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Soil cover crops for curly lettuce cultivation under no-tillage

Pâmela G Nakada-Freitas[1]; Thalita Helena Magalhães[1]; Stefani S Bustamonte[1]; Alan B de Oliveira[1]; Antonio Ismael Inácio Cardoso[2]; Carolina dos SB Bonini[1]; Ronaldo C Lima[1]; Alan RC Carvalho[1]; Humberto S de Araújo[3]

[1]Universidade Estadual Paulista (UNESP), Dracena-SP, Brasil; pamela.nakada@unesp.br; thalitahmagalhaes@gmail.com; stefany-irapuru@hotmail.com; bordimalan@gmail.com; carolina.bonini@unesp.br; ronaldo.c.lima@unesp.br; alan.rc.carvalho@unesp.br. [2]Universidade Estadual Paulista (UNESP), Botucatu-SP; Brasil; antonio-ismael.cardoso@unesp.br. [3]Agência Paulista de Tecnologia dos Agronegócios, Polo Regional do Extremo Oeste (APTA), Andradina-SP, Brasil; humbertosaraujo@yahoo.com.br

ABSTRACT

Plant soil covers bring many benefits to the soil, like physical, chemical and biological quality. It may behave differently if kept on the ground or if incorporated. The objective of this research was to evaluate the effect of cover crops under no-tillage and conventional tillage systems on curly lettuce production. The treatments were in a split plot: three plant coverings in the plot [lupines, black oats, 70% lupines + 30% black oats (consortium)] and in the subplots two cropping systems [no-tillage and conventional tillage (plowing and harrowing)]. The consortium of black oat + lupine in conventional planting produced more than the other treatments and lettuce yield of 69.4 t/ha. The no-tillage in the present study is in its third economic crop cycle and possibly has not yet acquired all the benefits in the soil profile.

Keywords: *Lactuca sativa*, *Avena strigosa*, *Lupinus albus*, no-tillage, conventional cultivation.

RESUMO

Coberturas vegetais de solo no plantio direto de alface crespa

As coberturas vegetais proporcionam muitos benefícios para o solo quanto à qualidade física, química e biológica. Pode comportar-se de forma diferente se mantido no solo ou se incorporado. Assim, objetivou-se avaliar o efeito de coberturas vegetais em sistema de plantio direto e convencional na produção da alface crespa. Os tratamentos foram em parcela subdividida: três coberturas vegetais na parcela [tremoço, aveia preta, 70% de tremoço + 30% de aveia preta (consórcio)] e na subparcela dois sistemas de cultivo [plantio direto e convencional (aração e gradagem)]. O consórcio como coberturas vegetais de aveia preta + tremoço em plantio convencional produziu mais do que os outros tratamentos e apresentou produtividade de alface de 69,4 t/ha. O plantio direto no presente estudo está em seu terceiro ciclo de cultura econômica e, portanto, possivelmente ainda não tenha adquirido todos os benefícios no perfil do solo.

Palavras-chave: *Lactuca sativa*, *Avena strigosa*, *Lupinus albus*, consórcio, plantio convencional.

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The no-tillage system (NTS) has been a target of researches because it presents many advantages; it reduces the carbonic gas emissions, avoids erosion and compaction of the soil, improves the soil water drainage, reduces the soil thermal amplitude favoring the microbiota and the development of roots, controls weeds, increases the organic matter and CEC (cationic exchange capacity) and increases the microbiota to cycle the nutrients (Lima & Madeira, 2013).

The use of plant covers in the off-season has the advantage of absorbing nutrients from sub superficial layers and after release them on the sub superficial layers of the soil, causing the decomposition and mineralization of its residues, which may contribute to decrease the quantity of mineral fertilizers in the annual cultures sown in succession (Cesar *et al.*, 2011).

In large cultures, there's already been many studies conducted on NTS. On the other hand, the Vegetable no-tillage system (VNTS) is a quite recent fact, the pioneers appearing around the year 2000, therefore, there are still few studies and there's still a lot to be studied. Some studies have already been developed, as in American lettuce (Hirata *et al.*, 2014), eggplant (Echer *et al.*, 2016), cauliflower and cabbage (Torres *et al.*, 2017), watermelon (Araújo *et al.*, 2019), tomato and broccoli (Branco *et al.*, 2017). Nevertheless, it's worth point out that the haystack dynamic and nutrients cycling is very variable, according to the geographic position of the production field, being influenced by the weather, fauna, the chemical and physical attributes of the soil, altitude, terrain, among others that are highly variable from region to region.

Different types of vegetables can or cannot adapt to the no-tillage system and different species used as covering

plants may influence on this adaptation. So, the goal of this study is to assess the effect of plant cover on the no-tillage and conventional tillage systems in the production of curly lettuce.

MATERIAL AND METHODS

The experiment was developed at the São Paulo State University (UNESP), College of Agricultural and Technological Sciences, Dracena-SP, Brazil, from July to November, 2019, Western region of São Paulo state (421 m altitude). The weather is Aw (semi humid tropical) (Rolim *et al.*, 2007), temperature and average thermal amplitude throughout the year of 22.1ºC and 6.9ºC, respectively; precipitations are irregular throughout the year, contemplating 29 mm in August, month with the lowest precipitation, whereas in January it is 116.2 mm, with annual average rainfall of 1204 mm (Climatedata.org, 2022). The soil is ultisol predominantly sandy, with 10.5, 7.3 and 82.2% in the 0-0.20 m layer, and 14, 7.1 and 78.8% in the 0.20-0.40 m layer, of clay, silt and sand, respectively.

Regarding the history of the no-tillage area, the lettuce is on its third cycle, when it comes to economical cultures. In the first year, cabbage was cultivated, and after cucumber. About the treatment with plant covers, it followed the same corresponding plot with their families [Poaceae, Leguminosae and the consortium (70% leguminosae + 30% Poaceae)]. In the first cycle (May to July 2018), lupines, black oats, and consortium (70% lupines + 30% black oats) were cultivated, and later, cabbage was cultivated (September to November 2018); in the second cycle (December, 2018 to February, 2019), stylosanthes Campo Grande, millet was cultivated in the consortium (70% stylosanthes Campo Grande + 30% millet); after the mowing, aodai cucumber was cultivated (March to May 2019). In the subplots, the same kind of soil preparation was followed: no-tillage and conventional tillage.

The treatments were in split plots with three plant covers on the plot (lupine, black oat, 70% lupine + 30% black oat), and in the subplot two cultivation systems [no-tillage and conventional tillage (plowing and harrowing)]. After the mowing, seedlings of curly lettuce were transplanted, cultivar Vanda, in 0.25 x 0.25 m spacing. The experimental design was in casualized blocks with four repetitions. Each plot of the research was of 330 m², with 41 m² of experimental plot and 1 m² of useful area in the lettuce assessment, including the border plants in this area.

The plant covers were sown on July 12th, 2019, following the recommendations of 85 kg/ha of lupine seeds and 60 kg/ha of black oat. The irrigation of the covering plants was performed by a sprinkling irrigation system, when necessary, in order to keep this soil with humidity and conditions for a good vegetative development of the plants.

The irrigation system was displayed in 12 m space between each sprinkler and 12 m between each line and average precipitation of the liquid depth of 4.9 mm/h in the working pressure of 2.5 bar and efficiency of 80%.

The plant covers were conducted until the beginning of blooming [70 days after sowing (DAS)] and later they were cut with backpack brush-cutter close to the soil. In the no-tillage cultivation, the haystack remained on the soil. In the conventional preparation, the haystack was only incorporated 27 days after the fallow with plowing and harrowing 20 cm deep, performing the transplantation of the seedlings right after, on October 18, 2019.

For the irrigation of lettuce, a system based on the Available Water Capacity (AWC) of 20 mm was used with a water drainage coefficient on the soil of 0.4. This means that it can consume until 40% of the stored water of the AWC in the soil (Doorembos & Kassan, 1979), with the maximal drainage of the AWC of 8 mm. The water was supplemented until field capacity (fc) with irrigation calculated from the reference evapotranspiration (ETo) collected in the automatic meteorological station, installed 250 m away from the research and culture coefficient (Kc), adopted as 1.

The management of the irrigation water was performed daily, always observing hydric balance through Eto, based on the equation of Penman-Monteiro/FAO (Allen *et al.*, 1998). During the field culture cycle, values of 159.6 mm of ETo PN-M were observed (evapotranspiration by Pennan-monteith), of 98.2 mm of rain, and a consumption of irrigation gross blade of 152.5 mm (Figure 1).

Before mowing, the soil was collected for the chemical analysis of each plot to adjust the liming if necessary and fertilization according to each treatment (Table 1). After the cultivation, the same procedure was performed. For the fertilization of the lettuce we used the formula 04-30-10

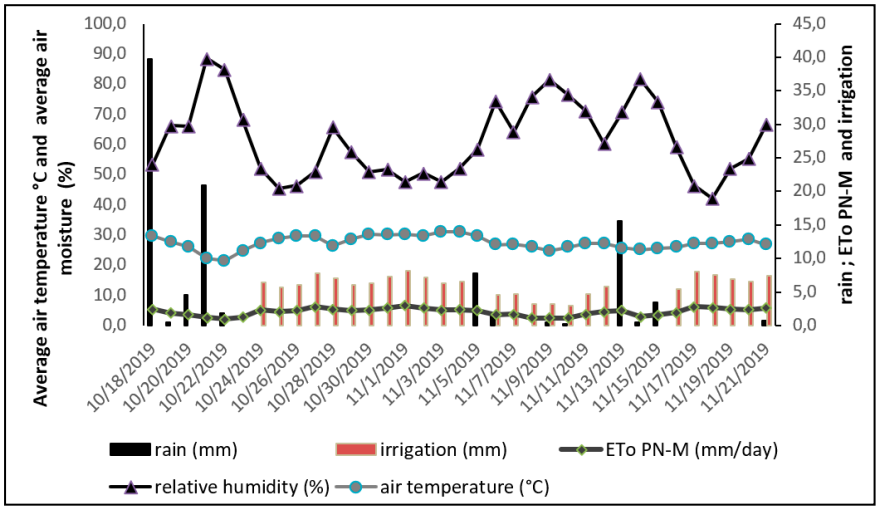

Figure 1. Average air temperature, average air moisture, rain, evapotranspiration by Penman-Monteith (ETo PN-M) and irrigation. Dracena, UNESP-FCAT, 2019.

Table 1. Chemical characteristics of the soil after the mowing of three kinds of plant covers and two tillage systems. Dracena, UNESP-FCAT, 2019.

Soil cover	Soil preparation	pH ($CaCl_2$)	P_{resin} (mg/dm³)	MO (g/dm³)	H+Al	Al	K	Ca	Mg	SB	CTC	V (%)
					(mmolc/dm³)							
Black oat	Conventional	6.4	76	18	11	0	0.7	35	10	45.7	56.7	81
Black oat	No-tillage	6.2	54	17	9	0	0.7	31	9	40.7	49.7	82
Lupine	Conventional	6.3	114	16	9	0	0.8	47	14	61.8	70.8	87
Lupine	No-tillage	6.2	58	14	10	0	0.8	27	9	36.8	46.8	79
Consortium	Conventional	6.1	94	16	10	0	0.7	40	9	49.7	59.7	83
Consortium	No-tillage	6.3	63	15	10	0	0.8	35	11	46.8	56.8	82

to attend the demands of the culture of 30-250-80 kg/ha (N-P-K) and 20 t/ha of laying hens manure (Filgueira, 2008). As there occurred no diseases and agriculture plagues, nothing else was applied.

The assessed variables were dry mass of the plant covers, obtained in three random points of each plot, from an area of 1.0 m², disposed in a paper bag inside an oven with air circulation at 65ºC, during 72 h (kg/ha); macrofauna of the soil, removing three blocks of soil of 0.25 x 0.25 m on each side and 0.10 m depth (Anderson & Ingram, 1993) in each plot and recording those above 2 mm size (individuals/m), two pickups were performed, one after the cultivation and the mowing of the plant covers and the other after the harvest of the lettuce. The lettuce characteristics were assessed 34 days after the transplantation (November 11, 2019): diameter of the aerial part (cm); length of the aerial part (cm), putting it on a bench, closing the side of the leaves and measuring the greatest length of the largest leaf; number of leaves, recording those from 3 cm on; stem length (cm); stem diameter (cm), after removing the leaves to be counted; dry and fresh mass of the aerial part (g); productivity (t/ha).

The data were submitted to the Shapiro-Wilk normality test within the normality in the level of 5% of probability, as well as the homoscedasticity test, resulting all the homogeneous variance for all the characteristics in study. Hereupon, the data were submitted to a variance analysis in the statistic program SISVAR and when significant differences were obtained ($p< 0.05$), Tukey test was applied to the plant covers and t-test to the tillage systems (Ferreira, 2011).

RESULTS AND DISCUSSION

About the haystack on the soil cover, there was a significant effect only for soil preparation, occurring higher production of dry mass in the conventional cultivation system compared to the no-tillage, 2.8 and 1.9 t/ha, respectively.

A difference in the accumulation of dry mass between the plant covers was expected, predominating a higher amount of dry mass of oat (Poaceae), therefore, it's a species with higher C/N relation in comparison to the leguminous (lupine). It can be presumed that the weather conditions, with average temperatures of 31.1ºC in the period, may have interfered in the lifecycle of the species, provoking an early bolting, since the cycle until the blooming of the black oat may vary between 75 to 85 DAS and the cycle of lupine of 120 DAS (Seprotec, 2023).

For the soil macrofauna, there were no significant differences between the treatments (plant covers x soil preparation) and the population average after the plant covers were of 184 individuals/m². A greater number of individuals in the plot with black oat in the consortium was expected, due to the fasciculate radicular structure of the poaceas, which normally have higher fresh mass of roots in comparison to the leguminous, which didn't happen. In the following analysis, after the cultivation of lettuce, this value has dropped to 60 individuals/m² in average between the treatments, also not occurring significant difference. This reduction in the value may have happened due to the decomposition of the organic matter throughout the time, as affirmed by Santos *et al.* (2008), that the density of fauna varies with the period of the pickup in the quantity of organic matter in the soil profile.

There were significant interactions on the diameter and length of the aerial part of lettuce, number of leaves, length and diameter of the stem, dry and fresh mass of the aerial part and productivity (Table 2).

For diameter of the aerial part of lettuce, in the plot of conventional tillage, the consortium stood out for not differing from the lupine. This is a great characteristic, because it influences in the commercialization, providing attractiveness to the consumer, once they are commercialized as units.

For the lettuce development, an adequate supply of N is necessary, being this element of fundamental importance in the development of the vegetable, obviously in balance with other essential elements (macro and micronutrients) and once, being there the presence of plant covers from the fabacea family, such as lupines, whose characteristic is to fix atmospheric nitrogen, having a lower C/N relation compared to poaceas, occurring a faster decomposition of the organic matter.

Yet, comparing the tillage systems, the conventional one resulted in higher values for all the plant covers: oat, lupine and consortium. With the incorporation of the plant covers in the soil profile, the decomposition of the organic matter must have occurred faster and provided nutrients to the lettuce, which is important to highlight about

Table 2. Characteristics of lettuce production cv. Vanda, 34 days after transplant in order to the preparation of the soil: conventional tillage and no-tillage systems and also about the kinds of soil cover: black oat, lupine and consortium (70% lupine +30% black oat). Dracena, UNESP-FCAT, 2019.

Soil preparation	Diameter of the aerial part (cm)		
	Black oat	Lupine	Consortium
Conventional	24 Ba[1]*	26 ABa	29 Aa
No-tillage	18 Bb	24 Ab	21 ABb
	Length of the aerial part (cm)		
Conventional	16 Aa	17 Aa	19 Aa
No-tillage	12 Bb	17 Aa	14 AB b
	Number of leaves		
Conventional	16 Aa	17 Aa	22 Aa
No-tillage	13 Ba	21 Aa	15 AB b
	Length of the stem (cm)		
Conventional	6.6 Aa	7.2 Aa	9.1 Aa
No-tillage	4.6 Ba	7,8 Aa	5.5 AB b
	Diameter of the stem (cm)		
Conventional	1.7 Aa	1.9 Aa	2.0 Aa
No-tillage	1.3 Ab	1.4 Ab	1.5 Ab
	Dry mass of the aerial part (g)		
Conventional	9.3 Ba	14.6 Aa	15.0 Aa
No-tillage	7.4 Aa	9.9 Ab	8.7 Ab
	Fresh mass of the aerial part (g)		
Conventional	126 Ba	137 Ba	624 Aa
No-tillage	51 Ba	109 Ba	382 Ab
	Yield (t/ha)		
Conventional	14.1 Ba	15.2 Ba	69.4 Aa
No-tillage	5.6 Ba	12.2 Ba	42.4 Ab

[1]averages with same capital letters in the line by Tukey test, and same lower-case letters in the column by t-test, don't differ between themselves, 5% probability; *averages followed by different letters in the line or the columns mean significant interaction, 5% probability.

the short cycle of the culture.

Studying the same characteristic, Santos *et al.* (2009) verified variations of diameter of the aerial part between 22 to 25.8 cm of curly lettuce cultivars (Isabela, Vanda, Vera, Verônica, Elba, Cinderela, and Itapuã 401), values close to the results of this research.

On the conventional tillage, the plant covers didn't differ between themselves, resulting in an average of 17 cm regarding the length of the aerial part, yet in the no-tillage, the lupine highlighted (17 cm), not differing from the consortium (14 cm) (Table 2).

The same behavior was observed for number of leaves, with an average of 18 leaves/plant, when cultivated in the conventional system, and not differing between the plant covers. In the no-tillage system, the lupine highlights (21 leaves) not differing from the consortium (15 leaves). This characteristic is of fundamental importance, because it provides a higher yield in salads preparation, contributing to a greater volume of the product and attracting the consumer.

For these characteristics, as the plant cover was incorporated to the soil in the conventional tillage system, the decomposition may have been faster favoring equally the cultivation of curly lettuce. Yet in the no tillage system, using leguminous and the consortium (70% lupine + 30% black oat) having a lower C/N relation than 25/1, it presents a faster decomposition (Borges *et al.*, 2015), being able to be this time faster under tropical weather areas compared to mild weather regions (Costa *et al.*, 2014) and it favors the release of nutrients for the development of the following culture, mainly having a greater benefit if it is a species of short cycle, such as the lettuce.

On the other hand, the poaceas release more residue in the soil, due to more lignin content, making possible the raise of carboxylic acid and humic acid, that structure and improve the aggregate of the soil (Carvalho *et al.*, 2008), but they have a higher C/N relation (65.8) with slower mineralization (Oliveira *et al.*, 2022).

Regarding the length of the stem (Table 2), there was no difference between the plant covers in the conventional tillage system (average of 7.6 cm), however, in the no tillage, there was a higher length when the lettuce was cultivated under the lupine (7.8 cm) not differing from the consortium (5.5 cm). Comparing the tillage systems, there was a significative effect only in the consortium with a higher length of the stem when cultivated in the conventional tillage system (9.1 cm). For stem diameter, the conventional system of soil preparation highlighted from the no-tillage to all the soil covers.

The highest length and diameter of the stem are not desirable characteristics, because it indicates that the plant is entering in the bolting phase, initiating the reproductive phase due to the elevated temperature, producing latex that tastes bitter, losing value in the market (Magalhães *et al.*, 2010).

The lettuce is preferentially cultivated under mild temperatures, having a better development in winter. Although its harvest occurred around October and November 2019, under temperatures of 34.8ºC in average, the bitter taste was not present, but

should have influenced the induction of the stem growth. Resende *et al.* (2017) assessed the performance of curly lettuce cultivars in winter and in summer, including cultivar Vanda and they verified 9.0 cm of stem length with the cultivation in winter and 10.2 cm of the same characteristic when cultivated in summer. These results confirm the stem elongation in the current research, although the authors still affirm that the length of the stem between 9 to 10 cm may be passive of commercialization. Graciano *et al.* (2020) observed 2.4 cm of stem diameter of the same cultivar in study, and they affirmed that there was no reversal of the plant from the vegetative phase to the reproductive one.

About dry mass of the aerial part, there was emphasis on the soil preparation conventional system of lupine (14.6 g) and consortium (15.0 g) and, comparing the tillage systems, the conventional system stood out on the same covers, compared to the no-tillage cultivation. Silva *et al.* (2019) got 8.86 g from the same cultivar, inferior result compared to the present study and they believe that excessive water in the soil may compromise a higher accumulation of dry mass.

For fresh mass of the aerial part, the best result was obtained in the consortium of the plant covers for both cultivation systems, nevertheless in the conventional system (624 g), it was superior to the no-tillage (382 g). Girardello *et al.* (2017) produced curly lettuce cultivar Bruna in a no-tillage system with different soil covers, and they concluded that the highest production of fresh mass of lettuce was in the cover of the consortium black oat + vetch. This result shows the success of the use of leguminous in the consortium of vegetables as soil cover.

In relation to the productivity, the behavior was similar to the one that occurred for fresh mass of the aerial part, with emphasis on the use of the consortium, being superior to the conventional preparation (69.4 t/ha) compared to the no-tillage (42.4 t/ha). Comparing these results with those from Silva *et al.* (2019) that got productivity of 14.4 t/ha from the same cultivar, resulting 74.2% lesser than the average yield from the present study, evidencing the high productivity of the present research. Although statistically there weren't differences, it was notorious that only the leguminous, though its countless advantages on the chemical improvement of the soil, produced less mass, even because the plants bloomed prematurely, producing less mass, and maybe exhausting faster. Thus, the consortium, due to the presence of poacea, may have contributed for a greater residual throughout the production of the lettuce.

Yet about the plant covers preceding the curly lettuce cultivation cultivar Vera, Corrêa *et al.* (2020) tested plant covers with corn, crotalaria, consortium of corn with crotalaria and spontaneous vegetation and, they observed that the leguminous in cover proved to be vantageous for the lettuce yield, highlighting the crotalaria without differencing from the consortium of corn with crotalaria, providing a greater productivity of lettuce (25.5 and 21.3 t/ha, respectively) in relation to the other treatments.

Probably, the conventional tillage system stood out from the no-tillage one by the short time of implementation in the area as described in the area records. Lettuce is a delicate greenery, of superficial and fasciculate radicular system with very short cycle, that's why it's essential that the culture has available nutrients close to their roots and a decompressed and very porous soil, effects that in the short term may be easily obtained with the incorporation of organic matter and by revolving the soil.

Most of the benefits of no-tillage didn't happen yet due to its implementation being still on the third no-tillage cycle and the fast decomposition of the cover deposited on the soil. Neto *et al.* (2007), studying the soil structure of the no-tillage system with corn after 2 to 14 years, determined that this soil structures, where the no-tillage was implanted for less than eight years are similar to the structures of the conventional tillage system. When it's implanted more than nine years ago, it's similar to structures of forest profile, concluding that the consolidation period of the no-tillage system stays between the 9th and the 10th year after its implementation, for the conditions of the studied area.

Regarding the chemical characteristics (table 3), it's important to highlight the superior content of P and Ca in the soil, when all the plant covers were cultivated and incorporated with conventional preparation of the soil and still mention how beneficial it is to the development of the lettuce culture, matching with the most superior

Table 3. Chemical characteristics of the soil after lettuce cultivation, cultivar Vanda, according to three kinds of plant cover (black oat, lupine, 70% lupine + 30% black oat) and two tillage systems (conventional and no-tillage). Dracena, UNESP-FCAT, 2019.

Soil cover	Soil preparation	pH ($CaCl_2$)	P_{resin} (mg/dm^3)	MO (g/dm^3)	H+Al	Al	K	Ca	Mg	SB	CTC	V (%)
					(mmolc/dm^3)							
Black oat	Conventional	6.3	102	15	10	0	0.7	32	10	43.6	52.6	82
Black oat	No-tillage	6.2	56	14	11	0	0.8	22	7	28	38	74
Lupine	Conventional	6.2	87	13	11	0	0.6	29	7	35.6	46.6	79
Lupine	No-tillage	6.2	62	12	11	0	1.1	17	6	24.6	33.6	73
Consortium	Conventional	6.3	81	14	11	0	0.5	27	6	33.4	43.6	78
Consortium	No-tillage	6.4	49	14	11	0	0.8	22	7	29.7	38.7	77

results of the agronomic characteristics of the culture. Mantovani *et al.* (2014) also observed a lesser development of the aerial part in the cultivation with a low content of phosphorus in the curly lettuce, and they stated that this nutrient takes part in the synthesis of ATP, that stores and transfers energy used in several processes of the plant's metabolism. The importance of calcium is unquestionable because it's a primordial component of the cellular wall, and when there is unbalance between the amount of nitrogen and calcium in the soil, there might be "tip burn" in the lettuce culture (Filgueira, 2008), what didn't happen in any of the treatments.

The consortium as plant covers of black oat and lupine in a conventional tillage, produced more than the other treatments and presented productivity of lettuce of 69.4 t/ha. The no-tillage in the present study is in its third cycle of economical culture and, therefore, likely it hasn't acquired all the benefits from the soil yet.

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