Evolution of soil cover and dry shoot phytomass accumulation of autumn/winter cover crops and its effect on the agronomic performance of soybean grown in succession

Evolução da cobertura do solo e do acúmulo de fitomassa seca de plantas de cobertura de outono/inverno e seu efeito sobre o desempenho agronômico de soja cultivada em sucessão

Evolución de la cobertura del suelo y acumulación de fitomasa seca de las plantas de cobertura otoño/invierno y su efecto sobre el comportamiento agronómico de la soja cultivada sucesión

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Abstract

The cultivation of cover crops under no-tillage systems can promote positive improvements in soil attributes and promote increases in grain yield of successor crops, such as soybeans. The aim of this work was to evaluate the evolution of soil cover and accumulation of dry shoot phytomass of autumn/winter cover crops and their impact on the agronomic performance of soybean grown in succession. Black oats (*Avena strigosa*), rye (*Secale cereale*) and turnip (*Raphanus sativus*) were used as cover species in single crops, dual and triple intercropping, in addition to the fallow and weeded controls. The percentage of soil cover (%) and the accumulation of dry shoot phytomass were evaluated at 30, 45, 60, 75, 90 and 105 days after sowing (DAS). In soybean crop, plant height, number of productive nodes per plant, number of pods per plant, mass of a thousand grains and grain yield were evaluated. The cultivation of turnip single provided the fastest soil coverage, with 90.0% at 45 DAS. The intercropping between rye + turnip provided the largest accumulations of dry shoot phytomass, greater than 7.0 Mg ha^{-1} at 105 DAS. The highest soybean yields were obtained in succession to the cultivation of black oat and rye in single, yielding approximately 3,300 kg ha^{-1}, 50% higher compared to fallow and weeded treatments.

Keywords: *Glycine max* L.; Cover crops; Succession of cultures; Coverage mix; Green fertilizing; No-till system.

Resumo

O cultivo de plantas de cobertura em sistema de plantio direto pode promover melhorias positivas nos atributos do solo e promover incrementos em produtividade de culturas sucessoras, como a soja. Objetivou-se com este trabalho avaliar a evolução da cobertura do solo e do acúmulo de fitomassa seca da parte aérea de plantas de cobertura de outono/inverno, e o seu efeito sobre o desempenho agronômico de soja cultivada em sucessão. Foram utilizadas como espécies de cobertura a aveia preta (*Avena strigosa*), o centeio (*Secale cereale*) e o nabo forrageiro (*Raphanus sativus*) em cultivos solteiros, consórcios duplos e triplo, além das testemunhas em pousio e capinada. Avaliou-se a porcentagem de cobertura do solo (%) e o acúmulo de fitomassa seca da parte aérea aos 30, 45, 60, 75, 90 e 105 dias após a semeadura (DAS). Na cultura da soja foram avaliadas a altura de plantas, o número de nós produtivos por planta, o número de vagens por planta, a massa de mil grãos e a produtividade de grãos. O cultivo do nabo forrageiro

solteiro proporcionou a mais rápida cobertura do solo, com 90,0% aos 45 DAS. O consórcio entre centeio + nabo forrageiro proporcionou o maior acúmulo de fitomassa seca da parte aérea, superior a 7,0 Mg ha^{-1} aos 105 DAS. Os maiores rendimentos de grãos de soja foram obtidos em sucessão ao cultivo de aveia preta e centeio solteiros, com rendimento de aproximadamente 3.300 kg ha^{-1}, 50% superior em comparação aos tratamentos em pousio e capinado.
Palavras-chave: *Glycine max* L.; Plantas de cobertura; Sucessão de culturas; Mix de cobertura; Adubação verde; Sistema plantio direto.

Resumen
El cultivo de cobertura en sistemas de labranza cero puede promover mejoras positivas en los atributos del suelo y promover aumentos en la productividad de cultivos sucesores, como la soja. El objetivo de este trabajo fue evaluar la evolución de la cobertura del suelo y la acumulación de fitomasa aérea seca de las plantas de cobertura otoño/invierno, y su efecto sobre el comportamiento agronómico de la soja cultivada en sucesión. Se utilizaron avena negra (*Avena strigosa*), centeno (*Secale cereale*) y nabo forrajero (*Raphanus sativus*) como especies de cobertura en monocultivos, intercalados dobles y triples, además del barbecho y control de malezas. Se evaluó el porcentaje de cobertura de suelo (%) y la acumulación de fitomasa aérea seca a los 30, 45, 60, 75, 90 y 105 días después de la siembra (DDS). En el cultivo de soja se evaluó la altura de la planta, el número de nodos productivos por planta, el número de vainas por planta, la masa de mil granos y el rendimiento de grano. El cultivo de nabo forrajero single proporcionó la cobertura de suelo más rápida, con 90.0% a 45 DDS. El consorcio entre centeno + nabo forrajero proporcionó la mayor acumulación de fitomasa aérea seca, más de 7.0 Mg ha^{-1} a 105 DDS. Los mayores rendimientos de soja se obtuvieron en sucesión al cultivo de avena negra simple y centeno, con rendimiento de aproximadamente 3.300 kg ha^{-1}, con 50% más alto em comparación com los tratamientos barbecho y control de malezas.
Palabras clave: *Glycine max* L.; Plantas de cobertura; Sucesión de culturas; Mezcla de cobertura; Adubación verde; Sistema de labranza cero.

1. Introduction

No-Tillage System (NTS) is a conservation management of the soil used in a large part of the Brazilian territory. In the warmer region of southern Brazil, such as northern Paraná, what has been noted is the repetition of soybean cultivation followed by corn in the second harvest. In colder regions, such as Rio Grande do Sul, Santa Catarina and Southern Paraná, the cultivation of soybean in the summer and wheat in the winter dominates the areas. These successive and repeated crops negatively impact the yield potential of the crops and the profitability of properties in the medium and long term (Canalli, et al., 2020), since there is a low diversity of species that can provide a greater contribution and diversification of straw and roots. Consequently, the availability of nutrients and improvements in the physical, chemical and biological attributes of the soil are limited (Blanco-Canqui, et al., 2011).

NTS is based on three pillars: the maintenance of soil cover by plant residues, the non-revolving soil and the crop rotation. Thus, the use of cover crops is necessary, either in rotation or even in intercropping with crops of economic interest. Its use provides advantages to the system, since each species has peculiar characteristics, such as different plant architectures and root systems, which favor the development of different groups of soil biota and the cycling of different nutrients (Cherr, et al., 2006). In addition, cover crops increase the biodiversity of the agroecosystem, which reduces the incidence of insect pests, diseases, nematodes and weeds (Altieri, et al., 2011). The choice of species for use as cover crops must meet some requirements, such as: be easy to establish; have a fast growth rate, and thus provide soil cover quickly; produce enough dry matter to keep the soil covered for a certain period; to be resistant and not host to the main pests that affect crops of greater economic interest; in addition to being economically viable in terms of installation, seeds and management (Reeves, 1994).

Several studies have emphasized the importance of cover crops for soybean management systems, improving crop development and grain yield (Nicoloso, et al., 2008; Schnitzler, 2017; Anschau, et al., 2018; Krenchinski, et al., 2018). Among the most used autumn/winter cover crops are black oats (*Avena strigosa* Schreb.), rye (*Secale cereale* L.) and turnip (*Raphanus sativus*), providing benefits to successive cultivation. Black oats and rye, for example, can add 2.0 to 8.0 Mg ha^{-1} of dry matter to the soil (Wutke, et al., 2013). On the other hand, turnip has as main characteristic the high capacity of soil decompaction and nutrient cycling (Giacomini, et al., 2004; Burle, et al., 2006).

One of the ways to optimize the use of cover crops is the use of intercropping. The association of grasses (such as oats and rye) with eudicotyledons (such as turnip and legumes), for example, aims at the rapid production of phytomass (grasses) and the supply of nutrients to the soil, especially nitrogen (eudicotyledons). Another advantage of this association is that the carbon/nitrogen ratio (C/N) of plant residues from intercropping is intermediate in comparison to that of single crops, which influences the speed of decomposition and release of nutrients from cultural residues (Giacomini, et al., 2004; Doneda, et al., 2012).

In this scenario, the use of species adapted to each agricultural region can maximize soybean yield in the crop succession system. Furthermore, it is possible that the intercropping of cover crops provides better agronomic performance for soybean grown in succession, compared to single crops or compared to fallow. Thus, the aim of this work was to evaluate the evolution of soil cover and the accumulation of dry shoot phytomass of single and intercropped crops of black oats, rye and turnip during the autumn/winter period, as well as the agronomic performance of soybean grown in succession.

2. Methodology

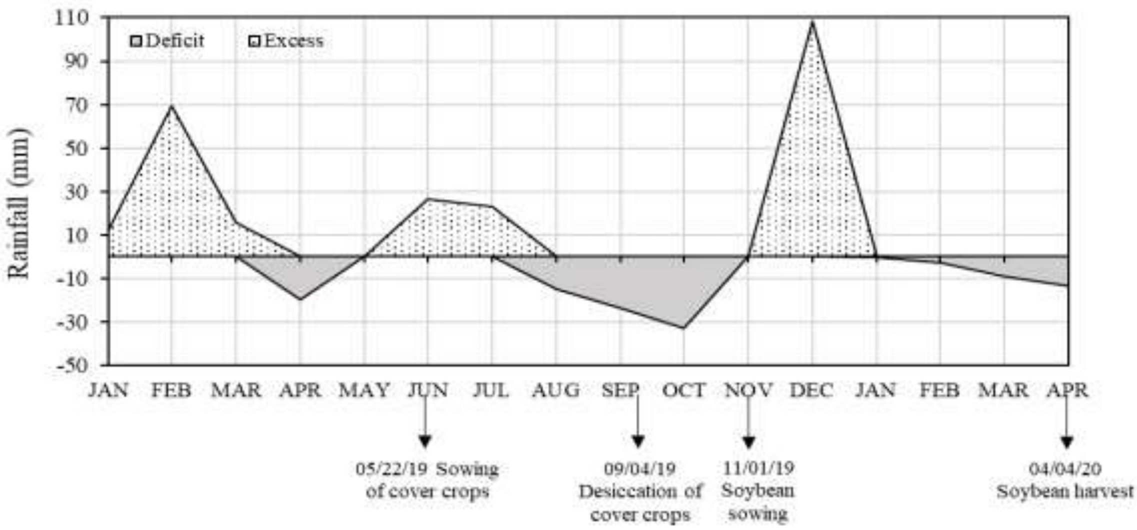
The experiment was carried out under field conditions at Fazenda Escola da Universidade Estadual de Londrina (UEL), in the city of Londrina, PR, Brazil, located at 23 ° 23' S and 51 ° 11' W, at an altitude of 566 m. The soil at the research area was classified as eutrophic Red Latosol (Oxysoil) (Santos, et al., 2018). The region has a Cfa-type climate, described as humid subtropical with hot summers and a defined dry season, according to Köppen's classification. The average annual air temperature is 21.2 °C and the average annual rainfall is 1,632 mm (Nitsche, et al., 2019). Through the meteorological data obtained in the meteorological station of the Instituto de Desenvolvimento Rural do Paraná (IDR) and water demand for soybean crops, it was possible to calculate the water balance for the experimental year, with the help of the spreadsheet developed by Rolim, Sentelhas and Barbieri (1998) (Figure 1).

The chemical attributes of the soil were determined before the installation of the experiment by collecting a composite soil sample, originating from 20 simple deformed soil samples collected in the experimental area, at a depth of 0.00-0.20 m. According to the analysis, the soil presents: pH ($CaCl_2$) 5.2; 39.0 g kg^{-1} organic matter in the soil; 10.5 mg dm^{-3} P; 0.96 cmolc dm^{-3} K^+; 5.6 cmolc dm^{-3} Ca^{2+}; 1.0 cmolc dm^{-3} Mg^{2+}; 0.0 cmolc dm^{-3} Al^{3+}; total CEC of 10.66 cmolc dm^{-3}; base saturation of 71.0%; 680 g kg^{-1} of clay; 90 g kg^{-1} of silt; and 230 g kg^{-1} of sand.

The experimental design adopted was randomized blocks, consisting of nine treatments and four replications. The following species were used as soil cover crops: black oats (*Avena strigosa*), rye (*Secale cereale*) and turnip (*Raphanus sativus*) and intercropping between black oat + turnip (BO + T), rye + turnip (R + T), black oats + rye (BO + R), and black oats + rye + turnip (BO + R + T), in addition to the fallow and weeded controls.

The plots were made up of 3 m wide x 7 m long, totaling 21 m². The mechanical sowing of the cover crops species was carried out on May 22, 2019, with a continuous flow seeder-fertilizer equipped with a fluted rotor as a distributor mechanism, with a spacing of 0.17 m between rows, totaling 14 rows per plot, at a sowing depth of 0.05 m. The fertilization consisted of 150 kg ha^{-1} of N-P-K of formulation 05-20-20. Prior to sowing, weeds in the experimental area were controlled with glyphosate (720 g ha^{-1}, Roundup Original®, 360 g L^{-1}).

Figure 1. Monthly climatological water balance, from January 2019 to April 2020, according to the meteorological data obtained in the IDR, Londrina, PR, Brazil.



Source: Authors.

The cultivars IAPAR 61- Ibiporã (*Avena strigosa*), IPR 89 (*Secale cereale*) and IPR 116 (*Raphanus sativus*) were used, with sowing densities of 58, 58 and 25 kg ha^{-1} of seeds in single cultures of black oats, rye and turnip, respectively. In dual intercropping, 50% of the amount of seeds used in single crops was used, and in the triple intercropping (BO + R + T), 33.3% of the amount of seeds of each species used in single crops was used. In the fallow control, there was no intervention, be it sowing or weed control, whereas in the weeded control, the weeds were controlled with manual weeding every fortnight, from 30 days after the installation of the experiment. In the other treatments, weeding of wild turnip (*Raphanus raphanistrum*) and other weed species was performed at 30 days after sowing (DAS) of the cover plants.

On September 4, the cover crops in the area were desiccated with glyphosate (720 g ha^{-1}, Roundup Original®, 360 g L^{-1}) + clethodim (144 g ha^{-1}, Select® 240 EC, 240 g L^{-1}) + alkyl ethoxylated phosphoric acid adjuvant (Lanzar®, 0.5% v/v). The application was carried out with a tractor sprayer with an application rate equivalent to 150 L ha^{-1}.

Sowing of soybeans was carried out with a precision seeder-fertilizer on November 1, 2019, using seeds from cultivar DM 66i68 RSF IPRO (DONMARIO Seeds). The seeds were industrially treated with pyraciostrobin (25 g L^{-1}, 2.5% w/v) + methyl thiophanate (225 g L^{-1}, 22.5% w/v) + fipronil (250 g L^{-1}, 25 % w/v) (Standak Top), at the dose of 2 mL kg^{-1}. In the sowing, row spacing of 0.45 m and a density of 14 seeds per linear meter were adopted. Fertilization in the sowing consisted of 300 kg ha^{-1} of N-P-K of formulation 02-24-18.

On November 20, 15 days after soybean emergence (DAE), glyphosate (720 g ha^{-1}, Roundup Original®, 360 g L^{-1}) was applied to eliminate weeds in the area in order to only to observe the effect of cover crops on soybean agronomic performance. At R2 soybean stage, a mixture of the fungicides trifloxystrobin (150 g L^{-1}) + protioconazole (175 g L^{-1}) (Fox®, 400 mL ha^{-1}) was applied for the preventive control of Asian soybean rust. At R5 soybean stage, was performed a new application of the same fungicides, along with insecticide. The mixture of insecticides imidacloprid (100 g L^{-1}) + beta-cyfluthrin (12.5 g L^{-1}) (Connect®, 750 mL ha^{-1}) was used to control stink bugs.

The variables evaluated in the cover crops were: percentage of soil cover and dry shoot phytomass (DSP) at 30, 45, 60, 75, 90 and 105 days after sowing (DAS). The evaluations of soil cover were accomplished through images captured by a digital camera (Canon Power Shot SX40 HS) at a height of one meter from the ground level. The photographed area was limited to a 0.5 x 0.5 m wooden square, randomly launched in the plots, with one photograph per plot. The digital images were processed in the Canopeo application and scores were given on a percentage scale where zero and one hundred represent absence and total soil coverage, respectively. Then, the plants present inside the wooden square were cut close to the surface of the soil, packed in paper bags and dried in an oven with forced air circulation at 65 °C until reaching constant mass (72 h). After drying, the samples were weighed on a precision scale (0.01 g) to determine DSP, which was presented in Mg ha^{-1}.

In soybeans, at the time of harvesting, the following were evaluated: plant height (PH), obtained by measuring from the plant's base to the apical end, with the aid of a scale in centimeters; number of pods per plant (NPP), obtained by counting all pods with grains in each plant; number of productive nodes per plant (NNP), obtained by counting nodes that presented productive pods, considering all nodes of the main stem and branches. These evaluations were carried out on 10 plants collected randomly in the plot. To determine grain yield and the thousand grain mass (TGM), the harvest was carried out manually in eight linear meters in the center of the plots (four linear meters in two lines), and the plants were mechanically tracked with the aid of a stationary thresher. Afterwards, the grains were cleaned in sieves and each sample was weighed on a precision scale (0.01g). Grain yield was estimated in kg ha^{-1}. To estimate the TGM, two samples of 100 grains were randomly selected from the bulk sample and weighed on a precision scale (0.01g). The humidity of the grains was corrected to 13%.

In the statistical analysis of DSP of the cover plants, the Box & Cox analysis was performed, through the statistical program R, in which it was necessary to transform the data to meet the assumptions of the analysis of variance. The analysis allowed to identify the best transformation, based on the use of a value λ (lambda), with the result obtained being 0.10. In contrast, there was no need to transform the soil cover data.

The data on DSP, soil cover and soybean agronomic performance were subjected to analysis of variance (ANOVA) ($p < 0.05$) and the means grouped by the Tukey test ($p < 0.05$), with the aid of of the Sisvar statistical analysis program (Ferreira, 2011). For DSP and soil cover, qualitative treatments (cover crops) were evaluated within each evaluation period. In addition, for the quantitative data (evaluation periods), regression adjustments were performed for each cover crop using the SigmaPlot 12.0 program. As they presented zero value in all evaluations, the data of the weeded control were not considered in the analysis of DSP accumulation and soil cover.

3. Results and Discussion

Evolution of soil cover provided by cover crops

The average values of the percentage of soil cover provided by the cover crops are shown in Table 1 and Figure 2. At 30 DAS, the treatment turnip was the one that presented the highest percentage of soil cover (34.5%). The other treatments provided soil cover between 15 and 22%, not differing from each other, with the exception of fallow, which obtained only 6.4% of soil cover (Table 1). At 45 DAS, the highest soil cover index was again provided by turnip (90%), not differing from the other treatments that also contained turnip in intercropping, demonstrating the rapid growth of this species. These treatments also did not differ from the fallow control, which obtained 83.7% of soil cover. In contrast, treatments containing only poaceae (black oats and/or rye) showed the lowest percentage of soil cover at 45 DAS.

At 60 DAS there was no significant difference between treatments in relation to soil cover, with an average of approximately 80%. However, it was in this assessment that most treatments had their peaks in the soil cover index (Table 1 and Figure 2). On the other hand, the treatments turnip and fallow (with a large infestation of wild radish (*Raphanus raphanistrum*)), showed peaks in the soil cover in the previous assessment, at 45 DAS, with a decrease from 60 DAS. This occurred due to the fact that from 45 to 60 DAS, both the turnip and the wild radish start the senescence process, since the crop cycle is short and may be less than 70 days (Fleck, et al., 2006). On the other hand, for oat and rye crops, the rate of increase in soil cover is high between 45 and 75 days after emergence (DAE) (Wolschick, et al., 2016), mainly because it is the period which coincides with the highest tillering, at 63 DAE (Deiss, et al., 2014). In general, the largest number of tillers in winter cereals occurs between 40 and 60 DAE (Large, 1954).

Table 1. Average values of percentage (%) of soil cover of black oats (BO), rye (R) and turnip (T) in single or intercropping cultivation during the autumn/winter period, at 30, 45, 60, 75, 90 and 105 days after sowing (DAS), Londrina, PR, Brazil, 2019/2020.

Treatments	Days after sowing					
	30	45	60	75	90	105
	Soil cover (%)					
Black oat (BO)	17.0 b	53.6 b	**79.2** a	71.3 ab	58.9 ab	35.0 ab
Rye (R)	18.0 b	64.5 ab	**70.9** a	51.4 c	23.8 c	12.4 b
Turnip (T)	34.5 a	**90.0** a	78.5 a	73.3 ab	67.7 a	17.0 ab
BO + T	20.0 b	74.1 ab	**82.1** a	73.4 ab	70.7 a	34.9 ab
R + T	21.6 b	73.4 ab	**84.4** a	72.4 ab	64.7 a	26.2 ab
BO + R	15.7 b	53.7 b	**79.9** a	61.4 bc	44.9 b	17.8 ab
BO + R + T	20.4 b	82.5 ab	**84.0** a	73.7 a	71.9 a	41.6 a
Fallow	6.4 c	**83.7** ab	74.0 a	63.4 abc	61.3 ab	19.3 ab
SMD (5%)	8.3	31.8	15.6	12.0	18.0	25.7
CV (%)	18.3	18.6	8.31	7.5	13.1	42.4

Means followed by the same lowercase letter in the column (compare different cover crops) do not differ from each other by the Tukey test ($p < 0.05$). Values highlighted in bold indicate the date on which the crop reached the maximum soil cover value. Source: Authors.

From 75 DAS, a reduction in the soil cover index was observed for all treatments. In relation to the previous assessment, there was a reduction in the percentage of soil cover of 7.9% for black oats, 19.5% for rye, 5.2% for turnip, 18.5% for black oats + rye, 8.67% for black oats + turnip, 11.9% for rye + turnip, 10.3% for triple intercropping, and 10.6% for fallow. With the exception of the treatment containing single rye and black oats + rye, the other treatments obtained the highest soil cover percentages, not differing statistically, with coverage rates between 63% and 74% (Table 1).

At 90 DAS, the behavior was similar to the previous evaluation in treatments containing turnip. These treatments maintained the highest percentage of soil cover, with an average of 65.88%, also not differing from fallow and single black oats (Table 1 and Figure 2). At 105 DAS there was a significant reduction in soil cover compared to 90 DAS for all treatments. The final values of soil cover were 35% for black oats, 12.4% for rye, 17% for turnip, 17.9% for black oats + rye, 34.9% for black oats + forage turnip, 26,2% for rye + turnip, 41.6% for the consortium between the three species (black oats + rye + turnip), and 19.3% for fallow treatment (Table 1 and Figure 2).

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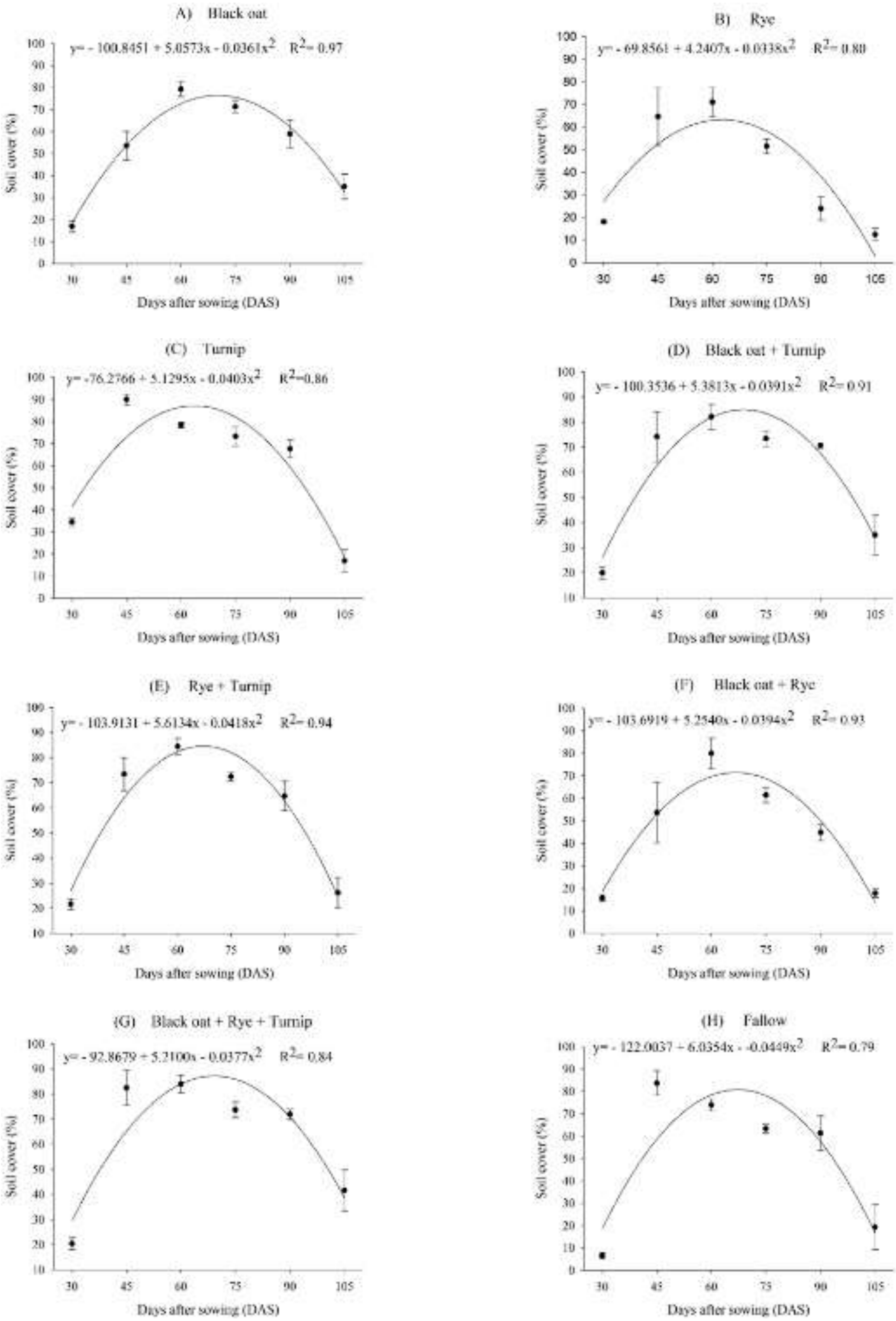
Figure 2. Evolution of soil cover provided by black oats, rye and forage turnip in single or intercropping cultivation during the autumn/winter period, at 30, 45, 60, 75, 90 and 105 days after sowing (DAS). Black oat (A), Rye (B), Turnip (C), Black oat + Turnip (D), Rye + Turnip (E), Black oat + Rye (F), Black oat + Rye + Turnip (G) and Fallow (H). The dots indicate the means (n = 4) and vertical bars indicate the standard deviation. Londrina, PR, Brazil, 2019/2020 season.



Source: Authors.

Evolution of accumulation of dry shoot phytomass (DSP) of cover crops

At 30 DAS the treatment that obtained the highest average DSP was the intercropping black oats + rye + turnip (1.2 Mg ha^{-1}), together with turnip with 1.0 Mg ha^{-1} which did not differ statistically from the other treatments (Table 2 and Figure 3). At 45 DAS, the turnip treatment provided the greatest DSP accumulation (2.8 Mg ha^{-1}), but it not differs from the treatments rye, black oats + turnip, rye + turnip, black oats + rye + turnip and fallow, with values between 2.0 and 2.8 Mg ha^{-1}. These treatments differed from black oats and from black oat + rye intercropping, with 1.3 and 1.5 Mg ha^{-1}, respectively. At 60 DAS, similarly to the previous evaluation (45 DAS), treatments containing turnip continued to show the highest DSP accumulation, with emphasis on the triple intercropping (black oats + rye + turnip) which had the highest DSP (3.3 Mg ha^{-1}). As with 45 DAS, black oats showed the lowest DSP accumulation, with 1.8 Mg ha^{-1}.

Table 2. Average values of accumulation of dry shoot phytomass (DSP) of black oats (BO), rye (R) and turnip (T) in single or intercropping cultivation during the autumn/winter period, at 30, 45, 60, 75, 90 and 105 days after sowing (DAS), Londrina, PR, Brazil, 2019/2020.

	Days after sowing					
Treatments	30	45	60	75	90	105
	DSP (Mg ha^{-1})					
Black oat (BO)	0.8 b	1.3 c	1.8 c	3.0 bc	3.3 b	**5.2** ab
Rye (R)	0.8 b	2.0 abc	2.0 bc	3.5 abc	3.8 ab	**5.4** ab
Turnip (T)	1.0 ab	2.8 a	3.0 abc	5.0 a	**5.4** ab	5.4 ab
BO + T	0.7 b	2.0 abc	3.1 ab	4.5 ab	5.4 ab	5.5 ab
R + T	0.8 b	1.9 abc	3.2 ab	5.2 a	6.0 a	**7.6** a
BO + R	0.8 b	1.5 bc	2.1 abc	2.5 c	3.6 b	**5.3** ab
BO + R + T	1.2 a	2.6 ab	3.3 a	4.5 ab	5.2 ab	**7.0** ab
Fallow	0.8 b	2.4 abc	2.7 abc	3.6 abc	4.0 ab	**4.1** b
SMD (5%)	0.3	1.2	1.3	1.8	2.3	2.9
CV (%)	13.2	24.9	20.2	19.6	21.2	21.3

Means followed by the same lowercase letter in the column (compare different cover crops) do not differ by Tukey's test ($p < 0.05$). Values highlighted in bold indicate the date on which the crop reached the maximum DSP value. Source: Authors.

At 75 DAS, the largest DSP accumulations were obtained in the rye + turnip and single turnip, with averages of 5.2 and 5.0 Mg ha^{-1} respectively. The other treatments that contained turnip in their composition, as well as single rye, obtained averages similar to the largest accumulations of DSP. On the other hand, the black oat + rye intercropping obtained the lowest SDP accumulation, together with the treatment of single black oats. The treatment maintained in fallow did not differ from the highest or the lowest averages of SDP accumulations (Table 2 and Figure 3).

At 90 DAS, the results were similar to those obtained in the previous evaluation, maintaining the greatest accumulation of DSP in the treatments in which the turnip was present, either in single cultivation or in intercropping with black oats and/or rye (Table 2 and Figure 3). In these treatments, the average production of DSP was 5.5 Mg ha^{-1}, highlighting the intercropping rye + turnip with greater DSP accumulation (6.0 Mg ha^{-1}). In the evaluation at 90 DAS, the treatments turnip and black oat + turnip peaked in the accumulation of DSP, with 5.4 Mg ha^{-1} (Figure 3).

In the last evaluation, at 105 DAS, the greatest accumulation of DSP was obtained by the consortium of rye + turnip (7.6 Mg ha^{-1}), which differed from fallow (Table 2 and Figure 3). The second largest DSP production was provided by the triple intercropping (7.0 Mg ha^{-1}). The other treatments presented average values of 5.15 Mg ha^{-1}, which corresponds to a DSP 29.5% lower in comparison to the rye + turnip intercropping. In this evaluation, most of the treatments reached the peak in the accumulation of DSP, with the exception of the single turnip treatment, which had its peak of accumulation at 90 DAS.

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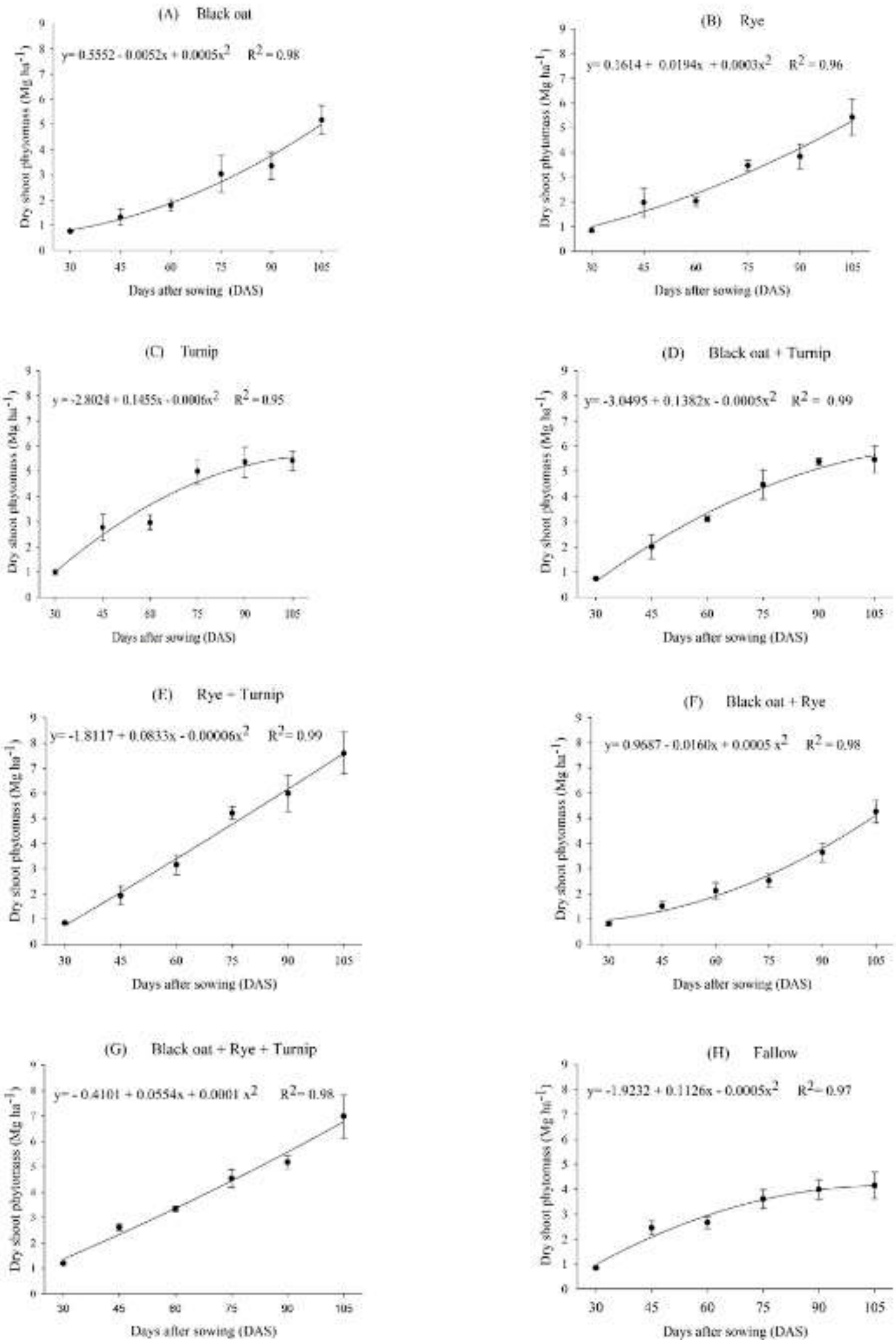
Figure 3. Evolution of the dry shoot phytomass (DSP) provided by black oats, rye and forage turnip in single or intercropping during the autumn-winter period, at 30, 45, 60, 75, 90 and 105 days after sowing (DAS). Black oat (A), Rye (B), Turnip (C), Black oat + Turnip (D), Rye + Turnip (E), Black oat + Rye (F), Black oat + Rye + Turnip (G) and Fallow (H). The dots indicate the means (n = 4) and vertical bars indicate the standard deviation. Londrina, PR, Brazil, 2019/2020.



Source: Authors.

In general, treatments containing turnip showed the largest accumulations of DSP since the first evaluations (Table 2). These results demonstrate the rapid production capacity of DSP by this species. Thus, this species proves to be an important alternative for cultivation in short periods, such as between the soybean harvest and the sowing of wheat, a period known as autumnal fallow. It was also observed a rapid accumulation of DSP in the fallow treatment, due to the high infestation of spontaneous species, mainly the wild radish (*Raphanus raphanistrum*), which has a large seed bank in the experimental area. For this reason, in all evaluations the fallow treatment did not differ from the single turnip, although lower absolute values were observed for that treatment (Table 2). This is because these species belong to the same genus (*Raphanu*s), have similar morphology and growth, having large, decumbent leaves and fast initial growth (Lorenzi, 1991). However, it was observed that, for both treatments, the evolution in DSP stabilizes after 75 DAS. From 45 to 60 DAS, the turnip and wild radish plants start the senescence process, since the crop cycle is short (Fleck, et al., 2006).

Agronomic performance of soybean grown in succession to cover crops

A significant difference was observed provided by the different successions of cover crops on the variables plant height (PH), number of pods per plant (NPP) and soybean grain yield (Table 3). However, for the variables number of productive nodes per plant (NNP) and mass of a thousand grains (MTG), there was no significant effect in response to cover crops.

Table 3. Average values of plant height (PH), number of productive nodes per plant (NNP), number of pods per plant (NPP), mass of a thousand grains (MTG) and grain yield of soybean in succession to cover crops (black oats (BO), rye (R) and turnip (T)) in single or intercropped cultivation during autumn/winter, Londrina, PR, Brazil, 2019/2020.

Treatments	PH (cm)	NNP	NPP	MTG (g)	Grain yield (kg ha^{-1})
Black oat (BO)	93 ab	24 a	56 a	214 a	3,312 a
Rye (R)	87 ab	27 a	55 a	207 a	3,229 ab
Turnip (T)	79 b	22 a	26 b	201 a	2,137 cde
BO + T	82 ab	28 a	54 a	203 a	2,727 abc
R + T	76 b	26 a	50 ab	203 a	2,277 cde
BO + R	103 a	25 a	45 ab	206 a	2,564 bcd
BO + R + T	92 ab	26 a	50 ab	209 a	2,664 abc
Fallow	78 b	29 a	39 ab	205 a	1,663 e
Weeded	77 b	25 a	27 b	204 a	1,865 de
CV %	10.29	19.04	25.45	2.56	12.35

Means followed by the same lowercase letter in the column do not differ by Tukey's test ($p < 0.05$). Source: Authors.

The highest PH was obtained by soybean grown in succession to the black oat + rye intercropping, with 103 cm, but without being statistically different from the cultivation on black oats, triple consortium, rye and black oats + turnip, which provided soybean plants with 93, 92, 87 and 82 cm in height, respectively (Table 3). The treatments turnip, rye + turnip, weeded control and fallow control obtained the lowest average plant height, with approximately 77 cm, and did not differ between them.

Black oats, rye, and black oat + turnip were the treatments that resulted in soybean plants with the highest number of pods per plant (NPP), with 56, 55, 54, respectively, not differing each other (Table 3). Then, the soybean plants grown on rye + turnip, black oats + rye and the triple intercropping (black oats + rye + turnip) showed average values of 48 pods per plant, not differing from the best treatments. However, soybean plants grown on turnip, fallow control and weeded control treatments resulted in soybean plants with a low number of pods, equal to 26, 39 and 27, respectively.

The highest soybean yields were obtained when the crop was sown on single black oats and rye, with 3,312 and 3,229 kg ha^{-1}, respectively (Table 3). Subsequently, the intercropping of black oats + turnip, black oats + rye and black oats + rye + turnip promoted yields above of 2,560 kg ha^{-1}, differing from rye + turnip and single turnip, which provided yields of 2,277 and 2,137 kg ha^{-1}, respectively. Finally, the fallow and weeded controls resulted in the lowest soybean yields, being only 1,663 and 1,865 kg ha^{-1}, respectively.

The treatment consisting of single black oats provided the best agronomic performance of soybean grown in succession (Table 3). Considering all the variables evaluated, this treatment was highlighted as a cover crop for the cultivation of soybean in succession. The soybean plants grown on black oats showed high rates of all evaluated yield components, reflecting the high grain yield. Likewise, soybeans grown on the treatment consisting of rye also showed good agronomic performance, with grain yield similar to the cultivation on black oats. On the other hand, the treatments formed by the controls (in fallow and weeding), as well as the single turnip, resulted in soybean plants with less agronomic performance. In comparison to the soybeans cultivated in succession to black oats, there is a reduction of about 50% in the grain yield in fallow and weeded controls treatments, and 35% when the soybean was grown on single turnip.

The low agronomic performance of soybean grown on turnip may be related to the low C/N ratio of this brassica, varying from 11/1 to 17/1, causing a rapid decomposition of its straw and, consequently, presenting an inefficient soil coverage (Carneiro, et al., 2008; Ziech, et al., 2015). Conversely, poaceae (grasses), such as black oats and rye, have a slower decomposition, as they have a C/N ratio greater than 20/1, providing soil coverage for a longer period of time (Ceretta, et al., 2002; Calonego, et al., 2012).

Although in the present work the treatments composed of rye + turnip and black oats + rye + turnip presented the largest accumulations of DSP at 105 DAS (Table 2), the presence of turnip in these treatments accelerates the straw decomposition. Thus, treatments with single black oats make it possible to cover the soil for a longer period, reducing the soil temperature and losses of water by evaporation (Bortoluzzi & Eltz, 2000). According to these authors, the maximum soil temperature during soybean cultivation in succession to black oats was reduced by 6 °C in comparison to the weeded control treatment.

The prolonged effect of soil cover provided by black oat straw, as well as for rye, may have attenuated the low rainfall observed in January and February 2020, leading to a water deficit in the period that coincided with the end of the vegetative phase and the beginning of the reproductive phase of the soybean crop (Figure 1). The low rainfall indexes observed during the period of conduction of the experiment reflected in the soybean yield components, consequently, in the grain yield in the treatments that did not present an efficient and lasting soil cover, as the treatments formed by turnip, fallow and weeded controls. According to Krenchinski et al. (2018), the water deficit results in soybean plants with lower heights compared to plants grown in years without water restriction. These authors also observed a positive effect of black oats during winter on yield components and soybean grain yield.

In the work carried out by Nicoloso et al. (2008), where there was good water availability during the conduct of the experiment, high yield (3.53 Mg ha^{-1}) was observed in response to treatments with black oats and black oats + turnip. However, in the present work it was observed that the consortium of black oats + turnip resulted in lower soybean grain yield (Table 3) in relation to the above-mentioned study. This can be explained by the lower proportion of black oats on the soil with the reduction in the amount of seeds of the poaceae for the formation of the intercropping.

In general, it is observed that there was an increase in soybeans grain yield for all treatments with cover crops compared to the controls in fallow and weeded (Table 3). Similarly, Anschau et al. (2018) also observed an increase in soybean grain yield with the use of cover crops during autumn/winter period, including black oat, turnip and peas, single or intercropped. However, the effect on soybean grain yield was less compared to the present study, with an increase of about 11%. Gazola & Cavariani (2011) observed an increase of 30% in the grain yield of soybean cultivar BRS 243 RR cultivated on white oats compared to fallow. However, for other soybean cultivars evaluated, there was no difference in grain yield.

In addition to poor soil protection efficiency, turnip has allelopathic potential over soybeans, as demonstrated by Nóbrega et al. (2009). These authors showed that the emergence of soybean seedlings was reduced when sown on a triple intercropping between black oats + turnip + vetch. The same result was also observed by Fleck et al. (2006), in which the presence of turnip during the first two months of the soybean cycle reduced plant height, leaf area, DSP accumulation, branch emission and growth and soybean grain yield. These observations corroborate the results of the present study, in which, in addition to the low grain yield, soybean plants grown on turnip showed lower plant height and number of pods per plant (Table 3). However, Debiasi et al. (2010), Wolschick (2014), and Henz and Rosa (2017) did not find differences in soybean grain yields in succession to single oat and turnip crops. Thus, the effect of cover crops can vary with each crop, depending on meteorological characteristics, in addition to others such as soil, cultivar and crop management.

In general, the treatments formed by black oats and rye provided better soybean agronomic performances compared to the intercropping (Table 3). However, in the long-term, intercroppings are believed to be more favorable, due to the diversity provided. In addition to the physical contribution of straw against water loss, it must be considered that other processes, such as nutrient mineralization and soil structure, reflect positively on the long-term soybean cultivation system (Krenchinski, et al., 2018; Spíndola, et al., 1997).

4. Conclusion

The cultivation of single turnip provides rapid soil coverage, reaching 90.0% at 45 days after sowing. However, the soybean grain yield grown in succession did not differ from the fallow and weeded control treatments.

The consortium between rye + turnip (7.6 Mg ha^{-1}) and black oats + rye + turnip (7.0 Mg ha^{-1}) provided the largest accumulation of dry shoot phytomass at 105 days after sowing.

The predecessor crops of single black oats (3,312 kg ha^{-1}) and rye (3,229 kg ha^{-1}) provide increments of approximately 50% in soybean grain yield compared to the treatments in fallow (1,663 kg ha^{-1}) and weeding (1,865 kg ha^{-1}).

In the future, further research will be conducted with the aim of evaluating the long-term effect of the cultivation of cover crops. In addition to the grain yield of commercial crops, other parameters will be evaluated, such as the occurrence of weeds and the physical, chemical and biological parameters of the soil.

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