Yield and economic analysis of soybean cultivation in succession with different autumn/winter crops in Midwest of Paraná, Brazil[1]

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ABSTRACT

Soybean and corn succession system widely adopt in different agricultural regions from Brazil. However, different species incorporation, especially in the autumn/winter season, can influence the soybeans profitability in succession system and farm economic return, providing benefits for the agricultural sector. The objective this work was to analyze the development of different species in the autumn-winter crop and the influence on soybean yield and the economic return of farm in Midwest of Paraná, Brazil. The study was conducted during 2019/2020 and 2020/2021 crop. A completely randomized design adopted, with eight treatments (autumn/winter season) and four replications. In autumn/winter season were composed of five crops in single system (black oat, brachiaria ruziziensis, oilseed radish, corn and wheat), two in intercropped systems (black oat with oilseed radish and corn with brachiaria) and fallow area (spontaneous plants). In the spring/summer season, soybean was cultivated. The biomass produced in the autumn/winter season varies with the species and cultivation system adopted. Soybean yield is higher when cultivated in succession to brachiaria, while the worst performance is obtained in succession to spontaneous plants. The cultivation of wheat in the winter and soybeans in the summer presents superior economic performance.

Keywords: agricultural systems; biomass; economic analysis; *Glycine max*.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) has high economic importance in Brazil, being produced from north to south under different soil and climate conditions (Cattelan & Agnol, 2018). Crop yield is reflection of the production environment (Corassa *et al.*, 2018), and the adoption of appropriate techniques and management influences the productive potential (Battisti *et al.*, 2018).

Soybean and corn succession system is adopted in large scale in producing regions, with emphasis in Goiás, Mato Grosso, Mato Grosso do Sul and Paraná (Garcia *et al.*, 2018; Nóia Junior & Sentelhas, 2019). However, species diversification in crop systems improve some chemical, physical and biological aspects of the soil, in addition to the incidence of spontaneous plants and nutrient cycling (Comin *et al.*, 2018; Buchi *et al.*, 2018; Forte *et al.*, 2018; Ramos *et al.*, 2019; Hunter *et al.*, 2019).

To incorporate new species into the agricultural production system, it is considered the impact to the environment, to successive crops and economic profitability (Singh *et al.*, 2021). The incorporate new species, mainly adopting the implementation of different species in the winter period (Franchini *et al.*, 2011), regarding the short and long-term

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economic impacts under yield components (Cai *et al.*, 2019).

Plants grown in winter positively influence the succession crop, through biomass production, soil changes, cultural weed control and nutrient dynamics in the production system (Baraibar *et al.*, 2018; Buchi *et al.*, 2018; Tanaka *et al.*, 2019). In southern Brazil, studies developed by Franchini *et al.* (2011) show that soybean yield is influenced by autumn/winter crop, obtaining better results after oat and wheat cultivation. Considering the diversity of adaptable species adaptable to the region, the study aimed to analyze the development of different species (black oat, brachiaria ruziziensis, oilseed radish, corn and wheat) in autumn-winter season, regarding the influence on soybean yield and the economic return of the farm.

MATERIAL AND METHODS

The study was carried on farm in Campo Mourão-PR (23°59'1"S, 52°29'52"W and altitude of 535 m) during 2019/2020 and 2020/2021 crop. The local climate is classified as Cfa, with an average annual temperature of 21.1 to 22 °C, annual precipitation between 1600 and 1800 mm, potential evapotranspiration from 1000 to 1100 mm and global solar radiation between 14.1 to 14.5 MJ m^{-2} day^{-1} (Nitsche *et al.*, 2019).

A completely randomized design was adopted with eight treatments (autumn/winter season) and four replications. In autumn/winter season were composed of five crops in single system (black oat, brachiaria ruziziensis, oilseed radish, corn and wheat), two in intercropped system (black oat with oilseed radish and corn with brachiaria) and control (spontaneous plants). In the spring/summer period, soybean was cultivated. The experimental plots measured 3.6 m x 5 m, with used area of 10.8 m^2.

The soil is characterized as LATOSSOLO VERMELHO according to Brazilian Soil Classification System, showing correlation with Ferralsols and Oxisols in WRB/FAO and Soil Taxonomy Classification, respectively (Santos *et al.*, 2018). The soil presented granulometric composition of 44% clay, 18% silt and 38% sand. The soil chemical composition from 2 different depths is shown in Table 1.

Temperature and precipitation data from Campo Mourão-PR were obtained by the Agricultural Decision Support System (SISDAGRO) of National Institute of Meteorology (INMET), presented in Table 2.

Before sowing, a dose (2 L ha^{-1}) of paraquat (200 g L^{-1}) was applied in total area for weed control. Wheat cultivation was carried out in the first half of May (2019 and 2020), while the other species were sown in the first half of March (2019 and 2020).

For wheat crop it was adopted 0.2 m of spacing between lines and 0.45 for other crops. In the intercropping of black oat and oilseed radish, sowing was carried out in interspersed rows, and in the cultivation of corn with brachiaria ruziziensis, brachiaria was sown between the corn rows.

Sowing fertilization in black oat and black oat intercropped with oilseed radish was performed with 10 kg ha^{-1} of N, 50 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of K_2O. In brachiaria, 10 kg ha^{-1} of N, 50 kg ha^{-1} of P_2O_5 and 60 kg ha^{-1} of K_2O were used. In single corn and intercropped with brachiaria 15 kg ha^{-1} of N, 100 kg ha^{-1} of P_2O_5 and 90 kg ha^{-1} of K_2O. In wheat, 15 kg ha^{-1} of N, 60 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of K_2O. In oilseed radish, 10 kg ha^{-1} of N, 40 kg ha^{-1} of P_2O_5 and 20 kg ha^{-1} of K_2O. In topdressing, 70 kg ha^{-1} of N was applied to corn (single and intercropped) and 40 kg ha^{-1} of N to wheat. Fertilization was carried out according to nutrient and soil contents (Pauletti & Motta, 2017). Urea (45% N) was used as N source, triple superphosphate (48% P_2O_5) for P and potassium chloride (60% K_2O) for K.

Crop management was carried out according to technical recommendations, using herbicides with the active ingredient of 2,4D amine (806 g L^{-1}), methyl metsulfuron (600 g kg^{-1}), glyphosate (445 g L^{-1}) and ethyl chlorimuron (250 g kg^{-1}); insecticides based on methomyl (255 g L^{-1}) and beta-cyfluthin (12.5 g L^{-1}) + imidacloprid (100 g L^{-1}); and fungicides based on mancozeb (800 g kg^{-1}), propiconazole (250 g L^{-1}), pyraclostrobin (333 g L^{-1}) + fluxapyroxad (167 g L^{-1}) and bixafen (125 g L^{-1}) + prothioconazole (175 g L^{-1}) + trifloxystrobin (150 g L^{-1}) using commercial product dosage according to culture recommended considering target and infestation/incidence.

Soybean (cv. M6410) sowing was carried out in the first half of November 2020, with line spacing of 0.45 m and population density of 311 thousand pl ha^{-1}. At sowing it was used 230 kg ha^{-1} of NPK formulated (06-35-06). Peat inoculant (Masterfix Soja™) was added to industrially treated seeds (TSI) at sowing time.

Weed control was carried out with glyphosate (445 g L^{-1}) and ethyl chlorimuron (250 g kg^{-1}). At flowering beginning, topdressing was carried out with 100 kg ha^{-1} of potassium chloride.

Table 1: Soil chemical characterization at the beginning of the experiment (March, 2019)

Parameter	Unit	Depth (cm)	
		0-20	20-40
pH ($CaCl_2$)	-	5.10	4.94
pH (H_20)	-	5.80	5.60
pH (SMP)	-	5.83	5.79
Calcium	cmolc dm^{-3}	6.07	5.10
Magnesium	cmolc dm^{-3}	2.87	2.04
Potassium	cmolc dm^{-3}	0.31	0.19
Sodium	mg dm^{-3}	3.67	4.17
Phosphor	mg dm^{-3}	8.67	3.43
CTC[(1)] pH 7,0	cmolc dm^{-3}	14.90	13.26
Efetive CTC[(1)]	cmolc dm^{-3}	9.26	7.39
Sum of bases	cmolc dm^{-3}	9.26	7.35
Bases saturation	%	62.21	55.57
Organic matter	%	4.20	3.83
Carbon	g dm^{-3}	24.34	22.19
Copper	mg dm^{-3}	16.63	20.37
Zinc	mg dm^{-3}	3.26	1.46
Manganase	mg dm^{-3}	119.40	109.50
Iron	mg dm^{-3}	59.50	50.20

O[(1)] CTC = cation exchange capacity.

For crop phytosanitary management, mancozeb (800 g kg^{-1}), azoxystrobin (120 g L^{-1}) + tebuconazole (200 g L^{-1}), pyraclostrobin (333 g L^{-1}) + fluxapyroxad (167 g L^{-1}), thiamethoxam (141 g L^{-1}) + lambda-cyhalothrin (106 g L^{-1}) and novalurom (100 g L^{-1}), were used according to level attack/infestation and culture recommendation.

At the end of autumn/winter cultivation, total biomass was determined for each species. Crops with corn and wheat, grain yield was determined. In 2019/2020 crop, soil resistance penetration during flowering soybean beginning was determined. During soil penetration resistance evaluation, the moisture condition was 24.16% (0-0.2 m depth), 24.7% (0.2-0.4 m depth) and 25.3% (0.4-0.6 m). The Penetrolog equipment (Falker™) with a 0.6 m cone-shaped rod was used.

During crops cultivation, technical-financial surveys were carried out in order to determine the production cost of the analyzed cultures, the financial return and the annual economic balance (U$$ ha^{-1} $year^{-1}$), according to the products/services costs and commercialization value referring to Campo Mourão-PR region.

To yield determination plants were collected in the useful area, and sent to Post-harvest Technology laboratory at the State University of Maringá (UEM). Grain mass was performed on an analytical balance (± 0.001 g), the water content in grains was determined by gravimetric method in oven with forced air circulation (105 °C for 24 hours). Grain yield was expressed in kg ha^{-1} with 14% standardized moisture content.

Biomass production and soybean yield data were subjected to analysis of variance and means grouped by Scott-Knott test with 5% of significance, by SISVAR software (Ferreira, 2019) used.

RESULTS AND DISCUSSION

Crop adoptions in between harvest period (autumn/winter) has the potential to impact the production system due to biomass production and the economic impact obtained. Cover crops can improve soil properties and increase yield, the effects can vary depending on, soil and climate conditions (Acharya *et al.*, 2019). Even yield increments are not high, there are benefits associated with accumulation and nutrients cycling (Peterson *et al.*, 2019).

Table 2: Average temperature and accumulated rainfall for each month in Campo Mourão-PR, Brazil

Monthly	2019	2020	2021	2019	2020	2021
	Temperature (°C)			Rainfall (mm)		
January	-	25.9	24.5	-	173.9	403.2
February	-	24.0	25.2	-	74.8	76.9
March	23.8	26.5	26.2	124.1	32.8	136.1
April	23.9	24.3	-	59.9	37.8	-
May	21.1	19.4	-	137.9	80.1	-
June	20.1	20.3	-	23.7	136.2	-
July	19.3	19.7	-	15.9	44.8	-
August	21.5	19.8	-	4.9	166.8	-
September	25.0	27.2	-	55.4	18.5	-
October	28.0	27.0	-	73.1	48.6	-
November	26.1	26.7	-	146.7	66.8	-
December	24.7	24.9	-	246.0	226.6	-

Source: SISDAGRO/INMET, 2022.

Biomass production showed significant difference between the species adopted in 2019/2020 crop (Table 3), the highest biomass production was obtained with oilseed radish cultivation in single system, while in 2020/2021 crop the highest biomass production was obtained with single corn cultivation.

Higher biomass values in autumn/winter 2019/2020 crop were obtained with oilseed radish, brachiaria and corn intercropped with brachiaria. In 2020/2021 crop, the highest biomass production was obtained with corn cultivation and corn intercropped with brachiaria.

The higher biomass production in the winter period tends to suppress the spontaneous plants development, being more efficient when using grass species (Baraibar *et al.*, 2018). Although still adopted in production areas, the spontaneous plants development cause negative effects on production system, considering the period with different plant proportions and species (Comin *et al.*, 2018).

Although the highest efficiency of crops biomass accumulation in the study, only corn allows the immediate economic return for grain production, biomass production tends to increase of carbon stock in the soil, generating

Table 3: Biomass production (kg ha^{-1}) in the autumn/winter season in Campo Mourão-PR, Brazil

Cultivation system	Culture	Crop 2019/2020	Crop 2020/2021
-	Spontaneous	521.70 d	1051.60 e
Single	Black oat	607.75 d	3884.55 d
Single	Brachiaria	3436.05 b	6095.60 c
Single	Corn	2954.60 c	9784.20 a
Single	Wheat	3038.90 c	6099.00 c
Single	Oilseed radish	4190.55 a	5316.60 c
Intercropping	Corn and brachiaria	3638.10 b	8564.46 b
Intercropping	Black oat and oilseed radish	2690.73 c	4364.35 d
Variation coefficient (%)		14.54	8.16

* Different letters in the column, differ from each other by the Scott-Knott test with 5% significance.

benefits for crops in succession and for long time (Aldridge *et al.*, 2019, McClelland *et al.*, 2021). According to Buchi *et al.* (2018), cover crops adoption in a short period of time, but with good development and mass accumulation, allows sustaining high wheat yields in succession in a no-tillage system, in addition to improving soil fertility.

Crops corn intercropped with brachiaria can contribute to productive efficiency, increasing biomass production and maintaining grain yield. According to Hunter *et al.* (2019), simultaneous cultivation with different species can increase biomass production, favor erosion control, weed suppression, nitrogen and carbon accumulation and change C/N ratio of remaining straw without changing yield. However, the management of species implantation in intercropped system must consider technical factors, corn intercropping with brachiaria ruziziensis in the same region Wenneck *et al.* (2021) found significant differences in yield and economic return as function of brachiaria sowing position.

Maintenance of remaining strow on soil surface combined with minimum soil disturbance are presuppositions for production in a no-tillage system, and have influence on soil's resistance to penetration, which the lowest values favor the establishment crops and soil water infiltration (Gabriel *et al.*, 2021).

In the first soybean crop of succession system, differences were observed in soil penetration resistance values. In all cultivation system were obtained values lower than 3 MPa. In soybean cultivation after black oat, brachiaria, wheat, oilseed radish and black oat intercropped with oilseed radish, the average values until 20 cm depth were less than 2 MPa, being lower than those obtained in cultivation after the development of weeds. (Figure 1).

According to Moraes *et al.* (2014), the critical limits of resistance to penetration in Red Latosol are 3.0 MPa when adopted minimum tillage with scarification and 3.5 MPa in no-tillage system. Although in all conditions analyzed the results were below the critical limit, a reduction in soil resistance to penetration was verified in areas with black oat, brachiaria, oilseed radish and black oat intercropped with oilseed radish in relation to the fallow area (spontaneous plants).

In corn cultivation, there was reduction in soil resistance to penetration in almost every profile analyzed when compared to fallow conditions. According to Ren *et al.* (2019), corn roots tend to perform well up to 40 cm in depth. The use of vegetation cover in periods between crops and species rotation in a no-tillage system tend to increase soybean and corn yields in relation to cultivation after fallow (Forte *et al.*, 2018).

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In the study, the highest soybean yield was obtained in succession with brachiaria during both analyzed crops (2019/2020 and 2020/2021). In 2020/2021 crop, higher productivity was also obtained for soybean in succession with brachiaria, while the worst performance was obtained with soybean cultivation after a period without cultivation, with development of spontaneous plants (Table 4).

Although brachiaria biomass production did not show superior results, the benefits associated with its cultivation related to soil improvements, such as reduced penetration resistance and improving nutrient cycling. According to Tanaka *et al.* (2019) biomass production of *Urochloa brizanta* or *U. ruziziensis* increases nutrients accumulation in the straw and increases soybean yield in succession, in a short-term impact.

In 2019/2020 crop, soybean yields after black oat, corn, wheat, oilseed radish and black oat intercropped with oilseed radish crops were statistically similar, while in the 2020/2021 crop, soybean after wheat showed higher yield than other crops. In both seasons, the worst soybean performance was obtained after fallow (spontaneous plants), which can be related to weed infestation, soil cover and nutrient cycling.

Regarding the economic analysis, in 2019/2020 crop the return was positive in autumn/winter growing period only for crops intended for grain production (corn and wheat), with the higher returns for wheat. Soybean economic return was higher after brachiaria cultivation, however best results obtained in the annual balance was in the wheat-soybean succession (Table 5).

In 2020/2021 crop, the best economic return was obtained for corn in single cultivation, followed by wheat. In soybean crop, the best economic return was obtained after brachiaria cultivation, while cultivation after spontaneous showed the worst results. Regarding the crop annual balance, the best performance was for wheat-soybean succession (Table 6).

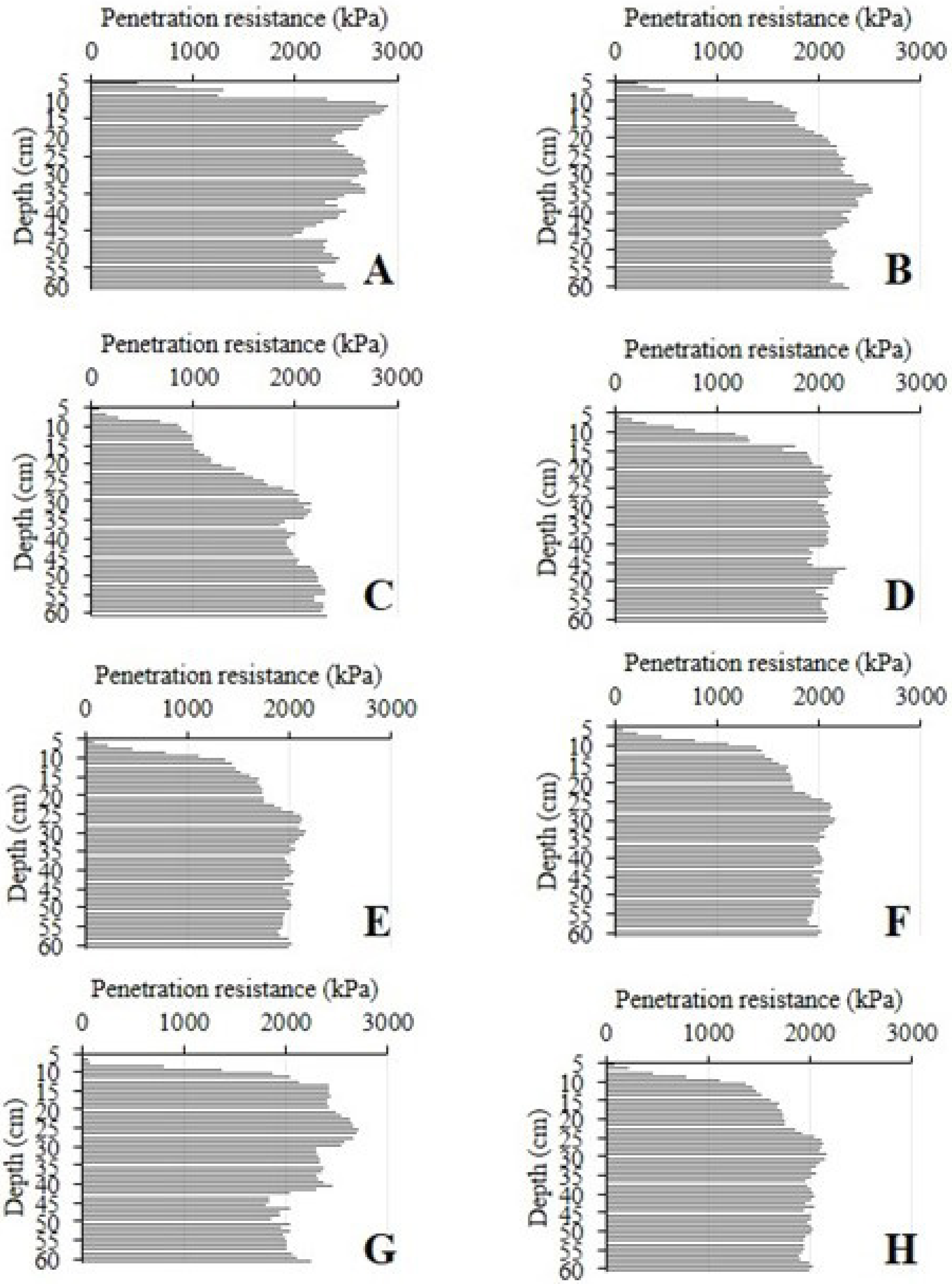

Figure 1: Resistance to soil penetration during the beginning of soybean flowering (2019/2020 crop) in the succession of different in autumn/winter season. A) Spontaneous; B) Black oats; C) Brachiaria; D) Corn; E) Wheat; F) Oilseed radish; G) Corn intercropped with brachiaria; H) Black oat mixed with oilseed radish

Table 4: Soybean yield in succession to different crops in the autumn/winter season in Campo Mourão-PR, Brazil

Autumn/winter season	Yield (kg ha^{-1})	
	2019/2020	**2020/2021**
Spontaneous	3234.49 c	2987.44 d
Black oat	3633.20 b	3401.14 c
Brachiaria	3924.36 a	4043.88 a
Corn	3663.49 b	3401.99 c
Wheat	3529.38 b	3763.55 b
Oilseed radish	3512.62 b	3506.84 c
Corn and brachiaria	3411.26 c	3501.65 c
Black oat and oilseed radish	3508.67 b	3524.09 c
Variation coefficient (%)	13.22	8.96

* Different letters in the column, differ from each other by the Scott-Knott test with 5% significance.

Grain production in autumn/winter season has economic and social relevance in food production, for corn yield and economic return are conditioned by climatic conditions and sowing date (Battisti *et al.*, 2020).

The best yield and soybean economic return were obtained in succession to brachiaria, however, when performing annual balance analysis, greater economic performance was obtained in areas with soybean cultivation in succession to wheat, resulting from the production and grains sale in the winter and maintaining high soybeans in summer. Differences in economic return between crops related to the selling price of the products.

Adoption of rotation systems, mainly with vegetation cover species, has a lower economic performance in the first years, with favorable economic results being high in the fourth year of rotation implementation according to characteristics species and production system (Cai *et al.*, 2019). Although crop rotation can improve soybean and corn yields in the long term, the determination of implanted species must consider performance variables and influence on the production system (Singh *et al.*, 2021).

Table 5: Economic balance (US$) of the 2019/2020 crop in Campo Mourão-PR, Brazil

	Autumn/winter season			Soybean			Annual balance
Culture	**Variable cost**	**Return**	**Balance**	**Variable cost**	**Return**	**Balance**	
Spontaneous	16.38	-	-16.38	413.57	815.68	644.79	628.41
Black oat	117.61	-	-117.61	413.57	916.23	745.33	627.72
Brachiaria	115.76	-	-115.76	413.57	989.65	818.76	703.00
Corn	376.49	262.68	-113.82	413.57	923.87	752.97	639.15
Wheat	344.17	448.43	104.26	413.57	890.05	719.15	823.41
Oilseed radish	112.68	-	-112.68	413.57	885.82	714.93	714.93
Corn and brachiaria	115.15	-	-115.15	413.57	884.82	713.93	713.93
Black oat and oilseed radish	364.49	188.63	-175.86	413.57	860.26	689.36	513.50

*Soybean return calculated with base price of U$$ 15.52 sc^{-1} (60 kg); Corn return calculated with base price of U$$ 5.33 sc^{-1} (60 kg); Wheat return calculated with base price of U$$ 8.73 sc^{-1} (60 kg). Real/Dollar conversion rate: 5.155.

Table 6: Economic balance (U$$) of the 2020/2021 crop in Campo Mourão-PR, Brazil

Culture	Autumn/winter season			Soybean			Annual balance
	Variable cost	Return	Balance	Variable cost	Return	Balance	
Spontaneous	44.49	-	-44.49	402.23	1356.70	954.46	909.98
Black oat	135.66	-	-135.66	402.23	1544.57	1142.34	1006.68
Brachiaria	139.21	-	-139.21	402.23	1836.46	1434.23	1295.02
Corn	431.53	715.57	284.04	402.23	1544.96	1142.72	1426.76
Wheat	364.63	709.20	344.57	402.23	1709.15	1306.92	1651.48
Oilseed radish	142.59	-	-142.59	402.23	1592.57	1190.34	1047.75
Corn and brachiaria	139.12	-	-139.12	402.23	1590.22	1187.98	1048.86
Black oat and oilseed radish	416.35	513.86	97.51	402.23	1600.41	1198.17	1295.69

*Corn return calculated with base price of US$ 14.53 sc^{-1} (60 kg); Wheat return calculated with base price of US$ 13.80 sc^{-1} (60 kg); Soybean return calculated with a base price of US$ 29.06 sc^{-1} (60 kg). Real/Dollar conversion rate: 5.505.

CONCLUSIONS

The biomass produced in the autumn/winter season varies with the species and cultivation system adopted.

Soybean yield is higher when cultivated in succession to brachiaria, while the worst performance is obtained in succession to spontaneous plants.

The cultivation of wheat in the winter and soybeans in the summer presents superior economic performance.

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REFERENCES

Acharya BS, Dodla S, Gaston LA, Darapuneni M, Wang JJ, Sepat S & Bohara H (2019) Winter cover crops effect on soil moisture and soybean growth and yield under different tillage systems. Soil and Tillage Research, 195:104430.

Aldridge CA, Baker BH & Omer AR (2019) Investigation of short-term effects of winter cover crops on compaction and total soil carbon in a long-term no-till agricultural system. Journal of Soil and Water Conservation, 74:77-84.

Baraibar B, Mortensen DA, Hunter MC, Barbercheck ME, Kaye JP, Finney DM, Curran WS & White CM (2018) Growing degree days and cover crop type explain weed biomass in winter cover crops. Agronomy for Sustainable Development, 38:65.

Battisti R, Ferreira MDP, Tavares EB, Knapp FM, Bender FD, Casaroli D & Alves Junior J (2020) Rules for grown soybean-maize cropping system in Midwestern Brazil: Food production and economic profits. Agricultural Systems, 182:102850.

Battisti R, Sentelhas PC, Pascoalino JAL, Sako H, Dantas JPS & Moraes MF (2018) Soybean Yield Gap in the Areas of Yield Contest in Brazil. International Journal of Plant Production, 12:159-168.

Buchi L, Wedling M, Amossé C, Necpalova M & Charles R (2018) Importance of cover crops in alleviating negative effects of reduced soil tillage and promoting soil fertility in a winter wheat cropping system. Agriculture, Ecosystems & Environment, 256:92-104.

Cai Z, Udawatta RP, Gantzer CJ, Jose S, Godsey L & Cartwright L (2019) Economic Impacts of Cover Crops for a Missouri Wheat–Corn–Soybean Rotation. Agriculture, 9:83.

Cattelan AJ & Agnol AD (2018) The rapid soybean growth in Brazil. Oilseeds & fats Crops and Lipids, 25:102.

Corassa GM, Amado TJC, Strieder ML, Schwalbert R, Pires JLF, Carter PR & Ciampitti IA (2018) Optimum Soybean Seeding Rates by Yield Environment in Southern Brazil. Agronomy Journal, 110:2430-2438.

Ferreira DF (2019) Sisvar: a computer analysis system to fixed effects split plot type designs. Revista Brasileira de Biometria, 37:529-535.

Forte CT, Beutler AN, Galon L, Castoldi CT, Winter FL, Holz CM, Bianchessi F, Concenço G, Chechi L, Ferreira MM, Andres A & Burg GM (2018) Soil Physical Properties and Grain Yield Influenced by Cover Crops and Crop Rotation. American Journal of Plant Sciences, 9:584-598.

Franchini JC, Costa JM, Debiasi H & Torres E (2011) Importância da rotação de culturas para a produção agrícola sustentável no Paraná. Londrina, Embrapa Soja. 52p.

Gabriel JL, García-González I, Quemada M, Martin-Lammerding D, Alonso-Ayuso M & Hontoria C (2021) Cover crops reduce soil resistance to penetration by preserving soil surface water content. Geoderma, 386:114911.

Garcia RA, Ceccon G, Sutier GAS & Santos ALF (2018) Soybean-corn succession according to seeding date. Pesquisa Agropecuária Brasileira, 53:22-29.

Hunter MC, Schipanski ME, Burgess MH, Lachance JC, Bradley BA, Barbercheck ME, Kaye JP & Mortensen DA (2019) Cover Crop Mixture Effects on Maize, Soybean, and Wheat Yield in Rotation. Agricultural & Environmental Letters, 4:01-05.

Instituto Nacional de Meteorologia – INMET (2022) Sistema de Suporte à Decisão na Agropecuária (SISDAGRO). Available at: <http://sisdagro.inmet.gov.br/sisdagro/app/index>. Accessed on: February 2nd, 2022.

McClelland SC, Paustian K & Schipanski ME (2021) Management of cover crops in temperate climates influences soil organic carbon stocks: a meta-analysis. Ecological Applications, 31:2278.

Moraes MT, Debiasi H, Carlesso R, Franchini JC & Silva VR (2014) Critical limits of soil penetration resistance in a rhodic Eutrudox. Revista Brasileira de Ciência do Solo, 38:288-298.

Nitsche PR, Caramori PH, Ricce WS & Pinto LFD (2019) Atlas Climático do Estado do Paraná. Londrina, IAPAR. 210p.

Nóia Junior RS & Sentelhas PC (2019) Soybean-maize succession in Brazil: Impacts of sowing dates on climate variability, yields and economic profitability. European Journal of Agronomy, 103:140-151.

Pauletti V & Motta ACV (2017) Manual de adubação e calagem para o estado do Paraná. Curitiba, SBCS/NEPAR. 482p.

Peterson AT, Berti MT & Samarappuli D (2019) Intersowing Cover Crops into Standing Soybean in the US Upper Midwest. Agronomy, 9:264.

Ramos MC, Pareja-Sánchez E, Plaza-Bonilla D, Cantero-Martínez C & Lampurlanés J (2019) Soil sealing and soil water content under no-tillage and conventional tillage in irrigated corn: Effects on grain yield. Hydrological Processes, 33:2095-2109.

Ren L, Nest TV, Ruysschaert G, D'Hose T & Cornelis WM (2019) Short-term effects of cover crops and tillage methods on soil physical properties and maize growth in a sandy loam soil. Soil and Tillage Research, 192:76-86.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VÁ, Lumbreras JF, Coelho MR, Almeida JÁ, Araújo Filho JC, Oliveira JB & Cunha TJF (2018) Brazilian Soil Classification System. 5ª ed. Brasília, Embrapa. 356p.

Singh J, Wang T, Kumar S, Xu Z, Sexton P, Davis J & Bly A (2021) Crop yield and economics of cropping systems involving different rotations, tillage, and cover crops. Journal of Soil and Water Conservation, 76:340-348.

Tanaka KS, Crusciol CAC, Soratto RP, Momesso L, Costa CHM, Franzluebbers AJ, Oliveira-Junior A & Calonego JC (2019) Nutrients released by *Urochloa* cover crops prior to soybean. Nutrient Cycling in Agroecosystems, 113:267-281.

Wenneck GS, Saath R, Araujo LL, Pereira GL, Oliveira GGF, Sá N & Volpato CS (2021) Yield and economic analysis of corn and brachiaria intercropping in the northwestern Paraná. Revista de Agricultura Neotropical, 8:6163.