conservative practices based in the minimal tillage, in the correct residual management and in the inclusion of cover crops that favors the crop rotation can avoid the occurrence of degradation of the organic matter, besides keeping or recovering the soil structure (BAYER et al., 2006). The highest mass production of the cover crops, compared to the fallow area, benefits the formation and stabilization of soil aggregates, due to the roots action, the increases in the organic matter content and microbial activity (MADARI et al., 2005).

CONCLUSIONS

The intercrop of black oat with field pea and with forage radish provided the highest dry matter yield, showing the potential of dry matter accumulation in relation to monoculture.

The cover crops were capable of improving the soil macroporosity, bulk density and penetration resistance when compared to the fallow area (control); however, they had no influence in soil aggregation due to the high compaction degree in the area.

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