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Effect of cover crops on physico-chemical attributes of soil in a short-term experiment in the southwestern Amazon region

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No-tillage is an agricultural system that is proposed as a sustainable soil management system. This paper aims to evaluate the short-term effects of cover crops on a no-tillage system, by assessing a number of physical and chemical attributes of soil of the Brazilian Amazon region. The experiment was carried out in a typical Ferralsol under a no-tillage system from March to December, 2014. A randomized block design, with four replicates was used. The performance and effects of fourteen cover crops (*Cajanus cajan*, *Canavalia ensiformis*, *Crotalaria juncea*, *Crotalaria ochroleuca*, *Crotalaria spectabilis*, *Stizolobium aterrima*, *Stizolobium cinereum*, *Pennisetum glaucum*, *Sorghum bicolor*, *Sorghum sudanense*, *Urochloa brizanha* cv. Xaraés, *Urochloa brizantha* cv. Piatã and *Urochloa ruziziensis* and *Zea mays*) and fallow (control treatment) on the soil quality were assessed. The cover crops were sown in the off season in April 2014, before the summer crop (maize). The levels of P, K, Ca^{2+}, Mg^{2+}, Al^{3+}, H+Al, saturation by aluminum, sum of bases, organic matter, pH and resistance to soil penetration were evaluated following the end of the cover crops growth. Some near-surface soil attributes were affected by the cover crops. *Urochloa* species improved the levels of potassium in the soil at depths up to 5 cm below the surface. The highest penetration resistance was observed in the superficial layer between 12 and 16 cm deep, with penetration resistance values varying between 2472 and 2912 kPa. The *Urochloa* exhibited satisfactory agronomic performance when grown under a simulated crop livestock integration system. It is concluded that the use of cover crops in a no-till system has the potential to improve the chemical quality of soil in the Southwestern Amazon region.

Key words: No-tillage, ecological intensification, sustainability, Rondonia, green manure.

INTRODUCTION

In the Amazon region, conventional agriculture is characterized by traditional practices of soil management, that provide significant and deleterious changes in the chemical, physical and biological properties of the soil, leading to a potential decline in the productive capacity of the agroecosystems (Schlindwein et al., 2012). Thus, the

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development and utilization of technologies that increase productivity in arable areas or that recover degraded areas are important to avoid increased deforestation of the native vegetation in the region (Cerri et al., 2010; Tollefson, 2010).

Crop yields in the tropical soils in Amazon are, in most cases, unsatisfactory due to low natural soil fertility and low investment capacity by farmers (Davidson et al., 2012). Soil mineralization and the loss of fertility, particularly organic matter, is high due to high temperatures together with high rainfall, that are experienced especially when tilling soil (Schlindwein et al., 2014). The use of a no-tillage system has proven to be an effective strategy to increase productivity and maintain sustainability of agroecosystem, this not only conditions the soil, thereby improving the supply of nutrients and water to plants (Mahama et al., 2016), but also provides benefits in terms of the physiology of plants such as increased grain yield (Carvalho et al., 2015; Aker et al., 2016).

Cover crop used in the implementation and maintenance of the no-tillage system is a key factor in its success (Derpsch et al., 2014). Cover crops keep the soil surface continuously covered by straw, recycling nutrients and making them available for successive crops via the gradual decomposition of the organic residues (Bender and Van Der Heijden, 2015). However, the perception of the use of straw by farmers can be very negative due the cost of implementation and the lack of information about the economic returns on the investment (Cerdà et al., 2017).

Negative changes in soil chemical and physical attributes have been found to be more pronounced when a conventional tillage system is employed as compared to systems adopting a conservation focused approach (Bogunovic et al., 2017). The use of cover crops promotes greater nitrogen cycling in agroecosystems, boosting the availability of nutrients to crops (Blanco-Canqui et al., 2014). Considering the predominance of dystrophic soils in the region, the use of leguminous plants which are able to fix atmospheric nitrogen as cover crops, provides a potential benefit by reducing the use of fertilizers (Rosa et al., 2011; Albuquerque et al., 2013). This is especially true when considering nitrogenous fertilizers, which are expensive and can be lost by leaching or volatilization (Mahama et al., 2016). Cover crops represent a strategy to avoid high emission of greenhouse gases resulting from agriculture and thereby contribute to mitigating the effects of climate change and promoting increased sustainability of agro-ecosystems (Lal, 2015; Basche et al., 2014).

Soil erosion and compaction may be responsible for soil depletion and reduce crop yields in the degraded areas (Chen and Weil, 2011; Martínez-Hernández et al., 2017). The resistance to penetration is a physical property of the soil used to evaluate the effect of soil management system on the root environment (Calonego et al., 2017). Depending on the level of compaction, root growth of the crops may be impaired (Cardoso et al., 2013), with negative effects on yield (Bogunovic et al., 2017). Soil resistance to root penetration is directly linked to the density and distribution of pores that are formed following the decomposition of plant roots (Lin et al., 2016). When the decomposition of these roots occurs due the activity of microorganisms, the soil pores and aggregates that form are more stable and have enhanced durability due the substances that act as cements in the walls of the pores (Nunes et al., 2014).

Straw positively contributes to the recovery and maintenance of soil quality (Mendonça et al., 2015; Pereira et al., 2016). The amount and quality of straw produced that determines the beneficial effects on soil fertility (Derpsch et al., 2014), depends on the appropriate choice of cover plants (Castro et al., 2015). Knowledge on the dynamics and the processes involved in the cycling of nutrients in the agrosystems will allow greater efficiency in the use of cover crops and a reduction in the negative impacts on the environment (Nascente et al., 2015). However, research on cover crops options in the Amazon region is scarce and so further information is required to assess the viability of no-tillage systems in the region.

The aim of this paper is to evaluate promising cover crops and determine their effects on a range of soil attributes in no-tillage system in the Southwestern Amazon region.

MATERIALS AND METHODS

The study was carried out in the experimental field of Embrapa (Brazilian Agricultural Research Corporation), in the city of Porto Velho, in the state of Rondonia, located at latitude 8°47'53'' S, longitude 63°51'02'' W, 87 m a.s.l. The experiment was carried out in the 2014/2015, with sowing of cover crops performed in the off season of 2014 prior to the subsequent summer maize crop. The experimental area was cultivated with soybean under no-tillage since 2008. The soil is classified as a typical dystrophic Ferralsol. Prior to the planting of cover crops, soil sampling and analysis was carried out to characterize the chemical properties (Table 1).

According to the Köppen classification, the regional climate is classified as Aw, tropical dry and wet, with an average annual temperature of 25.6°C (Alvares et al., 2013). The average annual rainfall is 2,200 mm, with a potential evapotranspiration annual average of 1,455 mm (Cunha, Shöffel, 2011), a rainy season from October to May and dry season from June to September (Alvares et al., 2013). Climatological data for the experimental period is presented in Figure 1.

In succession to a soybean crop that was cultivated from October 2013 to February 2014, fourteen species of cover plant were planted in March 2014: *Urochloa brizantha* cultivar Piatã; *Urochloa brizantha* cv Xaraés; *Urochloa ruziziensis*; sudan grass (*Sorghum sudanense* cv BRS estribo); pearl millet (*Pennisetum glaucum* cv BRS 1501); sorghum (*Sorghum bicolor* cv BRS 310); *Crotalaria juncea*; *Crotalaria ochroleuca*; *Crotalaria spectabilis*; pigeonpea (*Cajanus cajan*); jack bean (*Canavalia ensiform*); velvet bean (*Stizolobium cinereum*) and black Mucuna (*Stizolobium aterrima*), maize (*Zea mays* cv BR 106) and fallow (control plot).

Table 1. Analysis of the chemical attributes of the topsoil (0 to 0.20 m depth).

pH	OM	P	K	Ca^{2+}	Mg^{2+}	H+Al	Al^{3+}	CEC	AS	SB
H_2O	g kg^{-1}	mg dm^{-3}		---------------------- $cmol_c$ dm^{-3} ----------------					%	
5.05	38.36	7.13	0.20	2.67	1.96	10.77	1.59	15.61	27.81	30.25

The topsoil (0 - 20 cm) was analyzed for pH in water 1:2.5, organic matter content (OM) ($K_2Cr_2O_7$ 0.167 mol L^{-1}), phosphorus (P) (Mehlich 1), potassium (K) (Mehlich 1), calcium (Ca^{2+}), magnesium (Mg^{2+}), potential acidity (H+Al), aluminum (Al^{3+}) (KCl 1 mol L^{-1}), cation exchange capacity (CEC), aluminum saturation (AS) and sum of bases (SB).

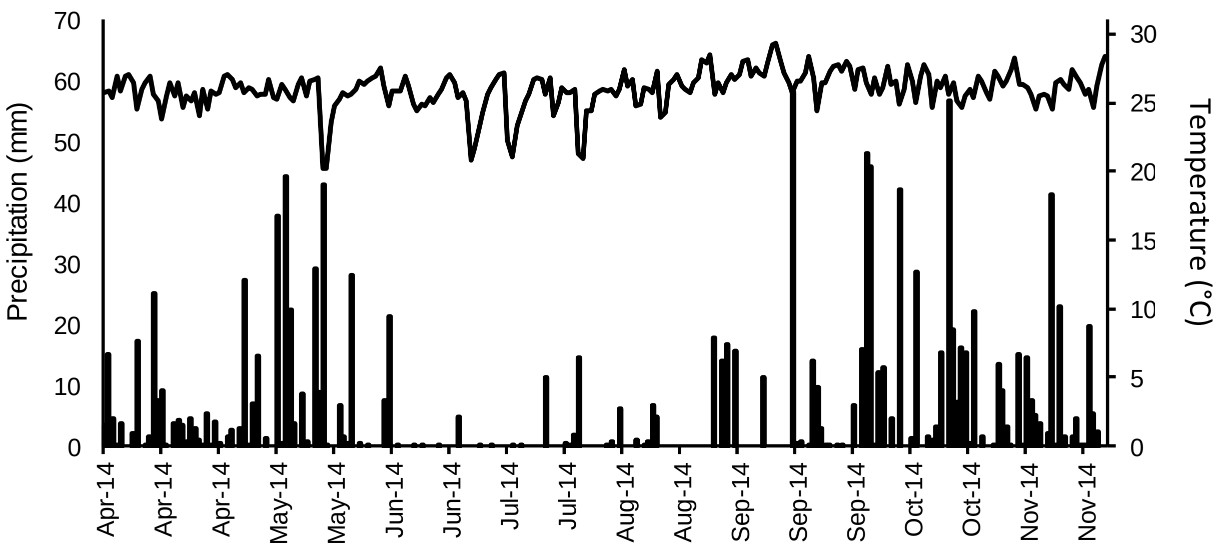

Figure 1. Daily rainfall (mm) and mean daily temperature (°C) of the experimental period from April 2014 to October 2015 in Porto Velho, Rondonia.
Source: National Institute of Meteorology and State Department of Environmental Development.

The spacing between planted row was 0.9 m for corn, 0.45 m for legumes and sorghum, and 0.225 m for all other crops. No rhizobium inoculation of legume seeds or application of fertilizer was used for any of the cover species. A completely randomized block experimental design was used, with four replicates. The dimensions of each plot were 50 m^2 (5 m x 10 m).

To evaluate the area of vegetation cover for each of the species, the leaf area index (LAI) was measured, which represents an indicator of protection and effectiveness of the cover crops (Derpsch et al., 2014). The maximum LAI was determined indirectly by a light attenuation method measured using a LAI-2000 canopy analyzer. The LAI measurements were made weekly at different points during the growth of the cover crops to obtain the maximum value for each treatment (Welles and Norman, 1991).

Evaluation of the yield of fresh and dry biomass of the plants and accumulation of nitrogen in the shoot tissue were carried out. The cover plants were cut, with a costal brush to 15 cm height from the surface. Termination of the cover crops was carried out by grouping the species into three groups. The cutting phases occurred for the group A (maize, millet, sorghum and sudan grass) on grain maturation; group B (legumes) when the species were in full bloom; and group C (*Urochloa* and fallow) receiving three cuts, performed at 55, 108 and 172 days after sowing (DAS). The *Urochloa* species received three cuts during their cycle, aiming to simulate grazing of the plants in an integrated crop-livestock system. All plots were desiccated prior to sowing of the maize crop in October, using a mixture of 1,440 g ha^{-1} glyphosate + 25 g ha^{-1} flumioxazine + 0.5% mineral oil.

After harvesting of crops, the samples were dehydrated in an oven (65°C for 72 h) and weighed to obtain the dry biomass. From these samples, a portion was removed and shredded in a Willey mill (2 mm mesh) to determine the nitrogen accumulation in the shoot (Embrapa, 2009). The replacement cost of this nutrient via application of urea, was calculated by taking into account the composition of the nitrogen fertilizer as 45% of N and having a purchase cost of US$654.55 per ton in the local market (Banco Da Amazônia, 2014). The corn crop was sown in December 2014, using a single-cross hybrid RB 9308 YG VTPRO through a no-till seeder with a 0.90 m space between rows to achieve a final plant density of 70,000 plants ha^{-1} (Aker et al., 2016).

After harvesting of all cover crops, soil samples in the layers 0 to 2.5; 2.5 to 5; 5 to 10 and 10 to 20 cm depth were collected at five separate locations per plot, forming a composite sample representative of each depth in each succession system (cover crops and fallow). The samples were air-dried, sieved in a 2 mm sieve and subsequently subjected to chemical analysis to evaluate the levels of P; K; Ca^{2+}; Mg^{2+}; Al^{3+}; H + Al; organic matter and pH, and to calculate the saturation by aluminum and bases according to methodology of Embrapa (2009). Soil resistance to penetration was determined using a digital automated soil compaction

Table 2. The maximum leaf area index (LAI), corresponding days after sowing (DAS), fresh and dry weigh biomass production, nitrogen accumulation and nitrogen saving costs of each cover crop.

Cover crops	LAI		Biomass (Mg ha^{-1})		Nitrogen	
	Maximum	DAS	Dry	Fresh	kg ha^{-1}	US\$ ha^{-1}*
Jack bean	4.65^{a}	80	12.50^{a}	40.60^{a}	343.24^{a}	499.26^{a}
Pigeonpea	2.90^{b}	80	12.26^{a}	33.25^{b}	334.85^{a}	487.06^{a}
Sudan grass	3.23^{b}	70	10.36^{a}	30.51^{b}	74.81^{c}	108.82^{c}
Crotalaria ochroleuca	2.60^{b}	80	9.82^{a}	31.35^{b}	235.84^{b}	343.04^{b}
Millet	3.91^{b}	60	9.61^{a}	34.59^{b}	129.14^{c}	187.85^{c}
Crotalaria spectabilis	6.12^{a}	80	9.24^{a}	33.9^{b}	269.02^{b}	391.31^{b}
Crotalaria juncea	3.72^{b}	60	8.9^{a}	32.4^{b}	184.94^{b}	269.01^{b}
U. brizantha cv Piatã	5.61^{a}	120	8.36^{a}	27.4^{b}	128.56^{c}	187.00^{c}
U. brizantha cv Xaraés	4.36^{a}	120	7.26^{b}	24.8^{b}	93.06^{c}	135.35^{c}
Sorghum	3.37^{b}	60	7.14^{b}	25.74^{b}	69.00^{c}	100.36^{c}
Velvet bean	6.35^{a}	90	6.78^{b}	28.6^{b}	216.19^{b}	314.46^{b}
Urochloa ruziziensis	4.11^{b}	120	6.76^{b}	29.87^{b}	92.11^{c}	133.97^{c}
Black mucuna	5.82^{a}	90	6.62^{b}	23.35^{b}	235.79^{b}	242.97^{b}
Fallow	0.88^{c}	120	3.29^{c}	10.53^{c}	50.22^{c}	73.05^{c}
Maize	1.87^{c}	70	1.78^{c}	5.64^{c}	22.18^{c}	32.26^{c}
Average	3.97	-	8.08	27.5	165.26	240.39
CV (%)	15.75	-	27.35	37.73	49.26	49.26

Values in the same column followed by the same letter are not significant at the 5% level of significance by the Scott-Knott test ($p < 0.05$). *Nitrogen accumulation in each cover crop was measured and converted into an associated cost based on the purchase price of the equivalent N amount (urea with 45% N) based on local market costs.

penetrometer, SoloTrack® (Falker) model, with tip number 2 (12.8 mm diameter), cone with 30° angle and base of 130.0 mm. The instrument was set to record every 1 cm depth, working at constant penetration speed. The readings were performed at 10 points (0 to 40 cm layer) alongside the sowing rows in each plot. In order to determine soil moisture content, samples from the 0 to 20 and 20 to 40 cm depths were measured using the gravimetric method (EMBRAPA, 2009).

With analysis of variance by F-test, the means by the Scott-Knott test ($p < 0.05$) were compared. For measurements of chemical and physical attributes of soil performed in different depths, the statistical analysis used a split plot model scheme. Statistical analysis was performed using the R 3.2.2 statistical package (R Core Team, 2016).

RESULTS AND DISCUSSION

It was found that a number of cover species had a high biomass production, in particular, the legume beans, pigeon pea, pigeon pea, crotalaria, and the grasses sudan grass, millet and *Urochloa* brizantha, cultivar Piatã (Table 2). All species, except maize, exhibited superior fallow performance for soil protection, taking into consideration the maximum LAI, fresh and dry biomass yield, shoot nitrogen accumulation and the estimated value of accumulation of nitrogen. Use of an off-season corn crop and leaving land fallow are the most common practices used in grain agriculture in the region. However, it is noteworthy that, in contrast to the way this experiment was carried out, in the southern regions of the state, in the Savanna, the maize crop is cultivated in the off-season using fertilizers and other inputs (Godinho et al., 2009).

Straw production is an important requirement for the no-tillage system. The use of cover crops for the protection of the soil during the off-season provides a diversification away from soybean or corn crops. According to Alvarenga et al. (2001), the minimum amount of dry biomass required for soil protection, to guarantee efficiency in the rotation system, is around 6 Mg ha^{-1} in no-tillage system. All cover plants evaluated in this study, except maize and spontaneous vegetation (fallow plots), reached that minimum amount.

The dry mass production of cover crops is dependent on both the time of sowing and the subsequent crop cover management. Thus, results varies with the region, local climatic conditions and management practices, such as side fertilization. Fertilization can be required for adequate residue production from cover crops used in no-tillage systems. In a Ferralsol of the Brazilian savanna, Torres et al. (2005) obtained high yield of dry biomass for millet (10.3 Mg ha^{-1}), while pigeon pea showed the lowest production (1.6 Mg ha^{-1}). Fallow (2.1 Mg ha^{-1}), black oat (2.4 Mg ha^{-1}), *C. juncea* (3.9 Mg ha^{-1}), *U. brizantha* (6.0 Mg ha^{-1}) and sorghum (7.1 Mg of dry matter mass ha^{-1}) showed intermediate yields. In a Savanna area in Goias, Brazil, well-fertilized cover crops were evaluated and except for the fallow treatment (3.1 Mg ha-¹), Carneiro et al. (2008) found that all cover crop options reached yields higher than 5 Mg ha^{-1}. In this study, the following dry biomasses were obtained in a ferrosol type soil: for *C. cajan* 17 Mg ha^{-1}*; Pennicetum americanum* 16.4 Mg ha^{-1}; *C. ensiformis* 14.7 Mg ha^{-1}, *Crotalaria spectabilis* 9.1 Mg ha^{-1}; *Lablab purpureum* 8.7 Mg ha^{-1}, *C. juncea* 8.0 Mg ha^{-1} and *Raphanus sativus* 5.3 Mg ha^{-1}

The maximum LAI averages obtained in the field differed between the cover crops with the maximum values for species varying between 0.88 and 6.35. It was found that the fallow treatment and corn had the lowest maximum LAI (Table 2). In maize, late sowing without fertilization, resulted in low growth and primary productivity. *C. ochroleuca*, *Cajanus*, Sudan grass, sorghum, *C. juncea*, millet and *U. ruziziensis* had similar maximum LAI values with a 58% difference in average values between the highest in *U. ruziziensis* (4.11) and lowest in *C. ochroleuca* (2.60).

High LAI values correspond with area of the underlying soil being exposed and is thus an important parameter in the evaluation of cover crops under a no-tillage system (Welles and Norman, 1991). Measurement of LAI of cover crops is essential for studies on plant performance in order to recommend them as suitable for cover and protection of the soil (Derpsch et al., 2014). The use of solar energy is influenced by several factors such as optical properties of leaves, light intensity and spatial distribution of leaves. The leaf area of a plant directly influences photosynthesis and as such is very important for the synthesis of carbohydrates, lipids and proteins which contribute to biomass production (Pedreira and Pedreira, 2007).

The accumulation of nitrogen in the dry biomass of the cover plants varied between 343.2 and 22.2 kg ha^{-1} (Table 2). The legumes promoted the largest increases, and can be explained by the biological fixation of nitrogen. The highest value of accumulated N was observed by the Jack bean (Table 2), which also produced the largest amount of dry biomass. Pigeon pea showed similar results with Jack bean in both straw production and N accumulation. In the grasses, the highest accumulation was found for millet which was higher than results obtained by Teixeira et al. (2011) that carried out evaluation on a sandy soil (3.5 Mg ha^{-1} of dry mass and 31.3 kg ha^{-1} of N). The *Urochloa* species were the next most productive followed by the Sudan grass and sorghum. The fallow produced a 126.4% greater amount (50.2 kg ha^{-1}) as compared to the off-season maize crop. The value was higher than those found by Aita et al. (2001), in fallow areas that accumulated N amounts in the order of 20.5 kg ha^{-1} and 1.2 Mg ha^{-1} of straw.

These results confirm those found by Heinrichs et al. (2001), showing that, in addition to contributing to the addition of biomass and organic matter in the soil, the cover plants may contribute to the reduction of N losses caused by nitrate leaching of the soil profile and also by keeping the nutrient in the plant tissue. Nitrogen exhibits great mobility within the agrosystem, and even with the losses that occur due to volatilization, leaching, percolation and runoff due to laminar erosion, it is estimated that 60 to 70% of this nutrient found in plant biomass is recycled and becomes available for succession crops (Mendonça et al., 2015). Therefore, the amount of N that returns to the soil in the form of plant residues constitutes a considerable portion of the total N absorbed by the plants in succession (Aita and Giacomini, 2003). In this way, the practice of crop succession or green fertilization, mainly via the use of legumes, is an important way to add nitrogen and can partially replace mineral fertilizer, as well as in recycling of other nutrients to plants by promoting a slow and synchronized release according to the needs of the plants (Santos et al., 2010).

An interactive effect between the different hedge plants for potassium levels at different depths, the base saturation and aluminum and exchangeable soil acidity was observed (Table 3). These preliminary results are considered as promising because the cover crops had only a season to cause effects on the soil. The beneficial effects expected from the production systems adopted for soil quality are most noticeable after several years of adopting the system (Mbuthia et al., 2015).

The use of *U. brizantha* cultivar Piatã promoted significant increases in the potassium content of the soil in the upper layers (0 to 5 cm), resulting in an increase of 119% as compared to the fallow control treatment (0.46 $cmol_c$ dm^{-3}). Considering the upper soil layers, *U. brizantha* cultivar Piatã exhibited higher potassium content as compared to other cover species. The grass species have a greater capacity to accumulate dry matter and nutrients in the straw, with the exception of nitrogen which is greater for the leguminous plants (Costa et al., 2014; Pacheco et al., 2011).

The available potassium contents were similarly higher in the superficial layer (0 to 2.5 cm depth) when the *U. brizantha* cultivar Xaraés (0.74 $cmol_c$ dm^{-3}), ruziziensis (0.63 $cmol_c$ dm^{-3}) and Jack bean (0.33 $cmol_c$ dm^{-3}) were used, with respective increases of 61, 37 and 35% as compared to the control fallow treatment. In the 2.5 to 5 cm layer, the off-season maize crop, which was sown with the other cover crops, had a 12% higher K content (37 $cmol_c$ dm^{-3}) than the fallow.

Regarding the nutrient distribution in the soil profile, it was observed that as the depth increased, a reduction in K content and sum of bases were observed, independent of the cover plant species used, supporting previously published data (Silveira et al., 2010). This effect is verified as a function of the nutrient cycling that occurs in agricultural systems, where the deposition of straw takes place in topsoil layers, making them available to crops (Sousa et al., 2016).

Table 3. Chemical attributes of potassium content (K), extractable aluminium (Al^{3+}), aluminium saturation (AS) and sum of bases (SB) of the soil at various depths following cultivation by different cover crops at Porto Velho, Rondonia.

Cover crops	K				Al^{3+}				AS				SB			
	$cmol_c$ dm^{-3}								%							
	0 - 2.5 cm	2.5 - 5.0 cm	5.0-10 cm	10-20 cm	0-2.5 cm	2.5 - 5.0 cm	5.0-10 cm	10-20 cm	0-2.5 cm	2.5 - 5.0 cm	5.0-10 cm	10-20 cm	0-2.5 cm	2.5 - 5.0 cm	5.0-10 cm	10-20 cm
U. brizantha cv Piatã	1.01^{Aa}	0.48^{Ba}	0.23^{Ca}	0.13^{Da}	0.00^{Ca}	0.66^{Cb}	2.21^{Ba}	3.34^{Aa}	0.00^{Ca}	9.75^{Cb}	37.25^{Ba}	40.75^{Ab}	78.50^{Aa}	49.50^{Ba}	27.00^{Ca}	16.25^{Da}
U. brizantha cv Xaraés	0.74^{Ab}	0.40^{Bb}	0.23^{Ca}	0.14^{Ca}	0.01^{Ca}	0.38^{Cb}	2.06^{Ba}	3.44^{Aa}	0.00^{Ca}	5.00^{Cb}	34.75^{Ba}	48.50^{Ab}	70.50^{Aa}	47.00^{Ba}	27.75^{Ca}	13.00^{Aa}
Urochloa ruziziensis	0.62^{Ac}	0.35^{Bb}	0.17^{Ca}	0.11^{Ca}	0.02^{Ca}	0.44^{Cb}	1.88^{Ba}	2.95^{Aa}	0.00^{Ca}	6.50^{Cb}	36.25^{Ba}	48.75^{Ab}	76.75^{Aa}	48.50^{Ba}	25.00^{Ca}	16.50^{Da}
Fallow	0.46^{Ad}	0.33^{Bc}	0.23^{Ca}	0.14^{Ca}	0.03^{Ca}	0.35^{Cb}	1.75^{Ba}	2.84^{Aa}	0.00^{Ca}	5.00^{Cb}	29.50^{Ba}	63.75^{Aa}	72.25^{Aa}	46.00^{Ba}	28.25^{Ca}	14.50^{Da}
Sudan grass	0.51^{Ad}	0.31^{Bc}	0.20^{Ca}	0.14^{Ca}	0.04^{Ca}	1.31^{Ba}	2.23^{Aa}	2.35^{Aa}	0.00^{Ca}	22.50^{Ba}	40.75^{Aa}	57.33^{Aa}	72.75^{Aa}	34.00^{Bb}	22.25^{Ca}	19.50^{Ca}
Corn	0.50^{Ad}	0.36^{Bb}	0.22^{Ca}	0.15^{Ca}	0.05^{Ca}	0.12^{Cb}	1.93^{Ba}	2.81^{Aa}	0.00^{Ca}	1.50^{Cb}	32.75^{Ba}	60.50^{Aa}	73.25^{Aa}	55.00^{Ba}	27.50^{Ca}	16.75^{Da}
Millet	0.46^{Ad}	0.31^{Bc}	0.20^{Ca}	0.15^{Ca}	0.06^{Ca}	0.67^{Cb}	1.98^{Ba}	3.29^{Aa}	0.00^{Ca}	10.50^{Cb}	33.50^{Ba}	62.50^{Aa}	70.50^{Aa}	44.25^{Ba}	29.75^{Ca}	15.75^{Da}
Sorghum	0.41^{Ae}	0.26^{Bc}	0.17^{Ca}	0.15^{Ca}	0.07^{Ca}	0.37^{Cb}	1.74^{Ba}	2.97^{Aa}	0.00^{Ca}	5.75^{Cb}	29.50^{Ba}	68.50^{Aa}	75.00^{Aa}	46.50^{Ba}	29.25^{Ca}	16.75^{Da}
Crotalaria juncea	0.46^{Ad}	0.28^{Bc}	0.21^{Ca}	0.15^{Ca}	0.08^{Da}	0.90^{Ca}	2.06^{Ba}	2.92^{Da}	0.75^{Ca}	13.00^{Cb}	34.00^{Ba}	55.75^{Aa}	69.75^{Aa}	40.25^{Bb}	27.25^{Ca}	18.25^{Da}
Crotalaria ochroleuca	0.44^{Ad}	0.30^{Bc}	0.22^{Ba}	0.13^{Ca}	0.09^{Ca}	0.91^{Ba}	2.21^{Aa}	2.89^{Aa}	1.00^{Ca}	13.75^{Cb}	39.25^{Ba}	57.00^{Aa}	64.75^{Aa}	38.75^{Bb}	22.50^{Ca}	14.25^{Da}
Crotalaria spectabilis	0.45^{Ad}	0.32^{Bc}	0.20^{Ca}	0.13^{Ca}	0.00^{Ca}	1.01^{Ba}	1.32^{Ba}	2.17^{Aa}	0.00^{Ca}	18.25^{Ba}	22.25^{Ba}	58.00^{Aa}	70.50^{Aa}	38.50^{Bb}	30.25^{Ca}	24.00^{Ca}
Pigeonpea	0.33^{Ae}	0.26^{Ac}	0.21^{Ba}	0.16^{Ba}	0.01^{Ca}	0.42^{Cb}	1.60^{Ba}	2.81^{Aa}	0.00^{Ca}	7.33^{Cb}	30.33^{Ba}	58.50^{Aa}	77.67^{Aa}	49.00^{Ba}	29.67^{Ca}	17.33^{Da}
Jack bean	0.61^{Ac}	0.37^{Bb}	0.21^{Ca}	0.13^{Ca}	0.02^{Ca}	0.30^{Cb}	1.82^{Ba}	2.80^{Aa}	0.00^{Ca}	4.25^{Cb}	32.00^{Ba}	59.25^{Aa}	73.00^{Aa}	46.25^{Ba}	26.50^{Ca}	16.75^{Da}
Velvet bean	0.38^{Ae}	0.27^{Bc}	0.20^{Ca}	0.12^{Ca}	0.07^{Ca}	1.46^{Ba}	1.93^{Ba}	2.52^{Aa}	0.75^{Ca}	25.50^{Ba}	32.75^{Ba}	60.75^{Aa}	70.00^{Aa}	39.50^{Bb}	27.50^{Ca}	21.50^{Ca}
Black mucuna	0.47^{Ad}	0.33^{Bc}	0.20^{Ca}	0.15^{Ca}	0.00^{Ca}	0.34^{Cb}	1.94^{Ba}	2.95^{Aa}	0.00^{Ca}	4.50^{Cb}	36.00^{Ba}	61.75^{Aa}	74.00^{Aa}	47.75^{Ba}	26.00^{Ca}	14.00^{Da}
Average	0.52	0.33	0.21	0.14	0.02	0.64	1.91	2.87	0.17	10.21	33.39	57.44	72.61	44.72	27.09	17.01

Values followed by the same lowercase letters in the same column, for cover crops and uppercase letters in the same row for depths, are not significant by the Scott-Knott test ($p < 0.05$). K was determined using the Mehlich 1 method; Al exchangeable KCl 1 mol L^{-1}.

The use of plants that are able to increase cycling and availability of nutrients can represent a sustainable strategy for crop production in Brazil and other tropical countries, especially when analyzing nutrients such as potassium. This is particularly the case for Brazil which is highly dependent on imports, with about 90% of the potassium consumed nationally being imported (National Association for Diffusion of Fertilizers, 2015). Therefore, alternatives that aim to increase the availability of potassium in the soil are essential.

An increase in toxic levels of aluminum in sublayers (2.5 to 5 cm depth) was found for the Sudan grass, followed by *C. juncea*, *C. ochroleuca*, *C. spectabilis*, black mucuna and fallow. Species that promote an increase in Al^{3+} content, caused decreases in the percentage saturation per base (V%). Among these species, only *C. juncea* and *C. ochroleuca* did not promote significant increases in aluminum saturation, in this same layer.

In addition, some species display the capability to decrease soil fertility, promoting the acidification by rhizosphere and exudates. This cause strapping of bases in the soil subsurface, promoting acidic conditions in deeper layers or the exudation of organic acids that promote imbalances in micro-fauna, creating an unsuitable environment for the optimal root growth (Li et al., 2014).

Cover plants had little influence on soil resistance to root penetration which may be due to the single season of cover crop growth (Figure 2). Lower soil penetration resistance was detected in the 0 to 5 cm layer and may be related to higher microbial activity in this region (Bender and Van Der Heijden, 2015). There was no difference in the 30 to 40 cm zone. The highest penetration resistance was observed in the layer between 12 and 16 cm deep, with penetration resistance values varying from 2472 to 2912 kPa (Table 4).

Oils that are compacted in the 12 to 16 cm zone probably resulted from the cumulative effect of previous inappropriate management regimes caused by the presence of animals and cultivation without following good practice. Excessive machine traffic and excess animal trampling are

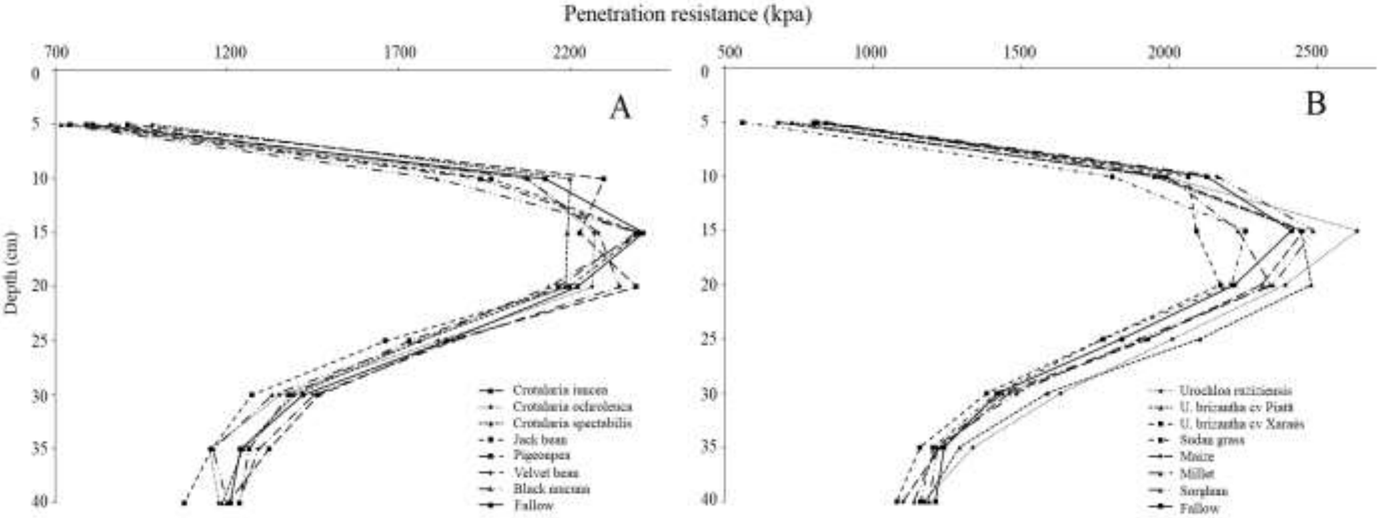

Figure 2. Average soil penetration resistance measurements over the 0 to 40 cm depth range for soils cultivated with legumes (A) or monocotyledonous plants (B).

Table 4. Maximum penetration resistance (kPa) analysis at the indicated depths (cm) for soils cultivated with different cover crops at Porto Velho, Rondonia.

Cover crops	Maximum pressure (kPa)	Depth (cm)
U. brizantha cv Piatã	2772.0[a]	13[a]
U. brizantha cv Xaraés	2798.0[a]	16[a]
Urochloa ruziziensis	2652.8[b]	13[b]
Fallow	2714.5[a]	12[b]
Sudan grass	2534.3[b]	14[a]
Corn	2629.0[b]	14[a]
Millet	2814.1[a]	14[a]
Sorghum	2762.7[a]	14[a]
Crotalaria juncea	2911.9[a]	13[b]
Crotalaria ochroleuca	2699.0[a]	13[a]
Crotalaria spectabilis	2744.1[a]	12[b]
Pigeonpea	2653.9[b]	12[b]
Jack bean	2593.0[b]	13[a]
Velvet bean	2736.5[a]	14[a]
Black mucuna	2472.2[b]	14[a]

Values in the same column followed by the same letter are not significantly different at the 5% level of significance by the Scott-Knott test ($p < 0.05$).

highlighted as possible factors that may compact the soil (Chen et al., 2011; Conte et al., 2011).

It was found in some studies that the critical limit is 2500 kPa in soils under pasture (Lanzanova et al., 2007) and 3500 kPa in soils under a no-tillage system (Tormena et al., 2007). In a dystrophic Ferralsol with a no-tillage system in the South of Brazil, Drescher et al. (2012) found penetration resistance values higher than 2000 kPa, especially in the layer between 10 and 12 cm. The resistance to penetration of a Rhodic Nitosol, managed under a no-tillage system was 920 kPa in the first layer of no-till soil after 1 year of scarification, whereas the continuous no-tillage control reached the highest resistance (3240 kPa) due to compaction in the 0 to 20 cm layer (Nunes et al., 2014). In the no-tillage system, soils exhibit greater cohesion and stability of their aggregates, and thus a higher penetration resistance value may not necessarily equate to soil compaction and stress conditions for crop growth and development.

The absence of significant effects of cover crops on soil can be due to short term use of cover crops in the production system (Mukherjee and Lal, 2015). In order to benefit from using cover crops to provide sustainable and intensive production systems, a medium and long-term approach is required (Cerri et al., 2010). This is due to the fact that the use of plants and straw influences the biological dynamics of soil (Franchini et al., 2007), with positive effects on overall fertility, especially in levels of soil organic matter after a few years (Maia et al., 2013). The application of organic matter to the soil over time, improves the physical and chemical conditions, specific surface area, soil stability (aggregate size) and soil organisms (Zeraatpishe and Khormali, 2012; Khaledian et al., 2013).

Conclusions

1. The use of *Urochloa* as a cover and fodder plant has a beneficial effect on soil chemical fertility, and increases the potassium content in the upper layers.
2. Fallow and off-season maize, without fertilizer application, exhibit the lowest soil coverage.
3. The highest penetration resistance levels were observed in the upper layer between 12 and 16 cm deep.
4. The appropriate choice of cover crop species is important for the success of no-tillage system in the southwest region of the Amazon.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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