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No-till broccoli production using different cover crop residues and nitrogen doses

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ABSTRACT

No-till vegetable farming is a feasible alternative to reduce erosion-induced losses and to increase soil nutrient availability, because cover crop residue protects the soil and its decomposition promotes nutrient cycling, which can improve the yield of the subsequent crop. The present study assessed the production and decomposition of cover crops and the agronomic performance of broccoli grown on this residue using different nitrogen doses in a no-till system. A randomized block design was used, in a split-split plot arrangement of main plots (cover crops), sub-plots (N doses) and sub-sub plots (decomposition times), with four repetitions. Seven cover crops were studied, as follows: [1) signal grass (SG); 2) sunn hemp (SH); 3) pearl millet (PM): 4) SG+SH; 5) SG+PM; 6) SH+PM and 7) SG+SH+PM]; in addition to four doses of nitrogen topdressing [T1) no N application (control); T2) 60 kg/ha N; T3) 90 kg/ha N and T4) 120 kg/ha N]; and five cover crop residue decomposition times: zero (cutting), 15, 30, 60 and 90 days after transplanting (DAT) the broccoli seedlings. Cover crop dry weight (DW) production, residue decomposition, and the head fresh (HFW) and dry weight (HDW) and yield (YLD) of broccoli were assessed. Among the cover crops, sunn hemp and the intercropped SG+SH treatment exhibited the lowest DW production and, along with signal grass, the shortest half-life ($T^{½}$) and highest residue decomposition rate. The best-performing broccoli plants were those grown using PM, SH and a combination of both as cover crops. The highest broccoli production was obtained using sunn hemp residue, regardless of nitrogen topdressing, with HFW of 788 g/plant and YLD of 30 t/ha.

Keywords: *Brassica oleracea* var. *italica,* organic matter, decomposition, nutrients, yield.

RESUMO

Produção de brócolis em plantio direto com diferentes coberturas vegetais e doses de nitrogênio

O plantio direto de hortaliças tem sido uma alternativa viável para diminuir as perdas causadas pela erosão e aumentar a disponibilidade de nutrientes no solo, pois a manutenção da palha na superfície protege o solo e, com a decomposição destes resíduos, ocorre a ciclagem de nutrientes. Esse fato pode proporcionar aumento da produtividade das culturas em sucessão. Neste estudo avaliou-se a produção e a decomposição dos resíduos de plantas de cobertura e o desempenho agronômico do brócolis cultivado sobre estes resíduos e com diferentes doses de adubação nitrogenada em sistema de plantio direto. O estudo foi conduzido em delineamento de blocos casualizados, em parcelas subdivididas (doses de N) e sub-subdivididas (tempos de decomposição), com quatro repetições. Foram avaliados sete tipos de cobertura, sendo 1) braquiária (B); 2) crotalária (C); 3) milheto (M); 4) consórcio B+C; 5) B+M; 6) C+M e 7) B+C+M. Foram avaliados também 4 doses de adubação nitrogenada em cobertura, sendo T1) sem aplicação de N (controle); T2) 60 kg/ha de N; T3) 90 kg/ha de N e T4) 120 kg/ha de N. Ainda, avaliamos cinco tempos de decomposição dos resíduos das plantas de cobertura, sendo: zero (manejo), 15, 30, 60 e 90 dias após o transplante das mudas de brócolis. Foram avaliados a produção de massa seca (MS) das coberturas, decomposição dos resíduos, massa fresca (MFC) e seca das cabeças (MSC) e produtividade (PROD) na cultura do brócolis. Crotalária e o consorcio B+C apresentaram a menor produção de MS e junto com a braquiária o menor $T^{½}$ vida e maior taxa de decomposição dos resíduos. O melhor desempenho do brócolis ocorreu quando as plantas foram cultivadas sobre os resíduos de M, C e nos consórcios destas plantas como coberturas. A maior produção de brócolis ocorreu no cultivo sob os resíduos de crotalária, independente da adição ou não de adubo nitrogenado em cobertura, com MFC de 788 g/planta e PROD de 30 t/ha.

Palavras-chave: *Brassica oleracea* var. *italica,* matéria orgânica, decomposição, nutrientes, produtividade.

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In Brazil, vegetable farming is associated with conventional tillage using agricultural equipment, which favors degradation of soil's physical, chemical and biological attributes, causing a considerable decline in organic matter content and nutrient stocks. This results in lower yields when compared to conservative crop management systems (Mazetto Junior *et al*., 2019). No-till vegetable production (NTVP) stands out as an alternative to intensive soil preparation and has been used to mitigate soil problems and maintain or improve crop yields (Silva *et al*., 2018; Massan *et al*., 2019).

NTVP is a dynamic innovative technique that requires constant monitoring and local adaptations to ensure successful implementation (Massan *et al*., 2019). Torres *et al*. (2017, 2021), studying cauliflower, cabbage and broccolis, and Silveira *et al*. (2021) green and sweet corn, found that signal grass (SG), pearl millet (PM) and sunn hemp (SH) grown individually and intercropped before the vegetables favored better production and quality. In addition to protecting the soil, these cover crops promoted greater nutrient availability after decomposition.

Maintaining cover crop residue on the surface is one of the challenges of NTVP, since organic matter decomposes more rapidly in locations with high temperature and adequate soil moisture. This residue helps increase the soil organism population, which accelerates decomposition and nutrient cycling (Potrich *et al*., 2014; Pacheco *et al*., 2017; Collier *et al*., 2018).

In areas with irrigated vegetables, decomposition can be up to three times faster when compared to natural conditions (Silveira *et al*., 2021; Torres *et al*., 2021). On the other hand, this accelerated decomposition shortens the residence time of soil cover, which may favor erosion (Massan *et al*., 2019).

However, a major obstacle in NTVP is synchronizing nutrient release from residue with crop demands (Diniz *et al*., 2017; Torres *et al*., 2021), since vegetables generally have a short cycle and nutrient uptake from the soil (Melo, 2015). Nevertheless, NTVP has become a feasible alternative to decrease the use of mineral fertilizers, especially N and K. Plant residue on the surface is known to increase soil organic matter content and cation exchange capacity, ensuring greater nutrient availability and less nutrient loss through leaching (Torres *et al*., 2017; Silva *et al*., 2018).

In this context, the hypothesis tested in the present study is that different nitrogen doses in vegetable fertilization accelerate plant residue decomposition rates, making more nutrients available, which may improve the agronomic traits of the crop. Thus, the aim was to assess the production and decomposition of cover crops and the agronomic performance of broccoli (*Brassica oleracea* var. *italica*) grown on this residue using different nitrogen doses in a no-till system.

MATERIAL AND METHODS

The study was conducted from November 2020 to May 2021 in an experimental area on the Uberaba Campus of the Federal Institute of Education, Science and Technology of the Triângulo Mineiro (IFTM) (19º39'42"S, 47º57'55''W, 795 m altitude).

The climate in the region is Aw, classified as warm tropical according to the updated Köppen's classification (Beck *et al*., 2018), with hot rainy summers and cold dry winters. Annual average rainfall and temperature are 1600 mm and 22.6ºC, respectively (Inmet, 2021); however, 791 mm and 24°C were recorded during the study period (Figure 1).

The soil in the experimental area was classified as dystrophic red latosol (Santos *et al*., 2018), with a sandy loam texture and the following characteristics in the 0 to 20 cm layer: 210 g/kg clay, 720 g/kg sand and 70 g/kg silt, pH 5.9 in H_2O; 14.7 mg/dm^3 of P (Mehlich-1); 112 mg/dm^3 K^+; 1.1 $cmol_c/dm^3$ of Ca^{2+}; 0.4 $cmol_c/dm^3$ of Mg^{2+}; 1.7 $cmol_c/dm^3$ of H+Al and 10.34 g/kg organic matter, cation exchange capacity of 3.49 $cmol_c/dm^3$, sum of bases (SB) of 1.78 $cmol_c/dm^3$ and base saturation (V%) of 51.

Prior to broccoli cultivation, the area was planted with corn under a no-till system (NTS) for approximately 85 days, using the same cover crops studied here (signal grass, pearl millet, sunn hemp and combinations of these plants). After harvesting the ears, the corn plants were cut and left on the soil surface. The present study began 15 days after harvesting, when the cover crops were planted.

A randomized block design was used, in a split-split plot arrangement consisting of twenty-eight plots (cover crops), subdivided into four subplots (N doses) divided into sub-subplots for decomposition times, with four repetitions. The main treatment was composed of seven cover crops: 1) signal grass (SG) (*Urochloa ruzizienses*); 2) sunn hemp (SH) (*Crotalaria juncea*); 3) pearl millet (PM) ADR 500 (*Pennisetum glaucum*); 4) intercrop of SG+SH; 5) SG+PM; 6) SH+PM and 7) SG+SH+PM. A secondary treatment of four nitrogen doses as topdressing was tested: T1) no N application; T2) 60 kg/ha of N; T3) 90 kg/ha of N and standard treatment T4) 120 kg/ha of N. The nitrogen in T2, T3 and T4 was split into three equal doses applied 20, 40 and 60 days after transplanting (DAT) respectively, around the base of the broccoli seedlings.

The cover crop seeds were planted using a Semina 2 seed drill, with five rows spaced 0.20 m apart. For the individual cover crop treatments, 25, 50 and 50 seeds per linear meter were used for SH, SG and PM, respectively, with 50% of each seed type in dual intercropping (SH+SG, SH+PM and SG+PM) and 33% in the triple intercropping treatment (SH+SG+PM).

The cover crops were grown for 104 days with no mineral or organic fertilizer. Signal grass showed the slowest initial development, with the remaining cover plants reaching an average of 50% flowering at around 100 days, when all the plants in a 2 m^2 area per plot were sampled to assess dry weight. The fresh plant matter collected was dried in an oven at 65ºC until constant weight and then weighed, with the results expressed in kg/ha.

Next, all the cover plants were desiccated with glyphosate (Gliz® 480 SL, 960 g/ha of ai) and 2,4-D dimethylamine (Aminol® 806, 1612 g/ha of ai), applied using a tractor mounted sprayer, at 250 L/ha flow rate.

The decomposition rate of the cover crop residue was determined using 2 mm mesh litter bags measuring 0.20 x 0.20 m, containing 30 grams of dry matter cut into pieces measuring up to 5 cm, in accordance with Pacheco *et al*. (2017), Collier *et al*. (2018), Silveira *et al*. (2021) and Torres *et al*. (2021).

Sixteen bags were distributed in each plot on the residue of the previous crops, consisting of four bags per subplot, totaling 448 bags. One bag was collected from each subplot (four per plot) 15, 30, 60 and 90 days after their distribution in the field. The plant matter in each bag was cleaned manually with a brush and tweezers, passed through a 0.053 mm mesh sieve, dried in a forced air oven at 65ºC until constant weight and then weighed to determine dry weight and decomposition rate.

The exponential mathematical model described by Thomas & Asakawa (1993) was applied to calculate plant residue decomposition using the equation $X = X_o e^{-kt}$, where X is the amount of dry matter remaining after time t, in days; X_o 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 T1/2 = 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.

The broccoli seeds used were those of the single head ‘Avenger’ cultivar (Sakata Seed Corporation), with a 90-day life cycle. The seedlings were produced in a greenhouse covered in plastic with closed sides, in 128-cell expanded polystyrene trays filled with commercial Bioplant substrate.

At 28 days after sowing, they were transplanted to the field into plant residue deposited on the soil surface, in 0.15 m-wide 0.20 m-deep holes made with a sow dibbler, spaced 0.50 m apart. No furrows were made in the experimental area.

The plots consisted of three 4.0 m-long rows spaced 0.6 m apart, with 0.5 m between plants and eight plants per row, totaling 24 plants per plot, with 1 m-wide corridors between blocks. Each plot measured 4.0 x 1.5 m (6.0 m^2), with the six center plants considered the study area.

Before transplanting, mineral fertilizer was applied to the holes, with all plots receiving the same base dressing of 50, 300 and 30 kg/ha of N, P_2O_5 and K_2O, respectively, using urea, single superphosphate and potassium chloride as the respective nutrient sources.

All plots received N and 70 kg/ha of K_2O as topdressing, with doses of the former applied according to the treatments. Topdressing was applied three times, at 20, 40 and 60 DAT, based on values proposed by Ribeiro *et al.* (1999). N doses varied in T1, T2, T3 and T4, but all treatments consisted of 50 kg/ha of N as base dressing, followed by 60, 90 and 120 kg/ha as topdressing in T2, T3 and T4, respectively, totaling 50, 110, 140 and 170 kg/ha of N over the crop cycle in the four treatments.

Plants were foliar sprayed at 15, 30 and 40 DAT to supply boron (B), molybdenum (Mo) and cobalt (Co), using 1 g/L boric acid solution (17% B) and 2.7 mL of Vitaphol CoMo®, which contains 10% Mo and 2% Co. Application aimed to completely cover the leaves without allowing the spray solution to drip.

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

There was only one incidence of diamondback moth (*Plutella xylostella*) and maize leafhopper (*Dalbulus maidis*) during the crop cycle, requiring three applications of the insecticides methomyl (Magesty®, 150.6 g/ha ai), and Warrant® 700 WG (imidacloprid, 35 g/ha ai). Pests were monitored daily in the field.

The plants were sprinkler irrigated as needed, in order to maintain soil moisture content close to field capacity.

Broccoli harvesting began at 80 DAT, as the inflorescences reached the commercial stage for harvesting, that is, when plants displayed firm, fully developed compact heads and closed green buds.

Head fresh weight (HFW) and yield (YLD) were assessed at harvesting and expressed in g/plant and t/ha, respectively. Yield was calculated by multiplying HFW by the total number of plants harvested. Next, samples from each treatment were oven dried at 65°C until constant weight to determine head dry weight (HDW).

Assumptions of normality and homogeneity of residual variances were verified using the Shapiro-Wilk and Bartlett tests, respectively. The values obtained for the studied characteristics 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 grouped using the Scott-Knott method. No doses and decomposition rates were submitted to regression analysis in SigmaPlot software version 12. Significance was set at 5% for all analyses.

RESULTS AND DISCUSSION

For dry weight (DW) production at desiccation, values obtained for PM alone (14.2 t/ha), followed by intercropped SG+SH+PM (13.7 t/ha) were significantly higher than those of the remaining cover crops (Figure 2A). The lowest DW production was recorded for SH grown alone (8.9 t/ha).

These high DW values can be justified by the large volume of rainfall during the study period (approximately 791 mm) (Figure 1), providing conditions for good plant development. In general, broccoli is adapted to the soil and climate conditions of the Cerrado and performs well even under low rainfall levels, as reported by Pacheco *et al*. (2017), Collier *et al*. (2018) and Torres *et al*. (2017).

In the present study, DW production values for SG (13.2), SG+SH (10.1), SG+PM (13.2) and PM+SH (13.4 t/ha) can be considered high. However, the value obtained for SG+SH was within the DW production ranges reported in other studies in the same region and growing season, of 4.8 to 11.9, 7.78 to 11.07, 7.34 to 8.9 and 8.14 to 13.7 t/ha for the same cover plants, respectively (Silveira *et al*., 2021; Torres *et al*., 2021; Nunes *et al*., 2022).

For corn and soybean grown under natural conditions in the same region and growing season, DW production for PM, SG and SH was 6.0 to 14.0, 7.0 to 12.0 and 4.0 to 9.0 t/ha, respectively, providing good soil coverage and protection (Torres *et al*., 2015; Collier *et al*., 2018; Mazetto Júnior *et al*., 2019).

The remaining DW at each assessment time followed the same pattern observed at cutting (time zero), since SH and SG+SH obtained the lowest value. However, differences were observed between the other treatments, with PM exhibiting the highest remaining DW values (Figure 2A) of 14.2; 12.2; 11.5; 11.0 and 8.7 t/ha for corresponding initial DWs of 100.0; 83.9; 76.5; 65.7 and 46.7%, respectively. On the other hand, SH obtained the lowest values of 8.9, 7.3, 6.7, 5.7 and 3.8 t/ha in relation to respective initial DWs of 100.0, 82.1, 74.8, 63.8 and 43.0% at cutting (zero), 15, 30, 60 and 90 days after litter bag distribution, respectively. These findings are similar to those reported by Torres *et al*. (2021) and Silveira *et al*. (2021) in vegetable crops grown in the same region.

Regression analysis indicated that remaining DW declined over time in all the cover crops studied, with 8.6, 7.6, 7.3, 7.1, 6.1, 4.8 and 3.8 t/ha after 90 days, corresponding to 61.1, 56.5, 55.5, 51.7, 46.7, 47.7 and 43.0% of initial DW for PM, PM+SH, SG+PM, SG+SH+PM, SG, SG+SH and SH deposited on the soil surface, respectively (Figure 2B).

Several studies have shown that SH produces less DW and exhibits a lower carbon-to-nitrogen ratio (C:N) when compared to pearl millet (Poaceae) (Pacheco *et al*., 2017; Collier *et al*., 2018). This low C:N is due to the plant's high biological nitrogen fixation (BNF), which favors faster decomposition of its residue, enabling less mobilization of the N from mineral fertilization by soil microorganisms (Torres *et al*., 2017, 2021).

The low C:N of SH combined with the fact that the signal grass was cut before peak flowering, with less carbon accumulated in its tissue, may have accelerated SH decomposition when grown alone and in the SG+SH treatment.

After 90 days, 43 and 47% respectively of the total residue deposited on the soil remained. Similar results were reported by Silveira *et al*. (2021) and Torres *et al*. (2021) in studies with irrigated vegetables grown in the same region.

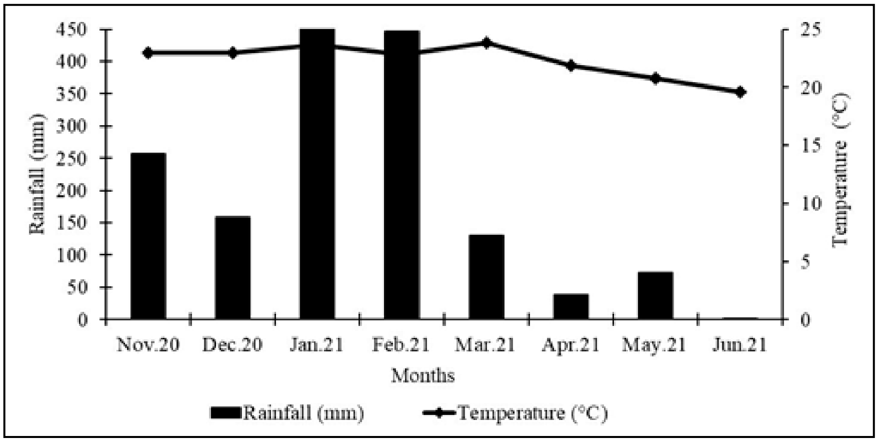

Figure 1. Average monthly temperature and rainfall, obtained from the weather station at IFTM in Uberaba-MG. Uberaba, IFTM, 2021.

Table 1. Decomposition constant (k) and half-life ($T^{½}$) of the cover crops under no-till vegetable production in Uberaba, MG. Uberaba, IFTM, 2021.

Cover crop	Remaining dry weight		
	K (g/g)	$T^{½}$ (days)	R2
Signal grass (SG)	0.0199	35	0.97**
Peal millet (PM)	0.0127	55	0.92
Sunn hemp (SH)	0.0169	41	0.97
SG+SH	0.0149	47	0.99
SG+PM	0.0142	49	0.92
PM+SH	0.0129	54	0.96
SG+SH+PM	0.0131	53	0.99

** = Significant ($p<0.05$); R^2 = Coefficient of determination.

According to Vargas *et al*. (2005), Poaceae have a higher lignin content when cut in the peak flowering stage, leading to a higher C:N and lower decomposition rate when compared to Fabaceae; however, they decompose rapidly when cut before this ideal point, as occurred with signal grass in this study.

Regression analysis indicated that nitrogen doses did not affect residue decomposition, since remaining DW values were constant for all the cover crops, with no significant differences (F= 2.3; P= 0.0081) (Figure 2C).

Although a linear regression curve was fit to SG and SG+PM, the coefficient of determination was low and therefore considered constant, as observed in the other treatments. This constant decomposition likely occurred because topdressing was applied locally, around the base of the plants.

The results might be different if topdressing had been applied across the entire area. Teixeira *et al*. (2010), in a study about millet and jack bean, and Potrich *et al*. (2014), about sugarcane, found that after applying N in the furrow and across the total area, distributing increasing N doses over the crop residue accelerated its decomposition, which was not observed in the present study.

The decomposition constant (k) of the regression equation was used to estimate the half-life ($T^{½}$) of the cover crop residue, with the lowest values obtained when signal grass was present alone or intercropped with pearl millet. At 35 days, half of the residue of these plants had decomposed, likely due to the earlier growth stage at cutting and the

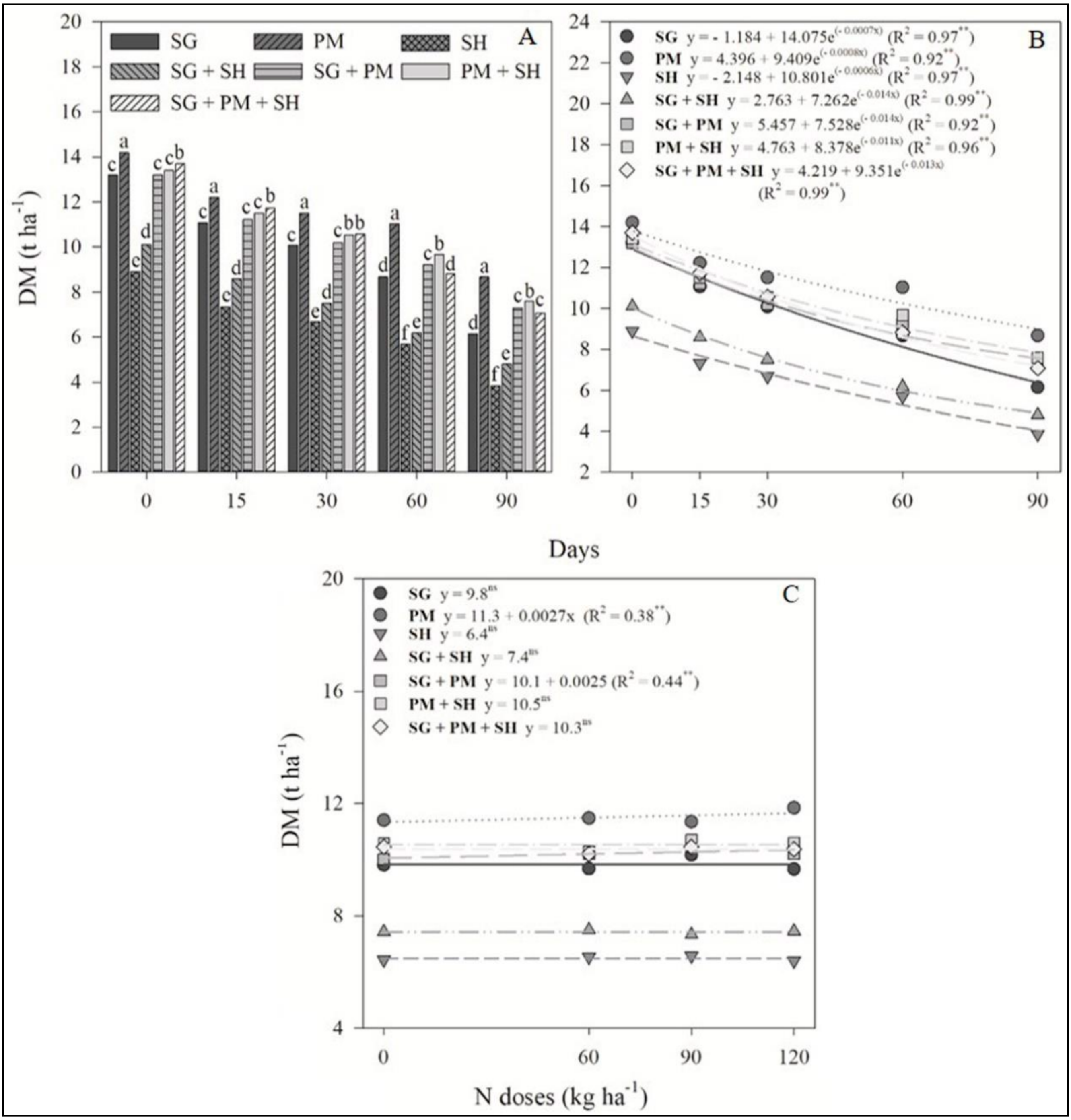

Figure 2. Remaining dry weight (DW) (A), decomposition (B) and effect of N doses (C) on cover crop residue in the time periods assessed, in Uberaba, MG. Uberaba, IFTM, 2021.

resulting low C:N ratio (Table 1).

The estimated T½ values of sunn hemp and signal grass were 35 and 41 days, respectively, indicating that the low C:N ratio of sunn hemp and early cutting of signal grass affected decomposition in treatments containing these plants, decreasing their T½, since the decomposition rate declined when pearl millet was present (Table 1). This may be due to the high lignin concentration of pearl millet, requiring greater N mobilization for decomposition, as reported by Vargas *et al*. (2005).

It should be noted that the temperature and soil moisture content in vegetable-growing areas increase the population of organisms that decompose organic matter (Potrich *et al*., 2014), accelerating the decomposition of plants with a low C:N ratio (Torres *et al*., 2017, 2021; Pacheco *et al*., 2017) by up to three times (Silveira *et al*., 2021; Nunes *et al*., 2022).

The HFW of broccoli was significantly influenced by the cover plants and nitrogen doses used. Sunn hemp provided the highest HFW values regardless of N dose (Figure 3A). The N doses used did not alter HFW in the SH, PM, PM+SH or SG+PM+SH treatments (Figure 3B). The greater N availability in the soil owing to sunn hemp BNF and high nutrient cycling in sunn hemp and pearl millet residue proves that, whether grown individually or intercropped, these two plants supply enough N to favor growth in the subsequent crop.

Corroborating these results, even without N topdressing, sunn hemp produced the highest HFW (788 g/plant) (Figure 3A), considered adequate for the consumer market. Additionally, the fact that sunn hemp as a cover crop may dispense with the need for N topdressing could significantly reduce broccoli production costs.

In the same region, for soil and climate conditions, Silveira (2020) observed that 9.8 and 8.4 t/ha of sunn hemp and pearl millet DW produced 103.3 and 113.6 kg/ha of accumulated N, respectively. Torres *et al.* (2021) applied 5.0 and 8.3 t/ha of DW of the same plants and obtained 103.3 and 113.6 kg/ha of accumulated N, respectively, which was cycled into the soil after the plants decomposed.

The adjusted regression curves showed that broccoli HFW remained constant for PM, SH, PM+SH and SG+PM+SH, demonstrating that higher N doses did not increase HFW. However, linear adjustment was observed for SG and SG+SH, with rising N doses significantly increasing HFW. Intercropped SG+PM showed quadratic adjustment, whereby HFW increased to 675 g/plant at 64 kg/ha of N and then declined from this dose onwards (Figure 3B).

The high HFW of broccoli grown on the residue of isolated or intercropped sunn hemp and pearl millet can be explained by the high DW production of the latter and BNF of the former when compared to other plants (Table 1). In addition to cycling a reasonable amount of nutrients, the slow decomposition of pearl millet protects the soil for longer, whereas sunn hemp provides greater N cycling (Pacheco *et al*., 2017; Collier *et al*., 2018; Torres *et al*., 2021).

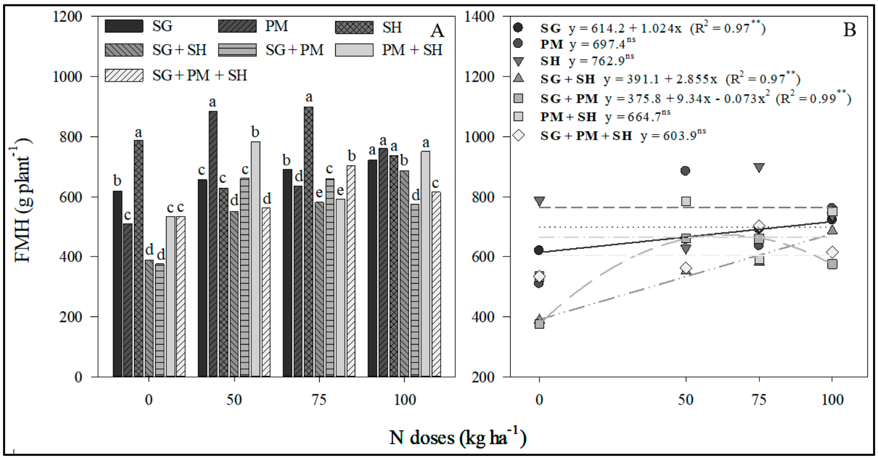

Figure 3. Head fresh weight (HFW) (A) and regression analysis (B) of N doses in broccoli grown with different cover crops, in Uberaba, MG. Uberaba, IFTM, 2021.

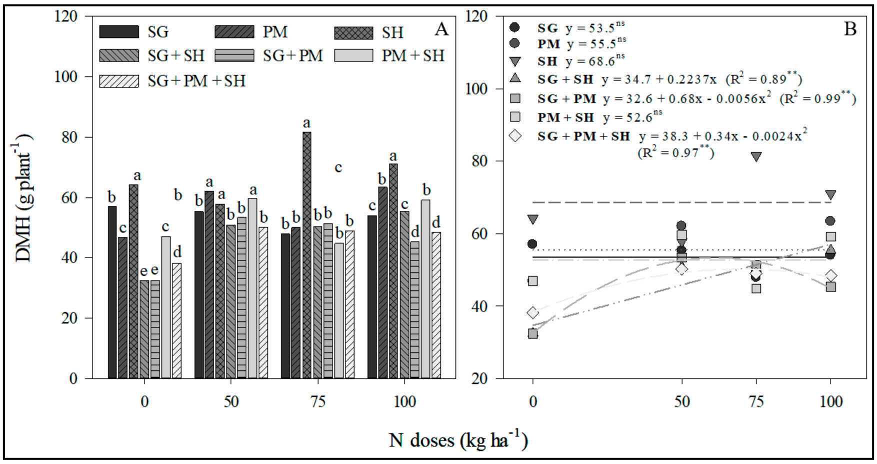

Figure 4. Head dry weight (HDW) (A) and regression analysis (B) of N doses in broccoli grown with different cover crops, in Uberaba, MG. Uberaba, IFTM, 2021.

According to Melo (2015), the consumer market prefers broccoli with 12 to 15 cm-wide heads and HFW between 300 and 400 g. In the present study, HFW varied from 552 to 763 g/plant. Broccoli HFW is higher in NTVF areas, which can be explained by the greater nutrient availability in the soil, as reported by Perin *et al.* (2015) and Torres *et al.* (2017, 2021).

Seabra Junior *et al.* (2014) assessed the production of fifteen single-head broccoli cultivars in Cáceres, Mato Grosso state (MT) under conventional tillage, with 60 kg/ha of N base dressing and 260 kg/ha of N topdressing and found that, in general, HFW ranged from 150 to 964 g/plant. However, cv. Avenger produced an HFW of 886 g/plant, the fourth highest HFW among the fifteen cultivars studied and similar to the values obtained in the present study using less nitrogen fertilizer (50 kg/ha as N base dressing and 120 kg/ha as topdressing).

Melo *et al.* (2010) evaluated six broccoli cultivars grown in the residue of pearl millet, corn, sorghum, corn intercropped with velvet bean, and in an area with no cover crops, applying 60 kg/ha of N as base dressing and 200 kg/ha as topdressing. The authors reported HFW between 173 and 457 g/plant, with the highest value recorded for cv. Avenger, which was lower than those obtained at all the nitrogen doses investigated in our study.

Silva *et al.* (2018) evaluated broccoli production as a function of N and K doses used in seedling fertigation and observed a linear increase in HFW as a function of N, varying from 195 to 285 g/plant from the lowest to the highest dose, respectively, lower than the results obtained in the present study. The authors also reported a linear increase in the head weight of broccoli grown in sunn hemp residue, which they attributed to greater N availability in the soil. This finding differs from our study, since there was no response to nitrogen topdressing when broccoli was grown in sunn hemp residue.

Diniz *et al*. (2017) studied the effect of sunn hemp residue on growth, production and N recovery and use efficiency in broccoli and observed a positive effect on growth and yield, findings similar to those of the present study.

Among the cover crops studied here, sunn hemp produced the highest average head dry weight (HDW) values in broccoli for all the N doses assessed (Figure 4A), although the other cover plants performed well at 60 kg/ha of N. The consistent performance of sunn hemp, regardless of the N dose applied, makes it a promising cover crop for short-cycle vegetables due to its rapid decomposition and nutrient release (Table 1).

N doses did not influence HDW in the PM, SH, SG and PM+SH treatments (Figure 4B), with values statistically higher than those obtained for sunn hemp (Figure 4A). Adjustment was linear for the SG+SH treatment, since higher N doses increased HDW, and quadratic for SG+PM and SG+PM+SH, with HDW rising to 53 and 49 g/plant at 74 and 83 kg/ha of N, respectively, but declining thereafter (Figure 4B). This behavior can be explained by the high C:N ratio of these Poaceae, causing greater N immobilization by soil microorganisms to decompose plant residue.

Silva *et al*. (2018) investigated broccoli production as a function of N and K fertigation and observed that high N doses produced a linear increase in the HDW of inflorescences, which varied from 19 to 28 g/plant, lower than the 32 to 81 g/plant recorded in our study.

Broccoli yield was affected by the different cover crops and N doses used, with significant interactions between the variables analyzed ($p<0.0001$; $F=19.73$). Yield was significantly higher at doses of zero (30.3 t/ha) and 90 kg/ha of N (36.9 t/ha) when sunn hemp was used as a cover crop, at 60 (35.4 t/ha) and 120 (30.4 t/ha) kg/ha of N for pearl millet and at 120 (32.9 t/ha) kg/ha of N for SG+SH (Figure 5A).

Studies conducted by Silveira (2020) and Torres *et al*. (2021) in the same region and growing season, with the same soil and climate conditions, demonstrated that sunn hemp cycled 107.3 to 130.7 kg/ha of N for DW production of 3.9 to 9.8 t/ha and pearl millet 50.5 to 173.8 kg/ha for 4.2 to 10.4 t/ha, respectively.

Regression curve adjustment indicated that the N doses used did not influence broccoli yield when grown in sunn hemp residue (Figures 3B and 4B), which produced the highest yield even without nitrogen addition (Figures 3A and 4A). These results demonstrate the greater autonomy of this cover crop in relation to nitrogen fertilizer, since BNF results in N accumulation in the plants, which then becomes available after cutting. The amount of N available in the soil through BNF was sufficient to produce HFW of 788 and 900 g/plant and yield of 30 and 37 t/ha at zero (no N application) and 90 kg/ha of N topdressing, respectively, positively affecting broccoli yield.

In the SG treatment, higher N doses increased soil N levels and, consequently, broccoli yield, with maximum production obtained at 120 kg/ha of N. This is likely due to the rapid residue decomposition and nutrient cycling of SG, which was cut at an earlier growth stage than the other cover

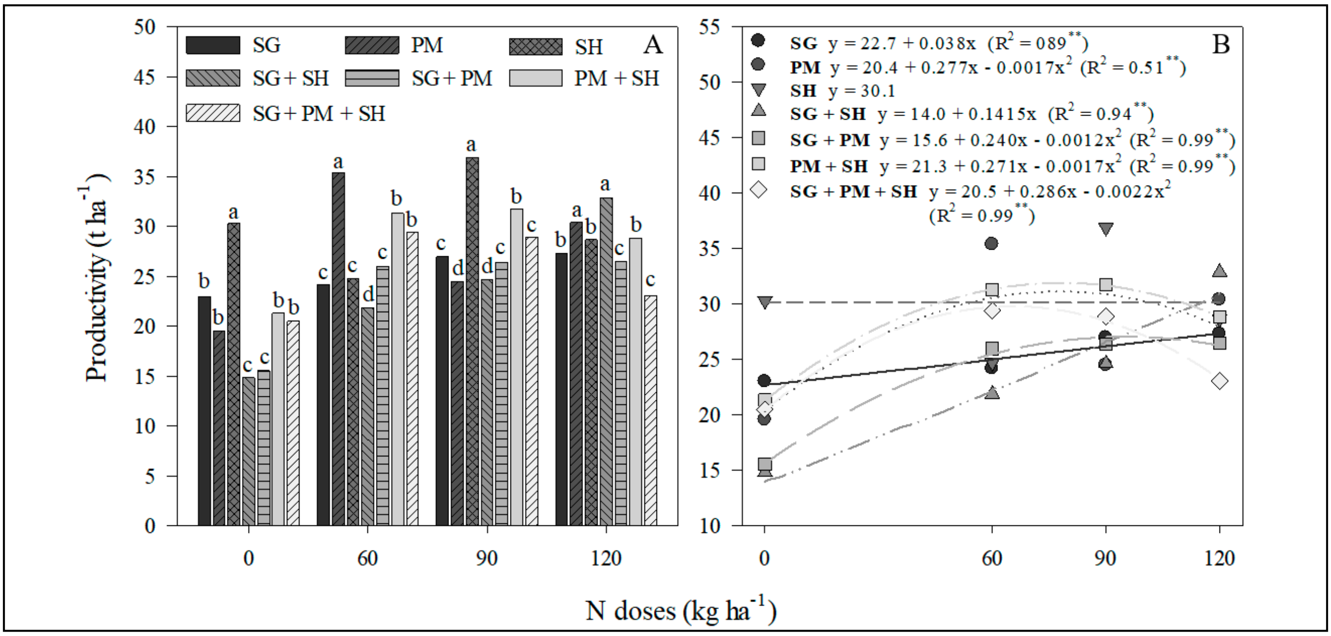

Figure 5. Yield of broccoli grown with different cover crops and interaction between the cover plants and nitrogen doses, in Uberaba, MG. Uberaba, IFTM, 2021.

crops, resulting in larger yields only at higher N doses.

This behavior can be justified by the high nutrient requirements of Brassicaceae in the final days of the crop cycle. Vieira *et al*. (2020) reported that the gradual release of nutrients retained in organic matter after decomposition favors development in the subsequent crop by reducing leaching-related nutrient loss, thereby increasing residual nutrient levels in the soil. This behavior was not observed for SG, SH or intercropping systems involving these plants, which exhibited a shorter $T^{1/2}$ (35 and 41 days, respectively), losing most of their nutrients in this period.

Quadratic adjustment was observed for PM, SG+PM, PM+SH and SG+PM+SH, since yield increased with N doses, with values of 31, 28, 32 and 30 t/ha at 81, 100, 80 and 65 kg/ha of N, respectively, declining thereafter (Figure 5B).

These results are justified by greater N immobilization by soil microorganisms to decompose the large amount of pearl millet residue on the soil surface, demonstrating the need for greater N supply when broccoli is grown in Poaceae residue, as reported by Vargas *et al*. (2005).

While the rapid decomposition of SG residue and the need for high N levels to decompose pearl millet residue produce a negative soil N balance, the gradual release of nutrients in SH residue and its greater autonomy in terms of N availability create a positive N balance (Torres *et al*., 2021). As such, the intercropped systems promote an intermediate balance in terms of the nutrient cycling efficiency needed for broccoli cultivation.

According to Melo (2015), broccoli cultivation using spacing that produces 20,000 plants/ha (50 x 100 or 70 x 70 cm) results in an average yield of 7 to 22 t/ha, lower than the total yield recorded in the present study (15 to 37 t/ha). This result corroborates the positive effect of the N doses and smaller plant spacing (50 x 50 cm) used in the present study, which produced a larger number of plants/ha (40,000 plants/ha).

This study demonstrates that the quality of cover crop residue may be more important than quantity in NTVP, since sunn hemp alone produced the highest yield despite exhibiting the lowest DW production, likely due to its greater N supply in relation to the other cover crops, to the extent that nitrogen topdressing was unnecessary.

The residence time of plant residue on the surface is also an important factor because the growth cycle of vegetables is short, meaning that crops with longer cycles could produce different results. Thus, in addition to quantity, future studies should assess the quality of cover crop residue, since this parameter seems to be highly relevant in the performance of subsequent crops, as shown in our study.

Sunn hemp and intercropped signal grass + sunn hemp exhibited the lowest DW production and, along with signal grass, the shortest half-life and highest residue decomposition rate.

Broccoli showed the best agronomic performance when grown in sunn hemp residue, followed by pearl millet and intercropping systems that combined these plants.

Broccoli grown in sunn hemp residue without nitrogen topdressing produced an average head fresh weight of 788 g/plant and yield of 30 t/ha.

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