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Effect of cover crops on common bean yield and soil physical properties under no-till system

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ABSTRACT. The aim of this study was to evaluate dry matter production of cover crops (oats, turnip, vetch and spontaneous plants) and their effect on bean yield and physical properties of soil after succession. The experimental design was randomized blocks, and treatments consisted of four species of cover crops: oat, turnip, vetch and spontaneous plants, with five replications. The cover crops were sown in winter; when in full bloom, they were cut close to the ground and left underground. The bean crop was then sown underneath this residue in a no-till system. The results show that the cover crop that yielded the most dry matter was oats with 4,900 kg ha^{-1}, which did not differ statistically from turnip with a yield of 4,000 kg ha^{-1}. The spontaneous plants produced the least amount of dry matter and differed from the other treatments. The development of vetch was hampered by the environmental conditions of Marechal Cândido Rondon, State of Paraná, with dry matter yield of 2,375 kg ha^{-1}. The highest bean yield (1,204 kg ha^{-1}) was found for the planting carried out in succession to oat, and the lowest after succession of vetch (697 kg ha^{-1}) and spontaneous plants (575 kg ha^{-1}). Cover crops had no effect on macroporosity and total porosity of soil depth from 0.05 to 0.20 m. There was a statistical difference in soil bulk density in the layer from 0.05 to 0.10 m, and bulk density (1.18 kg dm^{-3}) was obtained in the treatment where the bean crop was cultivated after spontaneous plants.

Keywords: green manuring, crop rotation, oat, oilseed radish, vetch, spontaneous plants.

Efeito de plantas de cobertura sobre a produtividade do feijão e propriedades físicas do solo em sistema de plantio direto

RESUMO. O objetivo do trabalho foi avaliar a produção de massa seca de plantas de cobertura de aveia preta, nabo forrageiro, ervilhaca comum e plantas espontâneas e seu efeito na produtividade do feijão e nas propriedades físicas do solo após a sucessão. O delineamento experimental utilizado foi de bloco ao acaso; os tratamentos foram constituídos de quatro espécies de plantas de cobertura: aveia preta, nabo forrageiro, ervilhaca comum e plantas espontâneas (pousio), com cinco repetições. As plantas de cobertura foram semeadas no inverno e quando estavam em pleno florescimento foram cortadas rente ao solo e deixadas sob o solo. Sob esta palhada a cultura do feijão foi semeada, no sistema de plantio direto. Os resultados demonstram que a planta de cobertura que proporcionou maior produção de massa seca foi à aveia preta com 4.900 kg ha^{-1}, sendo que não diferiu estatisticamente do nabo forrageiro com produção de 4.000 kg ha^{-1}. A vegetação espontânea produziu a menor quantidade de massa seca, e diferiu dos demais tratamentos. A ervilhaca apresentou o seu desenvolvimento prejudicado nas condições edafoclimáticas da região de Marechal Cândido Rondon, Estado do Paraná. A produção de massa seca da ervilhaca foi de 2.375 kg ha^{-1}. A maior produtividade da cultura do feijão de 1.204 kg ha^{-1} foi constatada para o plantio realizado em sucessão a aveia preta e as menores produtividade de 697 kg ha^{-1} e 575 kg ha^{-1} após sucessão de ervilhaca comum e plantas espontâneas respectivamente. As plantas de cobertura não influenciaram na macroporosidade, microporosidade e porosidade total do solo na profundidade de 0,05 a 0,20 m. Houve diferença estatística para a densidade do solo na profundidade de 0,05 a 0,10 m, sendo a maior densidade do solo de 1,18 kg dm^{-3}, obtida no tratamento em que a cultura do feijão foi cultivada em sucessão as plantas espontâneas.

Palavras-chave: adubação verde, rotação de culturas, aveia preta, nabo forrageiro, ervilhaca, plantas espontâneas.

Introduction

The common bean (*Phaseolus vulgaris* L.) is one of the main crops in Brazil, and has been developed under different technological levels and areas in various regions of the country. Nationawide production for the 2009/2010 harvest reached 3.3 million tons of beans. Paraná State contributed 24% with production around 800 thousand tons, followed by Minas Gerais State (19%) with 620 thousand tons (CONAB, 2010). In Brazil, the average yield of the common bean is 741 kg ha^{-1}, produced under levels of fertilization outside the recommended range (AGRIANUAL, 2004).

The search for higher yields and improvements in physical, chemical and biological soil properties require studies aimed at improving bean crop management systems. The no-till system may be an alternative for increasing the yield of this culture. Adding a good amount of straw is essential for maintenance of that system. The use of cover crops in winter in Brazil's southern region has been a good option to maintain soil moisture, reducing the risk of water deficit in the crop, as the bean root system is very shallow (SIMIDU et al., 2010).

Cover crops are grown with the purpose of protecting against soil erosion and nutrient loss, as well as to keep the soil surface permanently covered with plant or vegetative waste, and effectively managing most recommended for the protection and conservation soil (REBERG-HORTON et al., 2012; ALVARENGA et al., 2001).

In western Paraná, which features wet autumn and winter, the most used species as cover crop is the oat. In addition to protecting the soil, it serves as fodder for dairy cattle. According to Giacomini et al. (2004), there is interest by corn producers of corn in including other species such as vetch and radish, with the objective of reducing the use of nitrogen fertilizers.

Several studies have shown oat can to be an excellent option for biomass production, due to slow its decomposition, allowing crop residues to remain longer in the soil (DERPSCH et al., 1985). However, oats have smaller amount of N accumulation in biomass and release it slowly after handling. This can affect the supply of N and compromise the yield of subsequent crops (AITA et al., 2001; HEINRICHS et al., 2001).

Other suitable plants for soil cover are: vetch, for its ability to fix atmospheric N_2 (AITA; GIACOMINI, 2003; AMADO et al., 2000; HEINRICHS et al., 2001); radish, for its N cycling efficiency in soil. In some cases, those species provide grain yields equivalent to mineral nitrogen (AITA et al., 2001; GIACOMINI et al., 2004; HEINRICHS et al., 2001), although their crop residues are quickly broken down and therefore not very efficient in protecting the soil against erosive agents (WANG et al., 2012).

The use of cover crops in winter – before the main crop – in addition to producing biomass that enables no-till sowing (SOUZA; ALVES, 2003), can minimize the negative effect of soil degradation, because the mechanical action of roots or excretion of substances with cementing action may improve soil aggregation and structure (ROSA et al., 2012; ALBUQUERQUE et al., 2005; KOCHHANN; DENARDIN, 2000; WOHLENBERG et al., 2004) and can reduce the oscillation and amplitude of surface soil temperatures and evapotranspiration rates (COSTA et al., 2007).

According to Ingaramo, as cited by Alves et al. (2007), some of the main properties and physical factors to evaluate soil quality are: soil porosity, pore size distribution, soil bulk density, mechanical strength, hydraulic conductivity, particle size, and distribution and depth at which roots grow.

This work was carried out due to the need for further studies with winter cover crops under no-till for the bean crop. The aim of this study was to evaluate the dry matter yield of cover crops oat, wild radish, vetch and spontaneous plants, and their effect on bean yield and the physical properties of soil after succession.

Material and methods

The field experiment was carried out at the Experimental Station Professor. Dr. Antonio Carlos dos Santos Pessoa of the Experimental Stations Nucleus, State University of Western Paraná (UNIOESTE), located in the municipality of Marechal Candido Rondon, Paraná State, Brazil. The geographical coordinates are 54°01'45"W and 24°31'42"S, with an average altitude of 420 meters and mean declivity of 4%.

The Köppen climate classification is Cfa, a humid subtropical climate (mesothermal), hot, humid summers with a tendency for rainfall concentration (average temperature above 22°C), winters with infrequent frosts (average temperature below 18°C), with no defined season. The annual average rainfall is 1,500 mm. The soil of the experiment was classified as an Oxisol with clayish texture (EMBRAPA, 2006). Soil samples were collected from the 0-0.20 m layer and sent to the Laboratory of Environmental Chemistry and Instrumental Soil Fertility for chemical analysis (RAIJ et al., 2001). Analysis results should that the soil had the following chemical characteristics before the experiment: Ph = 4.83 ($CaCl_2$), $H^+ + Al^{3+}$ = 6.25 $cmol_c$ dm^{-3}, Al^{3+} = 0.15 $cmol_c$ dm^{-3}, P = 2.93 mg dm^{-3}, K = 0.58 $cmol_c$ dm^{-3}, Ca^{2+} = 4.44 $cmol_c$ dm^{-3}, Mg^{2+} = 1.73 $cmol_c$ dm^{-3} and 48.53 g dm^{-3} of organic matter. The use of the experimental area prior to implementation of the experiment was being conducted under a no-till system.

The experimental design was completely randomized blocks; the treatments consisted of four species of cover crops: oats (*Avena strigosa*), radish

(*Raphanus sativus*) and vetch (*Vicia sativa*) and a treatment in fallow land with winter weeds (control), with five replications. Each plot consisted of 9.0 m^2 of ground area.

In June 2008, cover crops were sown by hand, with spacing of 0.17 m, using 50 kg ha^{-1} of oat seed, 20 kg ha^{-1} radish seed and 45 kg ha^{-1} vetch seed, as recommended by Calegari and Ralich (2007). Sowing was done manually in the groove. Cover crops were cut when in full bloom, which occurred 90 days after sowing (DAS), leaving crop residues on the soil surface.

The cover crops were cut when oat was at the full flowering stage, vetch at flowering and radish at the end of flowering. To evaluate the fresh and dry matter of cover crops, two samples of 0.25 m^2 were randomly collected per plot, with the aid of a 0.5 x 0.5 m frame. First, the fresh matter was determined by weighing, and then the plants were dried in a forced air oven at 65 ± 2°C until reaching constant weight.

Fourteen days after cover crops were cut, evaluations were made of weed incidence in the plots of each treatment. The density and amount of shoot dry matter of weeds present in the plots were evaluated. To that end, one set plants within a 0.25 m^2 frame were collected per plot. The numbers of broadleaf, grasses and total plants were determined; they were then dried in a forced air circulation oven at 65 ± 2°C for 72 hours and weighed on a precision scale.

In October 2008, common bean (*Phaseolus vulgaris* L.) cv. IAPAR 81 - Carioca was sown by hand, using 13 to 15 seeds per meter with 0.50 m spacing between rows. The seeds were previously treated with fungicide Benomyl (100 g of a.i. 100 kg^{-1} of seed).

For fertilizer, 25 kg ha^{-1} of N, 50 kg ha^{-1} of P_2O_5 and 50 kg K_2O ha^{-1} were used, applied in the row, using urea, triple superphosphate and potassium chloride as sources, respectively. The rest of the nitrogen fertilizer was applied in top dressing 14 days after emergence by applying 30 kg ha^{-1} of N as urea.

Weed control and plant treatment were performed as needed and according to technical recommendations for the crop. The plants were harvested manually at the end of January, eliminating the two side rows and 0.5 m from the end of each row. The weight of one thousand seeds was determined by the average of eight samples of 100 grains taken at random, by correcting the moisture content to 130 g kg^{-1}. After the average value was taken, it was multiplied by ten and yield estimated was obtained.

After harvesting the beans, the undisturbed soil samples were taken with a 0.001175 m^3 steel cylinder (0.047 m in diameter and 0.025 m in height) at depths from 0.0-0.10 and 0.10-0.20 m. Soil samples were collected for physical analysis using a sampler developed by the UNIOESTE Laboratory of Agricultural Mechanization (LAMA). First, the samples were saturated by capillarity in trays, up to about two-thirds the height of the samples, for 48h. Total porosity was calculated as the water content of the saturated soil. The quantification of the values of macroporosity (pores ≥ 50 mm) and microporosity (pores ≤ 50 micron) was obtained by subjecting all samples to the potential of -0.006 MPa (EMBRAPA, 1997) using a tension table. The macropores were estimated as the difference between water content and saturated water content of the soil after application of the -0.006 MPa potential. The micropore volume was estimated as the water content retained in the potential of -0.006 MPa. Soil bulk density was determined by volumetric ring, where soil samples were dried at ± 105°C for 24 hours (CAMARGO et al., 2009).

The results were subjected to analysis of variance. The averages were compared by t test at 5% probability. The statistical program SISVAR (FERREIRA, 2000) was used for the analysis.

Results and discussion

The production of fresh and dry matter of cover crops and weeds is presented in Table 1. The results show that there were significant differences between the different species used, and the highest yields of fresh and dry matter were obtained with the cultivation of oats and wild radish.

The cover crop with the highest yield of dry matter was oat with 4,900 kg ha^{-1}, which did not differ statistically from radish with 4,000 kg ha^{-1}. The dry matter yield of oats is appropriate, considering that sowing occurred late and without fertilization. Similar results were obtained by Heinrichs et al. (2001) and Ceretta et al. (2002), whose dry matter production of oats were 4,910 and 4,050 kg ha^{-1}, respectively.

Table 1. Fresh and dry matter yield of different cover crops and weeds in winter. UNIOESTE. Marechal Candido Rondon, Paraná State, 2008.

Cover crops	Fresh Matter	Dry Matter
	(kg ha^{-1})	
Spontaneous plants	3,950 c	1,180 c
Oat	16,150 a	4,900 a
Turnip	7,400 b	2,375 b
Vetch	18,250 a	4,000 a
CV (%)	32.14	57.60

Averages followed by the same letter in the column did not differ by Tukey's test at 5% probability.

The spontaneous plants produced the least amount of fresh matter and dry matter, and differed from other treatments. The development of vetch was hampered by the environmental conditions in the region of Marechal Candido Rondon, State of Paraná. The dry matter production was 2,375 kg ha^{-1} – lower than oat and turnip. The dry matter yield was below its production capacity, which according to Calegari and Ralich (2007) ranges from 3,000 to 5,000 kg ha^{-1}, although Heinrichs et al. (2001) also had a lower dry matter yield (2,730 kg ha^{-1}) in their research. This low yield of vetch may be related to the slow development of this species due to the drought that occurred during the experiment.

Corroborating the results by Aita and Giacomini, (2003), also found lower dry matter yield for vetch as compared to oats.

In assessing the weight of one thousand seeds after a succession of different cover crops and weeds, there were no significant differences ($p > 0.05$) between the treatments. The yield of bean was influenced by different cover crops (Table 2).

Table 2. Weight of one thousand seeds and yield of common bean after succession with different cover crops. UNIOESTE. Marechal Cândido Rondon, Paraná State, 2008.

Cover crops	Weight of one thousand seeds (g)	Yield (kg ha^{-1})
Spontaneous plants	190 a	575 c
Oat	208 a	1204 a
Turnip	200 a	697 c
Vetch	203 a	982 b
CV (%)	4.16	14.57

Averages followed by the same letter in the column did not differ by Tukey's test at 5% probability.

The highest bean yield (1,204 kg ha^{-1}) was found for the sowing carried out in succession to black oats. This was likely due to the high dry matter yield of oat (4,900 kg ha^{-1}), which provided better ground cover. In addition, oat straw remains longer in the soil, because its decomposition is slower than vetch and radish. Its slow decomposition is due to the fact that this culture has a C/N ratio of 36.5 – higher than the other cover crops, which resulted in greater protection by reducing soil moisture losses (COSTA et al., 2007). Nevertheless, Lopes et al. (2007) found no significant differences in water content in the soil during studies with soybean crops under different cover crops.

Another reason for the increased yield of bean after the succession of oat straw is that oat is also a supplier of nutrients to crops succeeding in the medium and long term, especially in the surface layer – for instance the significant increases in levels of P and K in the surface layers of soil (FLOSS, 2000; GAMA-RODRIGUES et al., 2007).

Similar results were observed by Bittencourt et al. (2009), who obtained a yield of bean crops of 1,734 kg ha^{-1} after a succession of oat cultivated in winter. Different results were obtained by Giacomini et al. (2004), with the highest grain yield of maize obtained in treatments with single vetch compared to that obtained after single oat. The grass surpassed the legume by 34%.

The yield of bean plants after a succession of common vetch (697 kg ha^{-1}) and weeds (575 kg ha^{-1}) was drastically reduced. This is likely due to low dry matter yield, as well as the rapid decomposition of vetch straw (AITA; GIACOMINI, 2003; BASSO; CERETA, 2000), which may have resulted in reduced water availability in the soil.

Table 3 presents soil physical results. It was found that the various cover crops did not influence the macro-, micro- and total soil porosity at soil depths from 0.05 to 0.20 m.

It was expected that the cover crops would lead to improvement in soil porosity, but that did not occur. This was certainly due to the low dry matter yield of the cover crops, as a result of the drought that occurred during the experiment. Bertol et al. (2004) and Sousa Neto et al. (2008) also found no statistical difference between treatments for soil porosity when evaluating the physical properties of a soil under conventional tillage and no-till in crop rotation and succession.

The study observed no differences in microporosity between the two management systems, corroborating the results of Tormena et al. (2004) when evaluating the physical properties of soil ten years after using no-till alternated with scraping in a soybean-winter maize or wheat succession system and no-till of continuous corn-wheat-soybean-oats-soybean-radish. Similar results were observed by Alves and Suzuki (2004), who found no significant differences in macroporosity, microporosity, total porosity and bulk density of the soil after cultivation of four cover crops.

A statistical difference was found for the bulk density of the soil between weeds and other cover crops in the layer from 0.05 to 0.10 m (Table 3). The density in that layer ranged from 1.07 to 1.18 kg dm^{-3} and was lower than 1.55 kg m^{-3}; this is considered limiting for annual crops in soils with 200 to 550 g kg^{-1} of clay (REICHERT et al., 2003). The highest bulk density of 1.18 kg dm^{-3} was obtained in a treatment in which the bean crop was grown in succession to spontaneous plants. The explanation for higher value of soil bulk density in the fallow area is the lower dry matter yield of weeds (1,180 kg ha^{-1}).

Table 3. Macroporosity, microporosity, total porosity and bulk density of the soil in depths from 0.05 to 0.10 and 0.10 to 0.20 m after succession with different cover crops. UNIOESTE, Marechal Cândido Rondon, Paraná State.

Cover crops	Macroporosity	Microporosity	Total Porosity	Bulk density (kg dm^{-3})
		(m^3 m^{-3})		
		0,05-0,10 m		
Fallow	0.16 a	0.37 a	0.53 a	1.18 a
Oat	0.17 a	0.38 a	0.55 a	1.11 b
Turnip	0.15 a	0.37 a	0.52 a	1.07 b
Vetch	0.19 a	0.40 a	0.59 a	1.09 b
CV (%)	14.56	13.65	10.44	4.56
		0,10-0.20 m		
Fallow	0.17 a	0.38 a	0.55 a	1.08 a
Oat	0.20 a	0.36 a	0.56 a	1.08 a
Turnip	0.17 a	0.38 a	0.55 a	1.10 a
Vetch	0.15 a	0.37 a	0.53 a	1.09 a
CV (%)	9.15	6.96	5.15	7.25

Averages followed by the same letter in the column did not differ by Tukey's test at 5% probability.

Conclusion

Oat and radish were able to provide good amounts of dry matter, confirming the viability for production of ground vegetation cover during winter conditions in Marechal Candido Rondon, State of Paraná.

Under the experimental conditions of this work, the common vetch produced low amounts of dry matter.

The highest yield of beans was obtained after the succession of black oat and oilseed radish, and the use of vetch and/or fallow compromised bean yield.

Macroporosity, microporosity and total porosity were not affected by cover crops. Soil density at depths from 0.05 to 0.10 m was higher in in the treatment with weeds.

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