Broccoli in succession to pearl millet: nutrient cycling, production and soil chemical attributes[1]

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ABSTRACT

For its production, broccoli requires large quantities of nutrients in relatively short periods. As a conservation technique, the no-tillage planting of broccoli over the pearl millet straw in succession may interfere with the dynamics of nutrient release, inflorescence production and the chemical attributes of the soil. The objectives of this work were to evaluate nutrient cycling, broccoli production and soil chemical attributes in a no-tillage system in succession to pearl millet for two consecutive years. The treatments consisted of pearl millet (BRS 1501) with the straw maintaned whole over the soil, pearl millet with the ground straw, spontaneous plants with biomass maintaned on the soil and conventional system with soil tillage without cover maintenance. It was found that ground pearl millet on the soil surface intensifies the nutrients release rate and provides a less use by broccoli grown in succession. The continuous conventional system reduces the absorption of nutrients and the production of inflorescence of broccoli grown in highly-fertile soil. Pearl millet is efficient in maintaining potassium levels in the soil over broccoli crops in succession. The maintenance of whole pearl millet straw on the soil surface is a promising technique for growing broccoli in succession.

Keywords: *Pennisetum glaucum* L. (R Brown)*; Brassica oleracea* L. var. *italica* (Plenck); cover plants; vegetables; nutrient cycling

INTRODUCTION

Broccoli (*Brassica oleracea* L. v. Italica (Plenck) with a single inflorescence is a vegetable of important economic value, grown mainly in green belts and concentrated in small farms in the South and Southeast, with most of its production destined for the market in its fresh form (Melo *et al*., 2015).

As a conservation alternative, cover crops have been used in a no-tillage production system, preceding the main crops and establishing greater efficiency in controlling erosion and maintaining or increasing soil fertility (Wutke *et al*., 2014).

Among the characteristics that must be considered when choosing the appropriate species of cover plants, the rapid establishment, tolerance to water deficit, production of phytomass, suppression of weeds and the ability to recycle and release nutrients for crops in succession have to be considered (Marcante *et al*., 2011; Teixeira *et al*., 2011; Hirata *et al*., 2014). As it has such characteristics, pearl millet (*Pennisetum glaucum* L.) (Grisa *et al*., 2019) was the species selected for this work.

The decomposition rate of pearl millet residues, after the management of the straw is influenced by edaphoclimatic conditions (temperature, humidity, oxygen, pH, nutrients, soil physics and fauna) and the way in which it is managed (cutting, rolling or grind), as it interferes with the population and activity of the microbial biomass (Aita *et al*., 2014).

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In the soil tillage, the incorporated plant residues are more easily colonized by the microorganisms (conventional preparation) due to the greater contact between the soil and the plant biomass, accelerating its decomposition (Giacomini *et al*., 2003; Aita *et al*., 2014). The size of the residue particles can also interfere in the rate of decomposition and release of nutrients due to the changes in the specific surface and consequently in the susceptibility to the attack by microorganisms and also to variations in temperature and water retention in the soil (Angers, 1997).

According to the way the straw is managed, Teixeira *et al*. (2012) concluded that pearl millet is effective in nutrient cycling and it also can influence the nutritional status of the crops in succession. The cultivation of broccoli requires a large quantity of nutrients in relatively short periods, with the greatest nutritional requirement of single-flowered broccoli occurring during the formation and development of the inflorescence (Cecílio Filho *et al*., 2017).

Nutrients are generally supplied by highly-soluble mineral fertilizers that may result in significant leachate losses. Thus, growing pearl millet prior to broccoli can mitigate the loss of nutrients over the soil profile, considering that this species absorbs nutrients at greater depths (Pacheco *et al*., 2018).

Besides its potential to recycle nutrients, carbon input from both the aerial part and the roots of pearl millet must be considered as it results in the increase in the levels of soil organic matter and, consequently, improvement of chemical, physical and biological attributes (Teixeira *et al*., 2010; Teixeira *et al*., 2011; Marcante *et al*., 2011; Loss *et al*., 2013; Mazetto Júnior *et al*., 2019).

The objectives of this work were to evaluate nutrient cycling, broccoli production and soil chemical attributes in a no-tillage system in succession to the whole or ground pearl millet for two consecutive years.

MATERIAL AND METHODS

The experiment was carried out under field conditions, for two consecutive years, at the Federal Institute of Santa Catarina (IFC), Campus Santa Rosa do Sul. The geographical coordinates of the site are 29°8’15" South and 49°42’45" West, with an average altitude of 9 meters. The climate, according to the Köppen classification, is Cfa, humid subtropical with hot summer. The data referring to the average temperature and the monthly rainfall during the period of conduction of the experiment are shown in Figure 1.

The experiment was set in a Haploid Gleisol (Embrapa, 2018), which was drained to avoid flooding periods throughout the year and, before the installation, 167 g kg^{-1} of clay, 550 g kg^{-1} of sand and 240 g kg^{-1} of silt was added in the arable layer, in addition to the following chemical attributes: pH H_2O 6.3, greater than 100 mg dm^{-3} P (Mehlich-1); 292.3 mg dm^{-3} K^+; 7.8 cmolc dm^{-3} Ca^{+2}; 3.3 cmolc dm^{-3} Mg^{+2}; 2.6 cmolc dm^{-3} H+Al and 24 g kg^{-1} organic carbon. The area had been fallow for a year besides being previously used in conventional cultivation of vegetables. The preparation of the soil for the installation of the experiment consisted of the use of a rotary hoe at a depth of 20 cm and, for the continuation of the experiment in the next year, this procedure was repeated only for the treatment that involved soil turning.

The experimental design was in the randomized block, with four treatments and four replications. The treatments consisted of whole pearl millet (BRS 1501) (WM), ground pearl millet (GM), spontaneous plants (SP) and conventional system (CS), before planting broccoli.

The soil was not amendment for acidity nor fertilization before planting the pearl millet, which was sown at spacing of 0.20 m between rows and when the plants reached 5 cm in height, a thinning was carried out, maintain five plants per linear meter (250 thousand plants per hectare). In the SP treatment, the invasive species that emerged from propagules and seeds in the dissemination bank were maintained, with a predominance of the following plants: *Cyperus rotunds* L., *Eleusine indica* (L.) Gaerth (Elein), *Galinsoga quadriradiata* Ruiz & Pav; *Cynodon dactylon* (L.) Pers, *Commelina erecta* L. and *Amaranthus lividus* L.

The management of pearl millet and spontaneous plants was manual and performed at the beginning of flowering of the pearl millet plants. In treatments with whole pearl millet and spontaneous plants, they were cleared and distributed longitudinally in the plots and, in the ground pearl millet treatment, the operation was carried out with a crusher, keeping 3 ± 1cm pieces, evenly distributed over the plots. To quantify the production of plant mass of pearl millet and spontaneous plants, a square with an inner area of 0.25 m^2 was used in two random samples in each plot. Dry mass was determined by placing the samples in a forced air circulation oven at 65°C for 72 hours until constant weight.

Nutrient release rate was evaluated right after the management of pearl millet and spontaneous plants, concurrently with the broccoli cycle following the method described by Santos & Whilford (1981). Thus, 20 g of dry matter were placed in litter bags (2-mm mesh, dimensions of 0.20 x 0.20 m). Four bags per plot were collected in each sampling, which occurred at 0, 30, 45, 60, 75 and 90 days after field distribution. After collecting the samples, the plant residues were manually cleaned, dried in a forced air circulation oven at 65°C until constant weight. To describe nutrient release, the exponential mathematical model described by Thomas & Asakawa (1993) was used: $X = Xo\ e^{-kt}$, where: X is the amount of nutrient remaining after a *t* period of time (in day); Xo is the initial amount of nutrient, and k is the nutrient release constant. Nutrient half-life ($T_{1/2}$ life), which expresses the time required for half of the initial nutrient to be released, was calculated using the following formula $\left(\frac{T1}{2} = \frac{\ln(2)}{k}\right)$ (Paul & Clark, 1996). Mathematical equations that represent the release of the nutrient were elaborated using the SigmaPlot software version 11.

Broccoli seedlings (Salinas F1 Topseed) were distributed in two rows with nine meters in length containing 16 plants at a spacing of 0.7 x 0.5 m. Eight central plants of the plots were used for the evaluations. The fertilization consisted of the application of 200 kg ha^{-1} of N, with 30 kg ha^{-1} at planting and the remainder split into topdressings at 25 days after transplantation and at the beginning of flowering of broccoli, using urea (45% N), 120 kg ha^{-1} of P_2O_5 applied all at planting via simple superphosphate (20% P_2O_5) and 160 kg ha^{-1} of K_2O, with 50% of the dose at planting and 50% in topdressing at 30 days after transplanting, using potassium chloride (60% K_2O) (CQFS RS/SC, 2004). Broccoli was harvested when the inflorescences were at the maximum size, compact and with tightly closed granules by manually cutting them at the first leaf insertion.

Following the analysis of homogeneity and normality, the data were subjected to analysis of variance and the test of Tukey at 5% probability to assess the difference between the means observed in the experiment. The statistical program used was Sisvar (Ferreira, 2014).

RESULTS AND DISCUSSION

The dry mass of the aerial part and the C/N ratio of the pearl millet were 23 Mg ha^{-1} and 18.7, respectively, in the first crop and, in the second, the values were 8.8 Mg ha^{-1} and 33. For the spontaneous plants in the first crop, these values were 4.9 Mg ha^{-1} and 16.5 and, in the second, 3.9 Mg ha^{-1} and 25. The highest dry mass production in the first crop was particularly caused by the rainfall (Figure 1), which met the needs of treatments throughout the cycle, unlike the second year, when complementary irrigation was needed.

Figures 2 and 3 show the initial accumulations of nutrients in pearl millet and spontaneous plants and their release over the broccoli cycle. Greater accumulations of nutrients are observed in the first crop (Figure 2). Also, in relation to nutrient release, greater release constants (K) and shorter half-lives ($T_{1/2}$) in the ground pearl millet (Figure 2 and Figure 3). Half-lives shorter than 90 days indicate that at least half of the nutrients accumulated in the straw of the plants that preceded the broccoli were released during its cultivation. This behavior can be observed for P, K and S (Figures 2 and 3).

Decomposition dynamics and nutrient release depend on the quantity and quality of the residue (C/N ratio), edaphoclimatic conditions, incorporation of the residues and particle size (Giacomini *et al*., 2003; Torres *et al*., 2005; Aita *et al*., 2014). Thus, higher N-release constant was expected, especially in the first crop, as the C/N ratios of plant matter were lower. It is common to observed the

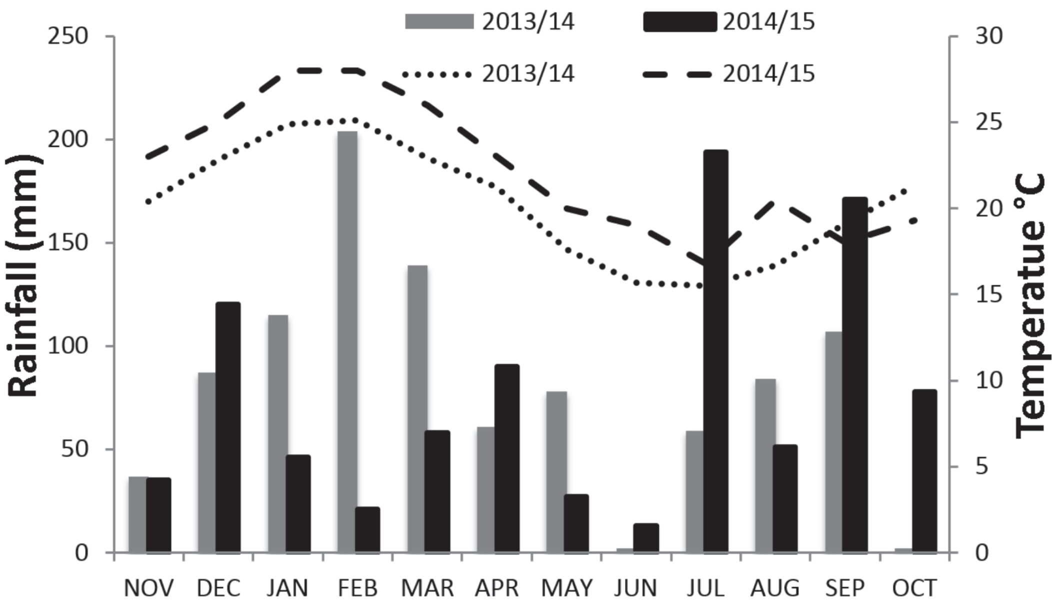

Figure 1: Monthly rainfall (bars) and average temperature °C (lines) obtained in the weather station at the Instituto Federal Catarinense - Santa Rosa do Sul campus, from November 2013 to October 2015. Pear millet planting: Nov. 28 2013 and Nov 19 2014. Pearl millet management: Jan 28 2014 and Feb 18 2015. Brocolli planting: Feb 07 2014 and Feb 28 2015. Brocolli harvest: Apr 30 2014 to May 14 2014 and from May 21 2015 to June 10 2015.

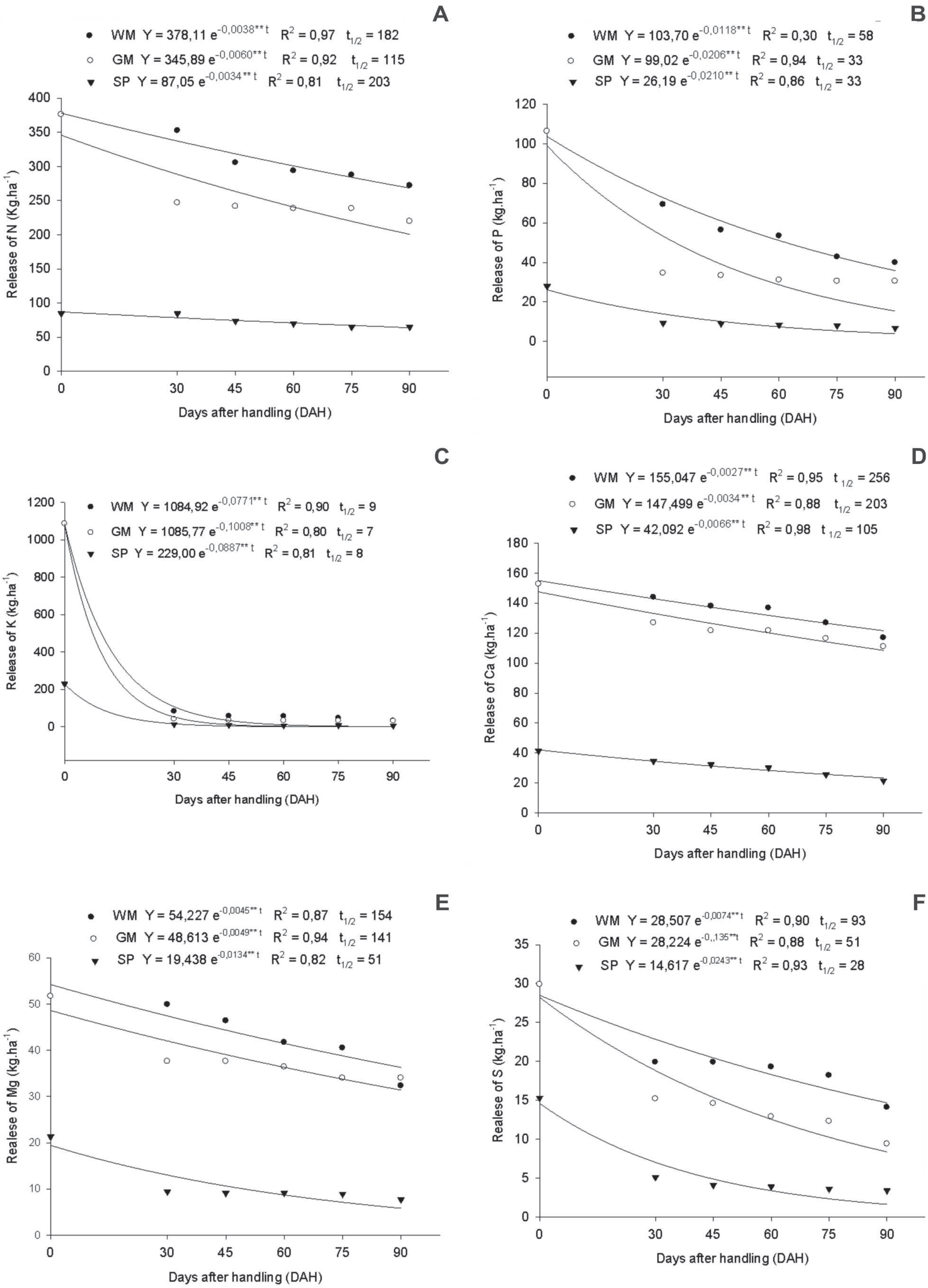

Figure 2: Accumulation and dynamics of nutrient release in the whole pearl millet (WM), ground pearl millet (GM) and spontaneous plants (SP) after management, over the broccoli grown in succession in 2013/2014. Santa Rosa do Sul/SC, IFC, 2019. A: (N); B: (P); C: (K); D: (Ca); E (Mg); F (S).

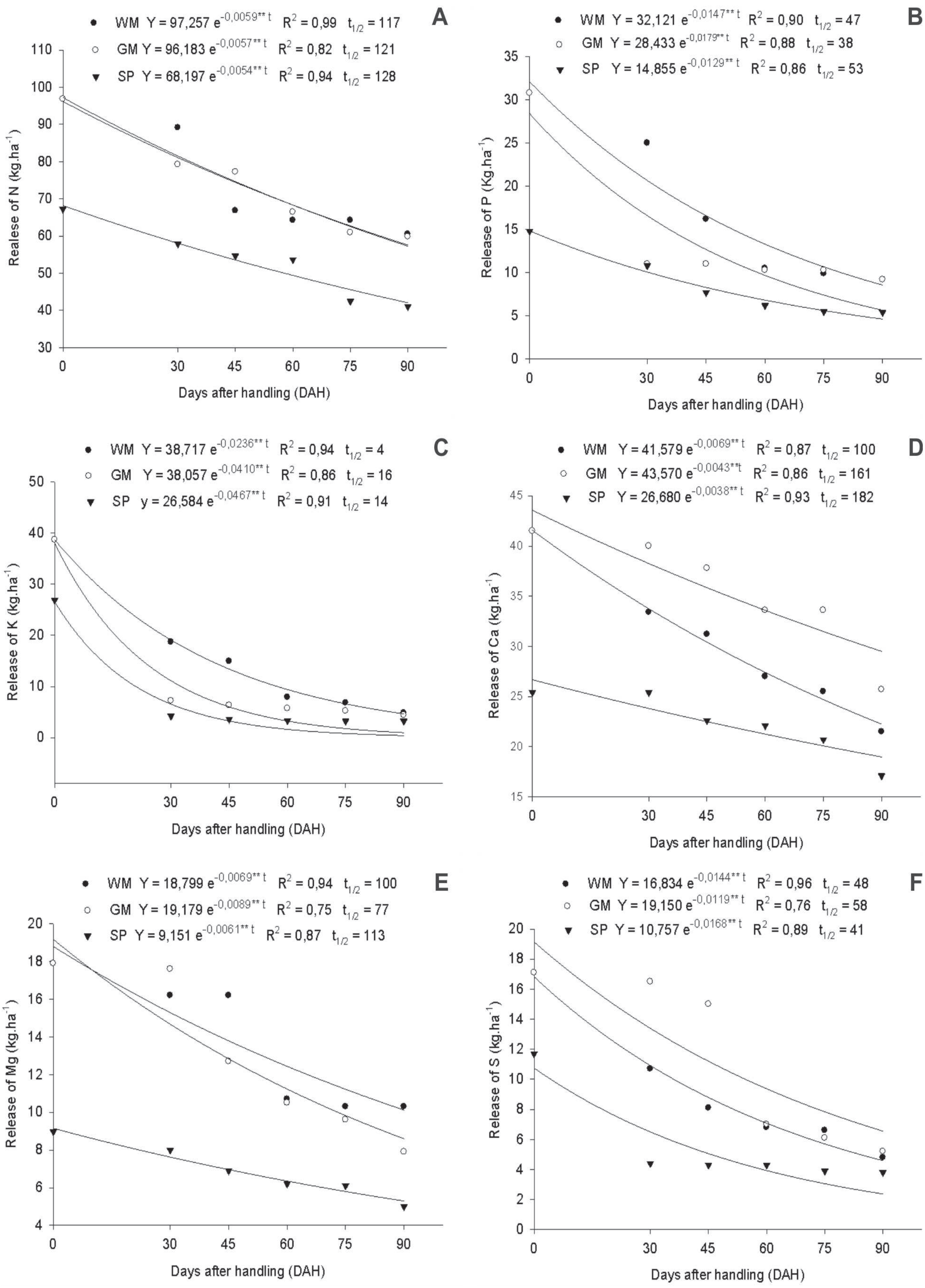

Figure 3: Accumulation and release dynamics of nutrients in whole pearl millet (WM), ground pearl millet (GM) and spontaneous plants (SP) after management over the broccoli crop grown in succession in 2014/2015. Santa Rosa do Sul/SC, IFC, 2019. A: (N); B: (P); C: (K); D: (Ca); E (Mg); F (S).

rapid release of K in the work of dynamics of nutrient release (Figures 2 and 3) besides being related to the fact that this element is not part of a cellular organic compound (Calonego *et al*., 2012; Taiz & Zieger, 2013), so the release for the medium gets more dependent on the rainfall. The high values of Ca half-life observed in this work (Figure 2D and Figure 3D) may be related, mainly to the fact that it is a constituent of the cell wall (Taiz & Zieger, 2013; Teixeira *et al*., 2011).

When evaluating the nutrient release from the aerial part of BRS 1501 pearl millet plants, Teixeira *et al*. (2011) observed a half-life of 131, 88, 4, 47 and 16 for N, P, K, Ca and Mg, respectively. Teixeira *et al*. (2012) in a study of nutrient decomposition and cycling of four soil cover plants, concluded that BRS 1501 millet is more effective than spontaneous plants in covering and nutrient cycling.

The accumulation of nutrients in broccoli from the first crop (2013/2014) was lower in the conventional system and after the ground millet (Table 1). The accumulation of nutrients in the second crop broccoli (2014/2015) shows, in general, lower means, particularly for N, P and K, when compared to the data of the first crop (Table 1). The conventional system on the accumulation of nutrients by broccoli is more evident in the second crop, which were lower. The accumulation of nutrients in the inflorescence (export) (Tables 1) does not follow those observed in the aerial part for most nutrients, resulting in unexpected results for N, P, K and Mg, which are considered of high redistribution in the plant (Malavolta *et al*., 1997). Despite the significant differences observed among treatments, the averages for each nutrient are not discrepant.

The lowest means of nutrient accumulation in broccoli grown in the conventional system reinforce the importance of using cover crops in the production systems as they promote nutrient cycling and priming effect, incorporating to the soil the organic compounds that stimulate microbial biomass activity, therefore, resulting in an increase in the productive potential of the soil, deepening in the root system and greater efficiency in the use of nutrients, particularly the most mobile in the soil, provided via highly soluble mineral fertilizers (Silva *et al*., 2009; Silva *et al*., 2014). The smaller accumulations of N, P, K and S by

Table 1: Nutrient accumulation in the aerial part (stem + leaves) and inflorescence of broccoli grown in succession to whole pearl millet (WM), ground pearl millet (GM), spontaneous plants (SP) and conventional system (CS) for two consecutive years. Santa Rosa do Sul/SC, IFC

Treatments	**Nutrient kg ha^{-1}**					
	N	**P**	**K**	**Ca**	**Mg**	**S**
	Aerial part 2013/2014					
WM	72.9 a	14.4 a	121.8 b	38.7 ab	6.9 b	20.6 a
GM	58.8 b	11.3 b	110.8 b	31.8 b	5.9 bc	16.6 b
SP	75.1 a	15.4 a	147.1 a	48.2 a	8.8 a	23.5 a
CS	51.7 b	10.7 b	100.4 b	31.7 b	5.6 c	16.9 b
CV (%)	6.0	6.4	8.4	12.9	8.3	7,6
	Inflorescences 2013/2014					
WM	40.3 a	7.2 a	38.8 a	2.2 a	2.2 a	5.6 a
GM	39.0 a	6.4 b	36.4 a	2.1 a	1.9 a	5.1 a
SP	37.2 a	6.5 ab	33.1 b	1.5 b	1.8 a	5.7 a
CS	39.9 a	6.5 ab	37.7 ab	2.0 a	1.9 a	5.7 a
CV (%)	5.5	4.9	4.1	8.7	6.5	5.3
	Aerial part 2Z014/2015					
WM	49.9 a	8.5 a	19.6 a	35.1 a	5.7 a	21.7 a
GM	50.8 a	8.7 a	18.2 ab	35.9 a	6.2 a	21.7 a
SP	52.1 a	8.6 a	13.6 c	28.3 b	5.1 a	14.9 c
CS	43.4 b	7.1 b	17.4 b	29.6 b	5.1 a	17.2 b
CV (%)	5.8	2.5	5.4	6.4	15.8	4.59
	Inflorescences 2014/2015					
WM	28.9 b	4.6 b	4.4 c	3.0 b	1.9 b	6.0 b
GM	37.8 a	4.4 b	7.5 a	4.3 a	2.5 a	7.8 a
SP	37.8 a	5.3 a	5.7 b	3.8 a	2.2 ab	7.3 a
CS	35.9 a	5.4 a	5.4 b	4.1 a	2.3 ab	7.8 a
CV (%)	4.5	4.6	4.3	6.9	11.8	5.9

Means followed by the same letter are not different from each other at 5 % of probability by the test of Tukey.

broccoli in succession to GM, possibly indicate less synchronization between the requirement for broccoli, which is greater between 60 to 90 days after emergence (Cecílio Filho *et al*., 2017), with the release rates of these nutrients, driven by the reduction in the size of the particles (Figures 2 and 3).

Table 2: Productivity of inflorescences of broccoli grown in succession to whole pearl millet (WM), ground pearl millet (GM), spontaneous plants (SP) and conventional system (CS) in the 2013/2014 and 2014/2015 crops. Santa Rosa do Sul/SC, IFC, 2019

Treatments	Productivity (Mg ha^{-1})	
	2013/2014	2014/2015
WM	11.01 a	10.18 a
GM	11.24 a	10.16 ab
SP	10.71 a	9.71 ab
CS	11.44 a	8.90 b
CV%	9.23	5.91

Means followed by the same letter do not differ at 5% probability by the test of Tukey.

The productivity of broccoli inflorescence is shown in Table 2. It can be seen that there was no significant difference between treatments, in the first crop; however, in the second culture, the WM was higher in relation to the CS.

The superiority of WM can be explained by the greater accumulation of nutrients by broccoli (Table 1), which resulted from a greater synchronization of the nutrient release by the residues with the crop demand, in addition to remaining with the straw on the soil surface for a longer time (Figures 2 and 3), which is important for soil protection against erosion, not only in the cultivation, but also in the off-season for maintaining soil moisture, therefore promoting the activity of microbial biomass and the cycling of nutrients (Teixeira *et al*., 2011; Hirata *et al*., 2014).

Table 3: Chemical attributes of the soil, sampled in the 0.0- 0.20 m depth-layer, in the broccoli production system in succession to the whole millet (WM), ground millet (GM), spontaneous plants (SP) and conventional system (CS) for two consecutive years. Santa Rosa do Sul/SC, IFC, 2019

Treatments	pH	MO	K	Ca	Mg	Al+H	CEC	V
	(H_2O)	%	cmol$_c$/dm^3					%
	Before experiment installation							
	6.3	4.3	0.75	7.8	3.3	2.6	14.5	82.2
	After plant management 2013/2014							
WM	6.2 a	4.6 a	0.42 b	8.2 a	3.4 a	2.8 a	14.8 a	81.7 a
GM	6.3 a	4.1 a	0.47 b	8.3 a	3.5 a	2.6 a	14.8 a	83.5 a
SP	6.3 a	4.3 a	0.85 a	7.8 a	3.3 a	2.7 a	14.6 a	82.0 a
CS	6.3 a	4.4 a	0.90 a	7.7 a	3.3 a	2.6 a	14.6 a	82.5 a
CV %	1.64	6.12	6.62	44.01	6.81	11.8	2.88	2.53
	After broccoli harvest 2013/2014							
WM	6.3 a	4.4 a	0.93 a	7.9 a	3.4 a	2.5 a	14.7 a	83.0 a
GM	6.4 a	4.3 a	0.84 a	7.8 a	3.4 a	2.3 a	14.4 a	83.7 a
SP	6.3 a	4.1 a	0.79 a	7.4 a	3.2 a	2.5 a	13.9 a	82.2 a
CS	6.3 a	4.1 a	0.78 a	8.1 a	3.5 a	2.6 a	15.0 a	83.5 a
CV %	2.0	5.9	14.7	5.3	7.6	15.8	5.5	3.03
	After plant management 2014/2015							
WM	6.2 ab	3.7 a	0.56 a	10.5 a	3.6 a	2.6 a	17.2 a	85.0 a
GM	6.2 ab	3.3 a	0.64 a	10.5 a	3.7 a	2.3 a	17.1 a	87.0 a
SP	6.1 b	3.5 a	0.66 a	10.2 a	3.7 a	2.8 a	17.2 a	84.7 a
CS	6.3 a	3.5 a	0.67 a	10.6 a	3.8 a	2.5 a	17.6 a	86.2 a
CV %	1.37	9.9	14.3	5.14	6.76	9.8	4.5	1.45
	After broccoli harvest 2014/2015							
WM	6.3 a	3.7 a	0.80 a	11.6 a	3.9 a	2.8 a	19.0 a	85.5 a
GM	6.3 a	3.6 a	0.74 ab	10.8 a	3.8 a	2.6 a	18.0 a	85.7 a
SP	6.4 a	3.3 a	0.67 ab	10.8 a	4.0 a	2.6 a	18.0 a	86.0 a
CS	6.4 a	3.6 a	0.50 b	11.7 a	4.2 a	2.7 a	19.2 a	86.0 a
CV %	2.32	8.91	14.4	7.23	8.96	13.29	7.14	2.0

Means followed by the same letter do not differ at 5% probability by the test of Tukey.

The soil chemical analyses show a highly fertile soil (Table 3), characterized by low acidity, high levels of organic matter, high cation exchange capacity (CEC), high base saturation (V) and high levels of phosphorus (P) and potassium (K) (CQFS RS/SC, 2004). High stability of the chemical attributes of the soil is observed over the experimental period, which reflects its high buffering power and the management used in the treatments, except for potassium, which had variations after the cultivation of millet and in the conventional system.

The pearl millet treatments show abrupt reductions in the potassium contents in the soil after the management of this species, which is justified mainly by the extracted amounts (Figures 2 and 3); however, at the end of the broccoli cultivation, a recovery and or an increase is found in the contents, which resulted from cycling and residual fertilization of broccoli. Different behavior is observed in spontaneous plant treatments and conventional system, where the potassium content in the soil gradually decreases over the crops (Table 3), indicating sharp potassium losses through leaching. In the conventional system, the reduction was from 0.75 $cmol_c\ dm^{-3}$ to 0.5 $cmol_c\ dm^{-3}$, corresponding to 235 kg ha^{-1} of K_2O (392 kg ha^{-1} of KCl).

Pear millet is considered a species with a high capacity to extract and recycle nutrients as its root system tends to be deep, giving it conditions to absorb nutrients, which annual crops do not absorb, because they have fewer deep roots (Oliveira *et al*., 2002; Braz *et al*., 2004; Teixeira *et al*., 2011). In order to estimate the dry matter yield and K accumulation in pearl millet, Oliveira *et al.* (2002) observed a productivity of 14.18 Mg ha^{-1} and an accumulation of 267.5 kg ha^{-1} of K, an intermediate result between the crops observed in this work and that shows the high potential of straw production and potassium cycling by this species.

The results of this work reinforce the importance of using pearl millet and in its forms, in the conservation production systems with the broccoli crop for interfering in the dynamics of nutrient release, production and chemical attributes of the soil. New studies with other cover crops, in different types of soil, could also contribute to the management and efficient use of nutrients in vegetables with high nutritional requirements and of great economic and nutritional importance, such as broccoli culture.

CONCLUSIONS

The management of ground pearl millet on the soil surface intensifies the nutrient release rates and provides less use for broccoli grown in succession.

The management of whole pearl millet on the soil surface is promising for growing broccoli in succession.

The conventional system of continuous production reduces the absorption of nutrients and the production of inflorescence of broccoli grown in highly fertile soil.

Pearl millet is efficient in maintaining potassium levels in the soil over broccoli crops in succession.

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