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No-till cabbage production in different cover crops and phosphorus sources in the Brazilian Cerrado

Guilherme F Alves [1]; José Luiz R Torres [1]; Hamilton Cesar de O Charlo [1]; Valdeci Orioli Junior [1]; Arcângelo Loss [2]; Antônio Carlos Barreto [1]

[1]Instituto Federal do Triângulo Mineiro (IFTM), Uberaba-MG, Brasil; guilhermefalves.rp@gmail.com; jlrtorres@iftm.edu.br (author for correspondence); hamiltoncharlo@iftm.edu.br; valdeci@iftm.edu.br; barreto@iftm.edu.br; [2]Universidade Federal de Santa Catarina (UFSC), Florianópolis-SC, Brasil; arcangelo.loss@ufsc.br

ABSTRACT

No-till planting and the use of organomineral fertilizers are crop management practices that increase soil organic matter, thereby mitigating leaching and cycling a considerable amount of nutrients, with the potential to improve crop yield. This study aimed to assess the agronomic performance of cabbage grown under a no-till system, using different cover crops and phosphorus sources. A randomized block design was used, with the main plot consisting of eight split plots for different cover crop treatments: 1) Signal grass (SG); 2) Sunn hemp (SH); 3) Pearl millet (PM); 4) SG+SH; 5) SG+PM; 6) SH+PM; 7) SG+SH+PM; 8) conventional tillage (soil preparation with no cover crop), and phosphorus (P) sources in the sub-plots: 1) mineral fertilizer (FM); 2) organomineral fertilizer (OF); 3) no P, with four repetitions. The following characteristics were assessed: cover crop fresh (FW) and dry weight (DW) (t/ha), residue decomposition and nutrient cycling; and cabbage head FW and DW (HFW and HDW) (g/plant) and yield (YLD) (t/ha). The highest FW and DW were recorded in the intercropped cover plant treatments; PM+SH and SG+SH residue exhibited the highest decomposition rate and P cycling into the soil. The highest cabbage HFW and YLD occurred in the SG+SH treatment, regardless of the fertilizer used. The MF used as P source produced a greater cabbage YLD when grown in PM residue. Under conventional tillage, YLD was higher when OF was used as P source.

Keywords: *Brassica oleracea* var. *capitata*, cover crops, no-till vegetable farming.

RESUMO

Plantio direto de repolho sobre resíduos de diferentes plantas de cobertura e fontes de fósforo no cerrado

O cultivo em sistema de plantio direto e a utilização de fertilizantes organominerais são práticas de manejo que amenizam a lixiviação e ciclam quantidades consideráveis de nutrientes, em virtude do aporte de matéria orgânica que proporcionam ao solo, e que podem melhorar o rendimento das culturas. Neste estudo objetivou-se avaliar o desempenho agronômico do repolho cultivado sobre diferentes resíduos de plantas coberturas e fontes de fósforo em sistema de plantio direto. O delineamento experimental foi de blocos ao acaso, em parcelas subdivididas, com oito tratamentos com plantas de cobertura na parcela principal: 1) Braquiária (B); 2) Crotalária (C); 3) Milheto (M); 4) B+C; 5) B+M; 6) C+M; 7) B+C+M; 8) cultivo convencional (preparo do solo sem planta de cobertura). Nas subparcelas avaliou-se as fontes de fósforo (P): 1) Fertilizante mineral (FM); 2) Fertilizante organomineral (FO); 3) Sem fornecimento de P, com quatro repetições. Avaliaram-se a produção de massa fresca (MF) e seca (MS) (t/ha) das plantas de cobertura; decomposição e ciclagem de nutrientes dos resíduos; MF e MS da cabeça (MFC e MSC) (g/planta) e a produtividade (PROD) (t/ha) do repolho. As maiores produções de MF e MS ocorreram nos consórcios das plantas de cobertura; Os consórcios de M+C, B+C apresentaram os resíduos com maior taxa de decomposição e ciclagem de P para o solo. Os maiores valores de MFC e PRODs do repolho ocorreram nas áreas cultivadas sobre resíduos do consórcio B+C, independentemente da fertilização utilizada. O FM utilizado como fonte de P proporcionou maior PROD do repolho quando cultivado sobre o resíduo de milheto. Quando em cultivo convencional do solo, a PROD do repolho foi superior quando utilizado o FO como fonte de P.

Palavras-chave: *Brassica oleracea* var. *capitata*, coberturas vegetais, plantio direto de hortaliças.

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Vegetable farming in Brazil is almost always associated with the intensive use of agricultural equipment for tillage, large amounts of soluble mineral fertilizers and sprinkler irrigation, which can increase water erosion and nutrient leaching (Torres *et al*., 2021). This management system compromises soil attributes, causing yield loss (Santos *et al*., 2017)

Brassicas are among the most widely consumed vegetables in Brazil due to its high nutrient content, commercial value and ability to grow in any region of the country, cabbage being one of the most important, as a quality food with high levels of potassium, calcium, fibers, sugars, citric and ascorbic acid, and vitamins A and C (Torres *et al*., 2015, 2017; Vieira *et al*., 2020).

No-till vegetable production (NTVP) is a technological innovation used to replace conventional tillage and has maintained or increased crop yields (Massan *et al*., 2019). A more recent technology is organomineral fertilizers (OFs), a mixture or organic matter and mineral fertilizer (Vieira *et al*., 2020).

OF application has improved the yields of crops grown under conventional tillage because organic matter (OM) in the fertilizer contributes to increasing the cation exchange capacity of the soil, reducing nutrient loss by leaching (Silva *et al*., 2020). This organic matter slowly releases nutrients that supply the needs of the crops throughout their growth cycle (Rodrigues *et al*., 2016).

The presence of a larger amount of organic anions in these OF blends results in greater competition for phosphorus (P) adsorption sites, thereby increasing plant-mineral interaction, reducing P fixation and decreasing P_2O_5 transformation into forms unavailable to plants (Sousa *et al*., 2013).

Although some studies with OFs applied to vegetables grown under conventional tillage have reported good yields in some crops, little is known about their use in areas under NTVP, where organic matter is continuously supplied after each crop cycle (Torres *et al*., 2019, 2021; Silveira *et al*., 2021).

Fertilization with OFs in vegetable growing areas may provide new insights on production and improve the physical and chemical quality of soil. However, since vegetables have a short growth cycle, the use of these slow-release fertilizers requires further investigation to safeguard against nutrient deficiencies in these crops. As such, this study aimed to assess the agronomic performance of cabbage grown under a no-till system in Uberaba, Minas Gerais state (MG), Brazil, using different cover crops and phosphorus sources.

MATERIAL AND METHODS

The study was conducted from November 2020 to July 2021, in an experimental area in its first crop cycle, on the Uberaba Campus of the Federal Institute of Education, Science and Technology of the Mineiro Triangle (IFTM) (19°39'19"S; 47º57'27''W, 800 m altitude), using an NTVP system.

The soil was classified as dystrophic red latosol (Santos *et al*., 2018), with a sandy loam texture and the following physical and chemical characteristics determined at a depth of 0-20 cm before planting the cover crops: 210, 710 and 80 g/kg of clay, sand and silt, respectively, pH $CaCl_2$ 5.1; 21.7 mg/dm^3 of P (resin); 0.29 cmol$_c$/dm^{3}of K^+; 1.7 cmol$_c$/dm^{3}of Ca^{2+}; 0.4 cmolc/dm^3 of Mg^{2+}; 3.1 cmolc/dm^3 of H+Al, V = 44%, 9.74 7g/dm^3 of organic matter and cation exchange capacity (CEC) of 5.5 cmol$_c$/dm^3.

No pH correction was performed due to insufficient liming time.

Climate in the region is Aw, classified as warm tropical according to the updated Köppen classification (Beck *et al*., 2018), with hot rainy summers and cold dry winters. Average annual rainfall, temperature and relative humidity are 1,600 mm, 22.6ºC and 68%, respectively (Inmet, 2021); however, 791 mm and 24°C were recorded during the study period (Figure 1).

A randomized block design (RBD) was used, in a split-plot arrangement with 24 treatments and four repetitions. The treatments were established by combining 8 cover crops (alone and intercropped) with 3 P sources. The eight cover plant treatments 1) Signal grass (SG) (*Urochloa ruziziensis*); 2) Sunn hemp (SH) (*Crotalaria juncea*); 3) Pearl millet (PM) (*Pennisetum glaucum*); 4) intercropped SG+SH; 5) SG+PM; 6) SH+PM; 7) SG+SH+PM; and 8) No cover (control, with conventional tillage). The sub-plots consisted of three sources to supply 100% of the P dose at planting: 1) monoammonium phosphate (MAP); 2) organomineral fertilizer (OF); and 3) no P (control). For conventional tillage, harrowing was performed twice to completely turn the soil.

With respect to the P sources studied, granulated MAP contained 11% N and 52% P_2O_5; and the pelleted OF supplied by Vitória Fertilizantes S.A. contained 6% N and 30% P_2O_5, with only N corrected according to the concentration of each source.

The area was used for forage (*Urochloa brizantha* cv marandu) over an extended period of time, followed by two successive soybean and corn crops, and then left fallow for a year before planting cabbage under an NTVP system.

In the no-till system used here, pearl millet was chosen as the first cover crop to provide mulch across the entire area, followed by the other cover plants. The cover crops were planted in experimental units measuring 5 m long by 6 m wide (30 m²).

Planting was carried out using a Semina 2 seed drill, with drill rows spaced 0.20 m apart, using 50, 50 and

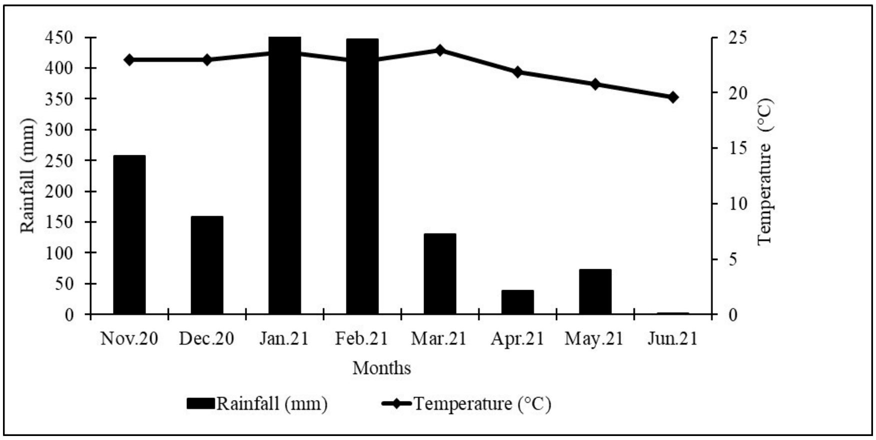

Figure 1. Average monthly temperature and rainfall, obtained from the weather station at IFTM in Uberaba-MG. Uberaba, IFTM, 2021.

25 signal grass (SG), pearl millet (PM) and sunn hemp (SH) seeds, respectively, for the individual cover crop treatments. For intercropped SG+SH, SG + PM, PM+SH, 50% of each seed dose was used, and 33% for the triple intercropped treatment (SG+SH+PM).

The cover crops were grown from October 13, 2020 to January 25, 2021 with no mineral or organic fertilizers. Since cover crops flower at different times, when 50% of the plants in the entire area reached peak bloom, a 2 m^2 area in each experimental unit was sampled for fresh weight assessment. Next, the material was dried in an oven at 65ºC for 72 hours or until constant weight and then weighed to determine dry weight, with results expressed in t/ha.

At the end of the growth period the plants were desiccated using glyphosate (Gliz® 480 SL, 960 g/ha ai) and 2.4-D dimethylamine (Aminol® 806, 1612 g/ha ai) with a spray volume of 250 L/ha, and cut close to the ground with a backpack brush cutter. Next, holes were made in the cover crop residue for subsequent fertilization and transplanting of the cabbage (*Brassica oleracea* var. *capitata*) seedlings.

The seedlings were produced from cv. Astrus seeds with a 90-day cycle, in 128-cell polystyrene trays filled with commercial Bioplant substrate and placed in a greenhouse with plastic roofing and closed sides.

On March 25, 2021, at a height of 10 to 15 cm, the cabbage seedlings were transplanted to holes (approximately 1.15 m wide and 0.18 m deep) previously made in the cover crop residue using a sow dibbler, with 0.70 x 0.50 m spacing.

The sub-plots with phosphate fertilizer consisted of four 4-meter long rows containing four plants per row, totaling 16 plants per plot with corridors between the experimental blocks. The four center plants were considered the study area for analyses.

The fertilizer doses applied to the cabbage plants were established based on soil analysis and the recommendations of the Soil Fertility Committee of Minas Gerais State (Fontes *et al*., 1999). The recommended nitrogen (N), phosphorus (P) and potassium (K) doses for cabbage were 150 kg/ha of N, 400 kg/ha of P_2O_5 and 240 kg/ha of K_2O. N and K were applied at transplanting and 30 and 45 days after transplanting (DAT), using 50 kg/ha of N and 80 kg/ha of K per application, whereas the full P dose was manually applied to each hole one day before transplanting.

Foliar spraying was carried out at 15, 30 and 40 DAT to supply boron (B), molybdenum (Mo) and cobalt (Co), using a solution of 1 g/L of boric acid (17% B) and 2.7 mL of Vitaphol CoMo®, which contains 10% Mo and 2% Co. Applications aimed to completely cover the leaves without allowing the spray solution to drip.

The plants were irrigated daily as needed, using a conventional sprinkler system consisting of spray heads spaced 9 m apart with a flow rate of 560 L/h and irrigation time of 20 min/day to maintain soil moisture content close to field capacity.

Weeds were controlled via a single application of fluazifop-p-butyl (Fusilade® 250 EW, 175 g/ha of ai) at 10 DAT and by manual weeding throughout the crop cycle.

Litter bags were used to quantify the decomposition rate of cover crop residue, as described by Santos & Whilford (1981). The 0.04 m^2 bags (0.20 x 0.20 m) were made from 2 mm mesh nylon and contained 30 g of cover crop shoots, previously oven dried at 65ºC for 72 hours or until constant weight.

Immediately after cabbage seedling transplanting, four nylon litter bags were distributed in each experimental unit and collected 90 days later. The bags were sampled at distribution to determine the baseline (time zero) and identify the onset of decomposition. The bags were collected from the field after 90 days, their contents removed and then oven dried at 65ºC for 72 horas or until constant weight. Each sample was manually cleaned to remove any mineral residue and subsequently determine dry weight, expressed in t/ha.

The exponential mathematical model described by Thomas & Asakawa (1993) was applied to calculate plant residue decomposition using the equation $X = Xoe^{-kt}$, where X is the dry weight remaining after time t, in days; Xo the initial amount of dry matter and k the decomposition constant.

Based on the k value, the half-life ($T^{1/2}$) of the remaining residue was calculated using the formula $T^{1/2} = 0.693/k$, proposed by Paul & Clark (1996), which expresses the time taken for half the residue to decompose or for half of the nutrients in the residue to be released.

In order to quantify nutrient cycling in the cover crop residue, the material removed from the litter bags was ground and sent to the laboratory for chemical analysis.

Total N was determined by the Kjeldahl method, P by colorimetry and K by spectrophotometry (Teixeira *et al*., 2017). Ca and Mg were measured by atomic absorption spectrometry and S by turbidimetry (Tedesco *et al*., 1995). Extraction of each nutrient was estimated based on the percentage of nutrient present in each sample, multiplied by the total dry weight.

Cabbage was harvested when head compactness (firmness) reached commercial grade, at 83 DAT, over a period of 10 days. After harvesting, the heads were sent to the laboratory to determine head fresh (HFW) and dry weight (HDW) and yield (YLD).

Assumptions of normality and homogeneity of residual variances were verified using the Shapiro-Wilk and Bartlett tests, respectively. The values obtained for the characteristics studied were submitted to analysis of variance using Agroestat statistical software. The F test was applied and, when significant, the means for the cover crops were analyzed using the Scott-Knott method. Decomposition rates were submitted to regression analysis in SigmaPlot software version 12,5. Significance was set at 5% for all analyses.

RESULTS AND DISCUSSION

The SG+PM and SG+PM+SH cover crop treatments obtained the highest FW production, at 50.2 and 53.2 t/ha, respectively, while the largest DW values were recorded for PM+SH (14.4 t/ha) and SG+PM+SH (15.7 t/ha). Sunn hemp exhibited the lowest FW and DW when compared to the other cover crops, with 26.8 and 7.5 t/ha, respectively (Table 1).

The FW and DW values obtained can be considered high for the region, which can be justified by the rainfall during the study period (October 13, 2020 to January 25, 2021), with a total of 915.0 mm and average temperature of 24.0°C.

The higher respective FW and DW values for SG+PM and SG+PM+SH; and PM+SH and SG+PM+SH when compared to the individual cover crops (Table 1) confirm the benefits of intercropping these species, such as increased biomass production due to the balanced carbon-to-nitrogen ratio (C:N) achieved between the intercropped species and better soil exploration via different root systems.

Intercropping cover plants, especially grasses and legumes, reduces nitrogen immobilization by soil microorganisms, promoting an increase in soil nutrient content and dry matter accumulation and greater water and nutrient use efficiency due to better soil exploration by the different root systems (Latati *et al*., 2016). Under tropical conditions such as those in the Cerrado, this is an interesting alternative to ensure mulch formation and increase soil organic matter content (Rodrigues *et al*., 2012).

Torres *et al*. (2017) and Mazetto Junior *et al.* (2019) studied FW and DW production in the same region and growing season and found FW values of 4.4 to 41.6 t/ha for SG, 8.5 to 41.7 t/ha for SH and 8.5 to 46.5 t/ha for PM, whereas the intercropped treatments SG+SH, SG+PM, SH+PM and SG+PM+SH obtained values of 19.1 to 39.0, 17.8 to 37.1, 11.1 to 44.8 and 28.7 to 49.8 t/ha, respectively. The results for DW were 3.4 to 13.2 t/ha for SG, 5.0 to 9.8 t/ha for SH and 6.1 to 14.2 t/ha for PM, with respective values of 7.2 to 10.0, 6.9 to 13.2, 6.9 to 13.4 and 8.0 to 13.7 t/ha for SG+SH, SG+PM, SH+PM and SG+PM+SH. In both studies, rainfall distribution in the region was a decisive factor in cover crop FW and DW production, with values similar to those observed in our study.

These same cover crops (SG, PM and SH) and combinations were assessed by Torres *et al*. (2015; 2017) and Silveira *et al*. (2021) in NTVP systems and showed promising results since, in addition to providing protection against soil erosion, they maintained soil moisture content for longer, reduced the volume of irrigation water needed and cycled a considerable amount of nutrients, thereby improving the agronomic indicators of the subsequent commercial crop.

Analysis of the decomposition rate of the different cover crops studied showed that, after 90 days, residue of 4.4 (58% of the initial total), 61 (63%) and 8.5 t/ha (75%) remained for SH, SG and PM grown alone and 6.8 (62% of the initial total), 10.3 (66%), 7.9 (71%) and 11.5 t/ha (73%) for SG+SH, SG+PM+SH, PM+SH and SG+PM, respectively (Figure 2). These findings indicate that decomposition was slower for PM grown alone or intercropped with other plants, which can be justified by the higher C:N between the plants used (Silveira *et al*., 2021; Torres *et al*., 2021).

On the other hand, SH exhibited the highest remaining DW after 90 days when grown individually or in

Table 1. Fresh (FW) and dry weight (DW) production of different cover crops under a no-till cabbage growing system in the Brazilian Cerrado, in Uberaba-MG. Uberaba, IFTM, 2021.

Cover crop	FW	DW
	t/ha	
SG	35.3 b	9.8 b
PM	37.6 b	11.4 b
SH	26.8 c	7.5 c
SG+PM	50.2 a	11.1 b
SG+SH	37.9 b	10.9 b
PM+SH	37.8 b	15.7 a
SG+PM+SH	53.2 a	14.4 a
F value	19.75**	13.21**
CV (%)	10.20	13.12

** = Significant ($p<0.05$). Means followed by the same lowercase letter in the column do not differ according to the Scott-Knott test (p = 0.05). SG = signal grass; PM = pearl millet; SH = sunn hemp.

Table 2. Dry weight (DW), decomposition constant (k) and half-life (T½) of the cover crops under no-till cabbage production in Uberaba-MG. Uberaba, IFTM, 2021.

Cover crop	DW		
	K (g/g)	T½ (days)	R^2
SG	0.024 a	29 d	0.98 **
PM	0.017 b	41 a	0.93 **
SH	0.024 a	29 d	0.98 **
SG+SH	0.027 a	27 d	0.97 **
SG+PM	0.018 b	39 b	0.99 **
PM+SH	0.021 a	33 c	0.99 **
SG+SH+PM	0.024 a	29 d	0.95 **
F value	2.97**	1.93**	--
CV (%)		5.47	

** = Significant ($p<0.05$); R^2 = Coefficient of determination. ** = Significant ($p<0.05$). Means followed by the same letter in the column do not differ according to the Scott-Knott test (p = 0.05). SG = signal grass; PM = pearl millet; SH = sunn hemp.

the intercropped treatments (Figure 2). Similar findings were obtained in other studies with this species when grown alone or intercropped with SG and PM (Soratto *et al*., 2012; Algeri *et al*., 2018). Greater decomposition of SH residue occurs because these plants generally have a low C:N ratio due to their high biological nitrogen fixation (BNF) (Soratto *et al*., 2012; Pacheco *et al*., 2013; Torres *et al.,* 2017).

Whether grown individually or intercropped, PM reduced the decomposition rate of residue, possibly because of its higher C:N ratio when compared to the other cover crops in the present study, as observed by Algeri *et al.* (2018), Mazetto Junior *et al*. (2019) and Torres *et al*. (2021) in research conducted in the Cerrado.

The half-life (T½) indicates when 50% of the cover crop residue has decomposed and can be estimated using the constant (k) of the decomposition curve equations (Table 2).

SH and SG grown alone, together (SG+SH) and intercropped with PM (SG+SH+PM) obtained lower T½ values than those of the other treatments. This can be explained by the high BNF of SH and the fact that SG had not reached peak bloom at cutting because of its slow initial development when compared to the other cover crops studied.

According to Collier *et al*. (2018), using Poaceae and Fabaceae as individual or combined cover crops improves FW and DW production by increasing soil organic matter content, which improves soil quality, since the plants are adapted

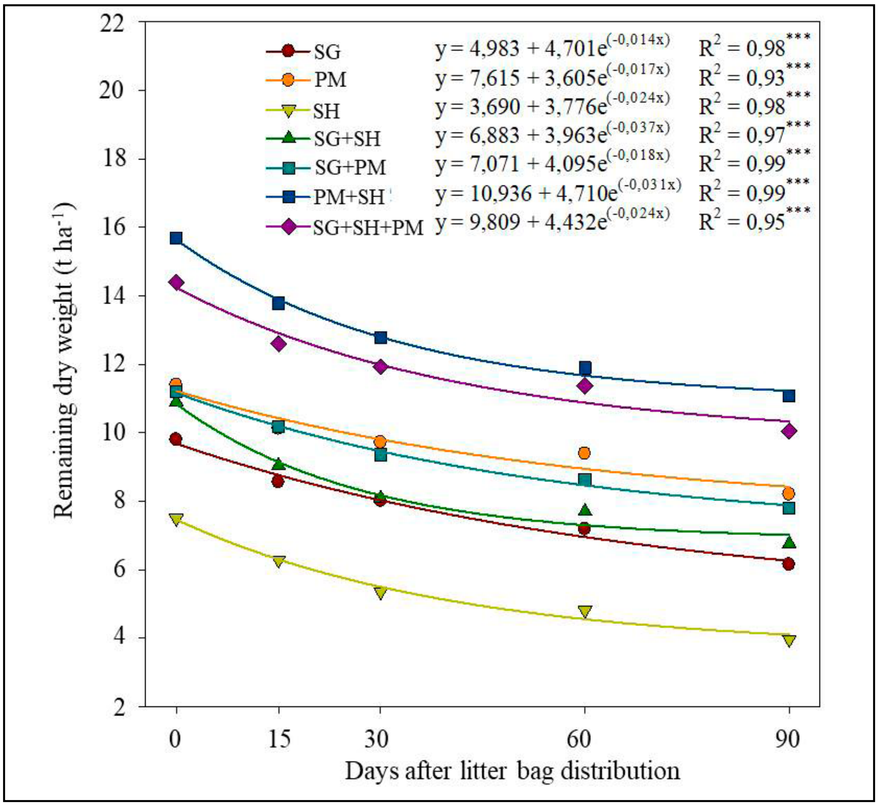

Figure 2. Remaining dry weight (DW) in the residue of the different cover crops (SG = signal grass; PM = pearl millet and SH = sunn hemp) over time, in Uberaba-MG. Uberaba, IFTM, 2021.

Table 3. Phosphorus content (PC) and accumulated phosphorus (AP) in the cover crop residue at time zero (TZ) and 90 days after cabbage transplanting in the phosphate fertilization treatments: no phosphorus (SP90), organomineral fertilizer (OF90) and mineral fertilizer (MF90), in Uberaba-MG. Uberaba, IFTM, 2021.

Cover crop	Phosphorus in the plant residue							
	Content				Accumulated			
	TZ	SP90	OF90	MF90	TZ	SP90	OF90	MF90
	g/kg				kg/ha			
SG	9.3 Ba	2.5 Bc	1.3 Bd	3.5 Bb	91.1 Ba	24.5 Cc	12.7 Cd	34.3 Bb
PM	5.0 Ca	2.2 Bb	0.8 Cc	1.7 Db	57.0 Da	25.1 Cc	9.1 Dd	19.4 Cc
SH	12.5 Aa	9.1 Ab	7.4 Ac	2.8 Bd	93.8 Ba	68.3 Bb	55.5 Bc	21.0 Cd
SG+SH	6.9 Ca	2.9 Bb	1.4 Bc	1.1 Dc	76.6 Ca	32.2 Cb	15.5 Cc	12.2 Dc
SG+PM	3.4 Ea	1.2 Cb	0.8 Cc	1.3 Db	37.1 Ea	13.1 Db	8.7 Dc	14.2 Db
PM+SH	12.0 Aa	9.3 Ab	8.1 Ac	7.3 Ad	188.4 Aa	146.0 Ab	127.2 Ac	114.6 Ad
SG+PM+SH	4.8 Da	1.9 Bb	0.3 Dc	2.1 Cb	69.1 Ca	27.4 Cb	4.3 Dc	30.2 Bb
F value	0.46**	2.51**	0.18*	0.51**	0.08*	0.33**	0.16*	1.95**
CV%	14.6							

* and ** = Means followed by the same lowercase letter in the rows and uppercase in the columns do not differ according to the Scott-Knott test (p<0.01 and 0.05). SG = signal grass; PM = pearl millet; SH = sunn hemp; CV = coefficient of variation.

Table 4. Mean head fresh weight (HFW), dry weight (HDW) and yield (YLD) of cabbage grown under different cover crop residues and P doses on a no-till system in Uberaba-MG. Uberaba, IFTM, 2021.

Treatment	HFW	HDW	YLD
	g/plant		t/ha
Cover crop (Cov)			
Signal grass (SG)	1248.9	63.2	31.7
Pearl millet (PM)	1690.4	93.3	42.7
Sunn hemp (SH)	1612.0	93.0	39.4
SG+SH	1801.4	95.1	49.7
SG+PM	1780.0	88.8	38.8
PM+SH	1549.7	83.1	39.8
SG+SH+PM	1599.3	92.7	33.8
Conventional	1420.2	69.3	35.5
P source (PS)			
No P	1331.8	73.5	34.7
Organomineral	1686.1	93.2	41.2
Mineral	1745.4	87.8	42.6
Interactions			
F test Cov	9.20**	17.41**	21.85**
F test PS	36.08**	32.64**	37.56**
F test Cov x PS	4.26**	5.78**	13.68**
CV (%)	13,26	11.89	9.87

** = not significant, significant at 5% probability; CV: coefficient of variation.

to the soil and climate conditions in the Cerrado. In the present study, PM+SH and SG+PM+SH exhibited the highest DW production (Table 1, Figure 2), but PM alone obtained the highest T½ and its intercropped treatments the lowest (Figure 2), demonstrating that PM residue directly affects the decomposition dynamics of soil cover, favoring an intermediate C:N in the intercropped treatments, especially those containing SH.

The combination of SG and SH produced a lower T½ in relation to SG+PM and PM+SH (Figure 2), resulting in greater residue decomposition and nutrient cycling. The same behavior was observed by Mazetto Junior *et al*. (2019), which, when combined with the BNF of SH and subsequent N availability in the soil after cutting, results in less mobilization of the N supplied via mineral fertilizers by soil microorganisms (Ferreira *et al*., 2018), ensuring greater availability of the nutrient for the production system.

Greater N availability associated with high temperatures and adequate soil moisture content tends to accelerate residue composition, which can be up to three times faster when compared to cultivated areas under natural climate conditions (Torres *et al*., 2019).

Silveira *et al*. (2021) reported T½ of 28 days for SG (k = 0.025), 80 days for PM (k = 0.087), 41 days for SH (k = 0.017), 43 days for SG+SH (k = 0.016), 69 days for SG+PM (k = 0.010), 77 days for PM+SH (k = 0.009) and 69 days for SG+SH+PM (k = 0.010). Except for SG, all these values are higher than those recorded in our investigation (Table 2), which is directly linked to the climate conditions in each study. By contrast, the T½ values of Torres *et al*. (2021) were lower than those obtained here, with 25 days for SG (k = 0.027), 28 days for PM (k = 0.024), 23 days for SH (k = 0.030) and 29 days for PM+SH (k = 0.024).

SG is a Poaceae that, when cut at the same inflorescence stage as other plants, generally has a similar C:N ratio compared to that of PM which, in turn, is typically higher than that of SH (Pacheco *et al*., 2013). However, in the present study, SG was cut at the onset of flowering, which explains the high residue decomposition rate (Figure 2) and its low T½ value (Table 2).

Algeri *et al*. (2018) assessed the biomass production and soil cover of individually-grown and intercropped SG, PM and SH and found that, when grown alone, SG develops more slowly than the other plants, which take longer to cover the soil, and its residue contains more accumulated carbon, meaning that it tends to decompose faster than PM and at a similar rate to SH, behavior also observed in our study.

Analysis of N, P, K, Ca, Mg and S accumulation in the residue of individually-grown SG, PM and SH resulted in respective values of 100.0; 9.3; 269.0; 29.4; 26.0 and 5.2 kg/ha, 89.3; 5.0; 172.8; 31.6; 16.8 and 7.4 kg/ha and 145.0; 12.5; 224.8; 35.6; 7.5 and 6.3 kg/ha, and in the intercropped treatments (SG+SH, SG+PM, PM+SH and SG+PM+SH), 106.0; 7.0; 365.5; 31.9; 19.8; and 3.9 kg/ha, 85.5; 3.4; 195.9; 40.0; 26.6 and 5.9 kg/ha, 94.0; 12.0; 284.9; 35.8; 29.0 and 12.7 kg/ha and 123.0; 4.7; 254.4; 36.9; 22.1 and 5.8 kg/ha, respectively.

According to Collier *et al*. (2018) and Torres *et al*. (2021), using different cover plants and maintaining their residue on the soil before planting commercial crops can reduce dependence on mineral fertilizer. This is because the mineralization of organic matter increases nutrient availability in the soil, largely due to the high BNF of legumes and the release of phosphate cations and anions into the soil solution, which occurs more rapidly in areas under NTVP, since high temperatures and moisture content contribute to increasing soil microbial activity, accelerating OM decomposition (Mazetto Junior *et al*., 2019).

Pacheco *et al*. (2013) analyzed nutrient accumulation in SG and PM and obtained the following values: N (116.1 and 29.3 kg/ha), P (10.4 and 2.6 kg/ha), K (92.9 and 12.7 kg/ha), Ca (53.8 and 8.9 kg/ha) and Mg (11.6 and 3.8 kg/ha).

Table 5. Unfolding of the interaction between cover crops and phosphate fertilizers for head fresh (HFW) and dry weight (HDW) production and yield (YLD) of cabbage grown under a no-till system in Uberaba-MG. Uberaba, IFTM, 2021.

Cover crop (Cov)	Fertilizer		
	No P	Organomineral	Mineral
		HFW (g/plant)	
Signal grass (SG)	512.2 bC	1550.5 aB	1684.1 aB
Pearl millet (PM)	1499.9 aA	1723.6 aA	1847.6 aA
Sunn hemp (SH)	1602.1 aA	1658.3 aA	1775.4 aA
SG+SH	1611.5 aA	1920.8 aA	1871.8 aA
SG+PM	1653.3 bA	1691.5 bA	1995.2 aA
PM+SH	1216.7 cB	1772.0 aA	1660.2 bB
SG+SH+PM	1461.2 bA	1813.3 aA	1523.5 bB
Conventional	1097.1 bB	1558.6 aB	1604.7 aB
F test	13.39**	2.15*	2.19*
CV%		13.26	
		HDW (g/plant)	
Signal grass (SG)	44.5 bD	78.1 aB	85.2 aB
Pearl millet (PM)	79.0 bB	91.1 bB	109.6 aA
Sunn hemp (SH)	81.1 bB	107.5 aA	90.4 bB
SG+SH	77.6 cB	113.0 aA	94.6 bB
SG+PM	101.1 aA	78.3 bB	86.9 bB
PM+SH	67.1 bC	95.8 aA	86.2 aB
SG+SH+PM	85.8 aB	99.3 aA	93.0 aB
Conventional	51.2 bD	81.8 aB	56.6 bC
F test	13.44**	6.87**	8.65**
CV%		11.89	
		YLD (t/ha)	
Signal grass (SG)	14.4 bE	40.4 aB	40.0 aB
Pearl millet (PM)	35.1 cC	43.0 bA	49.8 aA
Sunn hemp (SH)	40.0 aB	36.4 bC	41.8 aB
SG+SH	46.6 aA	48.0 aA	44.4 aA
SG+PM	39.4 aB	32.8 bC	44.0 aA
PM+SH	30.4 bD	44.3 aA	44.6 aA
SG+SH+PM	33.8 cC	45.3 aA	40.1 bB
Conventional	27.4 cD	38.9 aB	35.7 bB
F test	38.05**	6.52**	4.64**
CV (%)		9.87	

* and ** = Significant at 1 and 5% probability respectively; CV: coefficient of variation. Means followed by the same lowercase letter in the rows and uppercase in the columns do not differ according to the Scott & Knott test ($p<0.05$).

Greater accumulation was observed on the following year (2009/10) for N (98 and 78.8 kg/ha), P (19.6 and 16.2 kg/ha), K (112.4 and 53.8 kg/ha) and Ca (63.7 and 49.0 kg/ha), similar to the P values recorded in the present study.

With respect to P content in the cover crop residue, SH (12.5 g/ha) and PM+SH (12.0 g/ha) exhibited higher values at cutting when compared to the other cover plants, which also occurred at 90 days in the treatments without P (9.1 and 9.3 g/kg), with OF (7.4 and 8.1 g/kg) and MF (2.8 and 7.3 g/kg, not differing from SG at 3.5 g/kg), whereas SG+PM obtained the lowest P content at cutting and at 90 days (Table 3).

For accumulated P, the highest values were recorded for PM+SH at cutting (188.4 kg/ha) and 90 days after cutting, regardless of the P sources used (Table 3). The high values obtained in PM+SH without P (146.0 kg/ha) and with OF (127.2 kg/ha) and MF (114.6 kg/ha) are due to the greater DW production (15.7 t/ha) (Table 1) and remaining DW in this treatment (Figure 2), followed by SG and SH at cutting (91.1 and 93.8 kg/ha) in treatments without P (24.5 and 68.3 kg/ha) and with OF (12.7 and 55.5 kg/ha) and MF (34.3 and 21.0 kg/ha), related to low DW production (9.8 and 7.5 t/ha, respectively) (Table 1).

Collier *et al*. (2018) analyzed soil chemical attributes and the association between the residual effect of nutrient cycling in Fabaceae stubble and maize yield and concluded that sunn hemp is an advantageous option for total nutrient accumulation, since it increases available P levels in the soil and, consequently, the productivity of maize cobs, with values 24% higher than those recorded in maize grown on spontaneous vegetation.

Accumulated P tends to be released into the soil more rapidly for SG and SH and PM+SH, since these cover crops exhibited T½ of 29, 29 and 33 days, respectively (Table 2), values significantly lower than those recorded for PM (41 days) and SG+PM (39 days).

In areas under no-till production (NTP), the decomposition of Poaceae and Fabaceae used in crop rotation releases low-molecular-weight organic acids, which can block adsorption sites and thereby increase plant-available P, as reported by Maia *et al*. (2015).

The slower release of remaining P in dry matter is linked to the fact that, like most diesters, nucleic acids, phospholipids and phosphoproteins, P is less soluble in water because its release from plant tissue depends on soil microorganism activity. According to Khatounian (1999), P released from plant residue during mineralization can be absorbed by the subsequent commercial crop after the cover plants have been cut or be fixed in difficult-to-dissolve mineral compounds.

There was significant interaction between the cover crops and P sources for all the productive variables studied (Table 4). Unfolding of the significant interactions indicated that even when P was not applied, SG produced the lowest cabbage HFW (521.2 g), followed by PM+SH and the conventional treatment (Table 5). Similarly, when OF was used, the lowest yields were observed for cabbage grown in SG (1550.5 g) and under conventional tillage (1558.6 g), and with mineral fertilization, cabbage HFW was lower in SG, PM+SH, SG+PM+SH and the conventional treatment than for the remaining cover crops. The different P fertilizers had no effect on cabbage HFW in PM, SH and SG+SH (Table 5).

For all the cover crops assessed, OF resulted in higher cabbage HFW than that observed for MO or in treatments with no P source, except for SG+PM, which exhibited lower HFW values than those obtained with 100% mineral fertilizer.

According to Maia *et al*. (2015), available P is sensitive to variations in soil moisture content, which are common under NTP systems because soil moisture is maintained for longer, whereas conventional tillage promotes lower soil water levels with a resulting decline in available P, since diffusion depends on water.

For cabbage HDW, the highest values without P application were recorded in SG+PM (101.1 g/plant), with OF application in SH (107.5 g/plant), SG+SH (113.0 g/plant), PM+SH (95.8 g/plant) and SG+SH+PM (99.3 g/plant), and with MF in the PM treatment (109.6 g/plant). Comparison of the P sources demonstrated that cabbage HDW was highest in SG+SH+PM for all the sources, including the treatment with no P application (Table 5).

Yield (YLD) values were higher ($p<0.05$) with no P application in SG+SH (46.6 t/ha), while the use of OF produced the largest yields in PM (43.3 t/ha), SG+SH (48.0 t/ha), PM+SH (44.3 t/ha) and SG+SH+PM (45.3 t/ha) and MF application resulted in superior YLD values in PM (49.8 t/ha), SG+SH (44.4 t/ha), SG+PM (44.0 t/ha) and PM+SH (44.6 t/ha) (Table 5).

Generally, the lowest cabbage HFW, HDW and YLD values were always obtained with SG or under conventional tillage without soil cover, which confirms the importance of cover crop residue to mitigate problems such as erosion and leaching, and cycle considerable substantial amounts of macro and micronutrients into the soil, particularly N from biological fixation by sunn hemp. These findings are corroborated by previous research by Collier *et al*. (2018), Silveira *et al*. (2021) and Torres *et al*. (2021) under natural conditions and in irrigated areas.

However, the importance of interaction between the cover crop and P source was evident in the significant differences between HFW, HDW and YLD for the fertilizers used, whereby higher values were generally observed in areas with a cover crop when compared to the conventional treatment.

It should be noted that OF and MF application increased YLD in PM, SG, PM+SH, PM+SG+SH and conventional tillage when compared to no phosphate fertilization (Table 5). Among the cover crops studied, PM+SH exhibited greater remaining DW and accumulated P than the other treatments, regardless of the P source used.

However, PM+SH produced higher cabbage YLD values with OF and MF application when compared to treatments with no P.

The highest fresh and dry weight values were recorded when cover plants were intercropped.

Residue from the PM+SH, SH and SG treatments had the lowest $T^{1/2}$, fastest decomposition rate and highest P cycling.

The highest HFW values were obtained in PM, SH and SG+SH without P application or with the use of MF or OF.

The largest cabbage yields were observed in SG+SH without P fertilization or with the use of MF or OF.

Mineral fertilizer used as P source produced the highest yield when cabbage plants were grown in PM.

Under conventional tillage, cabbage yields were larger when OF was applied as a P source.

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REFERENCES

ALGERI, A; VILAR, CC; USHIWATA, SY; REIS, RGE. 2018. Produção de biomassa e cobertura do solo por milheto, braquiária e crotalária em cultura pura e consorciados. *Global Science and Technology* 11: 112-115.

BECK, HE; ZIMMERMANN, NE; MCVICAR, TR; VERGOPOLAN, N; BERG, A; WOOD, EF. 2018. Present and future Köppen–Geiger climate classification maps at 1-km resolution. *Scientific Data* 1: 1-12.

COLLIER, LS; ARRUDA, EM; CAMPOS, LFC; NUNES, JNV. 2018. Soil chemical attributes and corn productivity grown on legume stubble in agroforestry systems. *Revista Caatinga* 31: 279-289.

FERREIRA, LB; LOSS, A; GIUMBELLI, LD; VENTURA, BS; SOUZA, M; MAFRA, ÁL; KURTZ, C; COMIN, JJ; BRUNETTO, G. 2018. Organic carbon and nitrogen contents and their fractions in soils with onion crops in different management systems. *Soil Research* 56: 846-855.

FONTES, PCR. 1999. IN: RIBEIRO, AC; GUIMARÃES, PTG; ALVAREZ, VVH. *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5°. Aproximação*. Viçosa: UFV. 359p.

INMET – Instituto Nacional de Meteorologia. 2021. Gráficos. 08 de novembro. http://www.inmet.gov.br/portal/index.php/gráficos.

KHATOUNIAN, CA. 1999. O manejo da fertilidade em sistemas de produção. In: CASTRO FILHO, C; MUZILLIO, O (eds). Uso e manejo dos solos de baixa aptidão agrícola. Londrina: IAPAR, p.179-221.

(Circular, 108)

LATATI, M; BARGAZ, A; BELARBI, B; LAZALI, M; BENLAHRECH, S; TELLAH, S; OUNANE, SM. 2016. The intercropping common bean with maize improves the rhizobial efficiency, resource use and grain yield under low phosphorus availability. *European Journal of Agronomy* 72: 80-90.

MAIA, RS; VASCONCELOS, SS; CARVALHO, CJR. 2015. Soil phosphorus fractions and mycorrhizal symbiosis in response to the availability of moisture and nutrients at a secondary forest in eastern Amazonia. *Acta Amazonica* 45: 255-264.

MASSAN, I; ARLV; WUERGES, EW. 2019. *Trajetória, concepção metodológica e desafios estratégicos junto ao sistema de plantio direto de hortaliças (SPDH)*. In: FAYAD, JA; ARL, V; COMIN, JJ; MAFRA, AL; MARCHESI, DR (eds). Sistema de Plantio Direto de Hortaliças. Epagri: Florianópolis, p.43.

MAZETTO JÚNIOR, JC; TORRES, JLR; COSTA, DDA; SILVA, VR; SOUZA, ZM; LEMES, EM. 2019. Production and decomposition of cover crop residues and associations with soil organic fractions. *Journal of Agricultural Science* 11: 58-69.

PACHECO, LP; BARBOSA, JM; LEANDRO, WM; MACHADO, PLOA; ASSIS, RL; MADARI, BE; PETTER, FA. 2013. Ciclagem de nutrientes por plantas de cobertura e produtividade de soja e arroz em plantio direto. *Pesquisa Agropecuária Brasileira* 48: 1228-1236.

PAUL, EA; CLARK, FE. 1996. Dynamics of residue decomposition and soil organic matter turnover. In: PAUL, EA; CLARK, FE (eds). *Soil Microbiology and Biochemistry*. 2º ed. San Diego (SD): Academic, p.158-179.

RODRIGUES, GB; SÁ, MED; VALÉRIO FILHO, WV; BUZETTI, S; BERTOLIN, DC; PINA, TP. 2012. Matéria e nutrientes da parte aérea de adubos verdes em cultivos exclusivo e consorciado. *Revista Ceres* 59: 380-385.

RODRIGUES, M; PAVINATO, PS; WITHERS, PJA; TELES, APB; HERRERA, WFB. 2016. Legacy phosphorus and no tillage agriculture in tropical oxisols of the Brazilian savanna. *Science of the Total Environment* 542: 1050-1061.

SANTOS, HG; JACOMINE, PKT; ANJOS, LHC; OLIVEIRA, VA; LUMBRERAS, JF; COELHO, MR; ALMEIDA, JA; CUNHA, TJF; OLIVEIRA, JB. 2018. *Sistema brasileiro de classificação de solos*. 3° ed., Brasília, DF: Embrapa Informação Tecnológica, 356p.

SANTOS, LH; LOSS, A; CANTON, L; VENTURA, BS; FERREIRA, GW; KURTZ, C; BRUNETTO, G; LOVATO, PE; COMIN, JJ. 2017. Chemical properties in macroaggregates of a humic dystrudent cultivated with onion under, No-till and conventional tillage systems. *Revista Brasileira de Ciência do Solo* 41: 0160419.

SANTOS, PF; WHILFORD, WG. 1981. The effects of microarthropods on litter decomposition in a chihuazhuan ecosystem. *Ecology* 62: 654-669.

SILVA, LG; REGINALDO, C; LANA, RMQ; DELVAUX, JC; FAGAN, EB; MACHADO, VJ. 2020. Chemical changes and development of soybean with use of pelletized organominerals fertilizer based of sewage sludge and filter cake. *Acta Scientiarum Agronomy* 42: 1-9.

SILVEIRA, BS; TORRES, JLR; ORIOLI JÚNIOR, V; FAVARO, JHS; COSTA, LL; CHARLO, HCO. 2021. Cover crops in the production of green and sweet corn. *Horticultura Brasileira* 39: 94-101.

SORATTO, RP; CRUSCIOL, CAC; COSTA, CHM; FERRARI NETO, J; CASTRO, GSA. 2012. Produção, decomposição e ciclagem de nutrientes em resíduos de crotalária e milheto, cultivados solteiros e consorciados. *Pesquisa Agropecuária Brasileira* 47: 1462-1470.

SOUSA, RT; DUARTE, IN; KORNDORFER, GH; HENRIQUE, HM. 2013. Fontes mineral e orgânica de fosforo e disponibilidade desse nutriente para o solo. *Enciclopedia Biosfera* 9: 1196-1202.

TEDESCO, MJ; GIANELLO, C; BISSANI, CA; BOHNEN, H; VOLKWEISS, SJ. 1995. Análise de solo, plantas e outros materiais. 2.ed. Porto Alegre, Departamento de Solos da Universidade Federal do Rio Grande do Sul. 1995. 174p. (Boletim Técnico de Solos, 5).

TEIXEIRA, PC; DONAGEMMA, GK; FONTANA, A; TEIXEIRA, WG. 2017. *Manual de métodos de análise de solos*. 3.ed. rev. e ampl. Rio de Janeiro: Embrapa, 573p.

THOMAS, RJ; ASAKAWA, NM. 1993. Decomposition of leaf litter from tropical forage grasses and legumes. *Soil Biology and Biochemistry* 25: 1351-1361.

TORRES, JLR; ARAUJO, AS; BARRETO, AC; SILVA NETO, OF; SILVA, VR; VIEIRA, DMS. 2015. Desenvolvimento e produtividade da couve-flor e repolho influenciados por tipos de cobertura do solo. *Horticultura Brasileira* 33: 510-514.

TORRES, JLR; GOMES, FRC; BARRETO, AC; ORIOLI JUNIOR, V; FRANÇA, GD; LEMES, EM. 2021. Nutrient cycling of different plant residues and fertilizer doses in broccoli cultivation. *Horticultura Brasileira* 38: 11-10.

TORRES, JLR; GOMES, FRC; BARRETO, AC; TAMBURÚS, AY; VIEIRA, DMS; SOUZA, ZM; MAZETTO JÚNIOR, JC. 2017. Application of different cover crops and mineral fertilizer doses for no-till cultivation of broccoli cauliflower and cabbage. *Australian Journal of Crop Science* 11: 1339-1345.

TORRES, JLR; MAZETTO JÚNIOR, JC; SILVA JÚNIOR, J; VIEIRA, DMS; SOUZA, ZM; ASSIS, RL; LEMES, EM. 2019. Soil physical attributes and organic matter accumulation under no-tillage systems in the Cerrado. *Soil Research* 57: 712-718.

VIEIRA, DMS; CAMARGO, R; TORRES, JLR; SILVA, AA; LANA, RMQ; CARVALHO, FJ. 2020. Growing vegetables in succession in different soils and doses of phosphorus in an organomineral fertilizer. *Revista Brasileira de Engenharia Agrícola e Ambiental* 24: 806-813.