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Autumn Maize Intercropped with Tropical Forages: Crop Residues, Nutrient Cycling, Subsequent Soybean and Soil Quality

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ABSTRACT: Autumn maize intercropped with tropical forages can raise the amount of crop residues and improve nutrient cycling, favoring subsequent soybean crop. The objective of this study was to evaluate the effect of forms of implementation of intercropping of irrigated autumn maize with tropical forages on yield, decomposition, nutrient accumulation and release, and on the ratio of lignin/total N of forage residues, yield components, and grain yield of subsequent soybean, and on soil physical and chemical properties, under no-tillage in lowland *Cerrado*. The experiment was arranged in randomized blocks in a factorial (4 × 3 + 1) design with one control and four replications. The treatments consisted of four forages: Palisade grass, Congo grass, and two Guinea grass cultivars (Tanzânia and Áries); and three methods of sowing intercrops of forage-autumn maize: forage sown simultaneously with maize in the sowing furrow, mixed with fertilizer; forage sown by broadcasting on the day of maize sowing; and forage seeds mixed with fertilizer broadcast on maize in growth stage V4; plus a control (maize monoculture). The decomposition and nutrient release rate of the forage residues were evaluated by the litter bag method, 30, 60, 90, and 120 days after desiccation. Sowing the forages in the furrow and by broadcasting raise the total amount of maize residues compared to method V4. Regardless of the forage type and sowing methods, intercropping increases the amount of residues compared to maize monoculture. The forages and sowing methods had no influence on nutrient accumulation in the residues at the time of desiccation and at the lowest lignin/total N ratio in Congo grass residues, and a logarithmic

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decay was observed. Forage and sowing methods did not influence the macronutrient release rate from crop residues for 120 days after desiccation; the release of N, P, K and Mg is logarithmic and the release of Ca and S exponential. Forage and sowing methods do not influence yield components and grain yield of subsequent soybean. However, intercropping increased grain yield of subsequent soybean compared to soybean after maize monoculture, and preserved the soil chemical and physical properties.

Keywords: lowland *Cerrado*, no-tillage system, crop residues, Panicum, Urochloa.

INTRODUCTION

No-tillage system (NTS) is currently a good alternative for the sustainability of tropical farming systems, in particular with a view to erosion reduction, nutrient cycling, water storage, and long-term improvements of the soil physical and chemical quality (Mateus et al., 2016). However, most grass crops of commercial interest produce only insufficient amounts of residue for an appropriate mulch cover of the soil (Allen et al., 2007).

Associated with the low amount of residue, climatic characteristics of regions with dry (low and irregular rainfall) and warm winters, as in the lowland *Cerrado* of Brazil and the African savannas, increase the risk of failure of a second crop in the fall (late growing season), destined for grain, silage or only for biomass formation (Allen et al., 2007). Consequently, these areas are left fallow for a period of more than seven months a year (Dinar et al., 2008; Borghi et al., 2013). Moreover, plant residues decompose quickly in these regions (Pariz et al., 2011a; Costa et al., 2014). Summing up, all these conditions affect the sustainability of NTS.

Perennial tropical forage species such as the genera *Urochloa* (Syn. *Brachiaria*) and *Panicum*, aside from producing large amounts of dry matter, which is critical for residue formation in NTS, also have high C/N and lignin/total N ratios, reducing the decomposition rate and protecting the soil against erosion and solar radiation action for a longer time (Pariz et al., 2011a; Costa et al., 2014). Maize also produces large amounts of dry matter and can increase residue production in intercrops with these forages, with positive effects on soil physical properties and the productivity of subsequent soybean (Chioderoli et al., 2010; 2012).

The inclusion of tropical grasses in intercropping, rotation and/or sequence with grain crops in agricultural systems such as NTS represents a contribution to the maintenance and even improvements of the chemical and physical soil properties (Chioderoli et al., 2012; Mendonça et al., 2013; Costa et al., 2015). Mainly the inclusion of species with different root systems and plant residues with different C/N and lignin/N rates can influence the rates of decomposition and nutrient cycling.

Crop residues on the soil surface represent important reserves, from which nutrients can become available rapidly and at high rates (Rosolem et al., 2003), or slowly and gradually, according to the interactions between climate factors, mainly rainfall and temperature, macro and microbiological activity of the soil, and residue quality and quantity (Alcântara et al., 2000; Oliveira et al., 2002; Pariz et al., 2011a). However, for an effective cycling of a forage species, the nutrients released from the residues and the demand of the subsequently grown cash crop should be synchronized (Braz et al., 2004).

In this context, the hypothesis was that the autumn irrigated maize intercropped with tropical forages could raise the amount of crop residues and improve nutrient cycling, not decrease the grain yield compared to maize monoculture and favor subsequent soybean crop. The objective was to evaluate the effect of methods of intercropping of irrigated autumn maize with tropical forages on productivity, decomposition, and nutrient accumulation and release, on the ratio of lignin/total N of forage residues, yield components and productivity of subsequent soybean, and on soil physical and chemical properties, under no-tillage in lowland *Cerrado*.

MATERIALS AND METHODS

The experiment was carried out in the 2010/2011 growing season, in Selvíria, Mato Grosso do Sul (20° 18′ S, 51° 22′ W; 370 m asl) in an irrigated area (central pivot) of the Fazenda de Ensino, Pesquisa e Extensão of the Faculdade de Engenharia de Ilha Solteira – *Campus* de Ilha Solteira. According to the Köppen classification system, the climate is Aw, i.e., humid tropical with rainy summers and dry winters. The data of rainfall, and maximum, average and minimum temperature of the experimental period are in figure 1.

The soil was classified as *Latossolo Vermelho Distroférrico* (Santos et al., 2013), a Typic Haplorthox, in according to Soil Survey Staff (2014). The history of the crop sequence in the experimental area was 10 years of NTS (rotation of maize for grain and silage, soybean for grain, common bean for grain and tropical grasses intercropped with maize for grazing and residues) and the preceding crop had been soybean. The soil physical and chemical properties in the 0.0-0.2 m soil layer were first analyzed on 05/06/2010, with the following results: sand, silt and clay: 220; 120 and 660 g kg^{-1}, respectively; bulk density: 1.51 Mg m^{-3}; macro, micro and total porosity: 0.074; 0.339 and 0.413 m^3 m^{-3}, respectively. The results of soil chemical properties were: pH($CaCl_2$) 4.9; organic matter (OM) 22 g dm^{-3}; P (resin) 25 mg dm^{-3}; H+Al, K^+, Ca^{2+}, and Mg^{2+} 37; 2.7; 15 and 9 $mmol_c$ dm^{-3}, respectively; base saturation 41.9 %. The physical properties were analyzed by the methods suggested by Claessen (1997) and the chemical properties as described by Raij et al. (2001).

The area was irrigated by pivot sprinkler irrigation, considering the least limiting water range for the crops under study. To establish the water holding capacity (WHC), the following equation was used:

$$\text{WHC (mm)} = [(\text{FC} - \text{PWP})/100] \times \text{BD} \times \text{ERD} \qquad \text{Eq. 1}$$

where FC is the field capacity (%), PWP the permanent wilting point (%), BD soil bulk density (Mg m^{-3}) and ERD the effective root depth (m). These data were obtained from the soil water retention curve, with FC = 20.25 %, PWP = 14.58 %, BD = 1.51 Mg m^{-3}, and ERD = 0.20 m. Therefore, the WHC of the soil was 17.12 mm.

The water was supplied at a flow rate of 3.3 mm h^{-1}. Irrigation was applied each time the maximum evapotranspiration (ETm) reached 7.57 mm (less than 44.3 % of WHC). The ETm was estimated by the equation:

$$\text{ETm (mm d}^{-1}\text{)} = \text{Kc} \times \text{ETo} \qquad \text{Eq. 2}$$

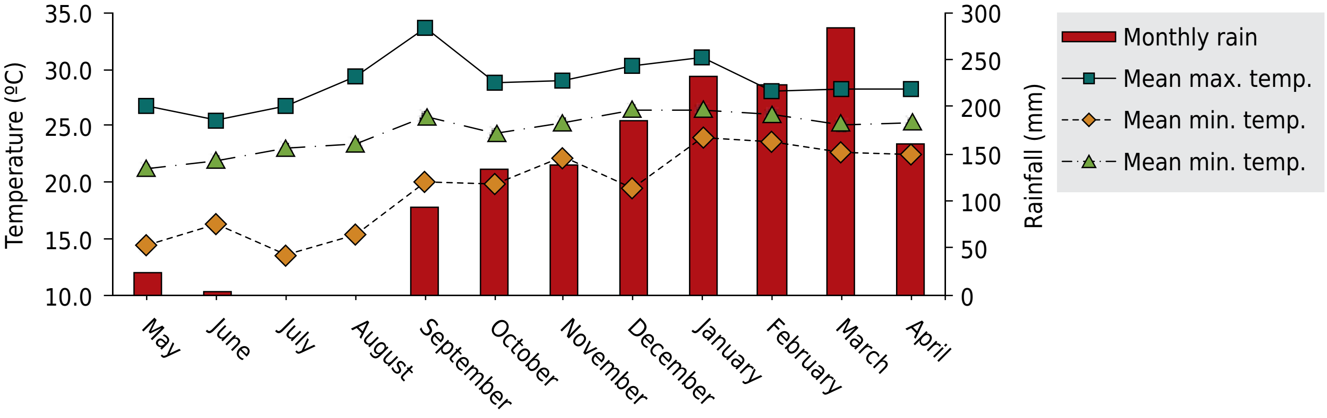


Figure 1. Mean rainfall values, maximum, minimum and mean temperature from May 2010 to April 2011, in Selvíria, Mato Grosso do Sul. Source: Laboratório de Hidráulica e Irrigação, Faculdade de Engenharia (FE/UNESP), Campus de Ilha Solteira, SP.

where Kc is the crop coefficient and ETo the reference evapotranspiration. ETo was estimated by:

$$\text{ETo (mm d}^{-1}) = \text{Kp} \times \text{ACE} \qquad \text{Eq. 3}$$

where Kp is the coefficient of tank Class A and ECA the evaporation of tank Class A (mm d^{-1}). Water evaporation (mm) was measured daily from tank Class A and Kp as proposed by Doorenbos and Pruitt (1977), based on the surrounding area, wind speed and relative air humidity.

The experiment had a randomized block, factorial (4 × 3 + 1) design with one control, consisting of 13 treatments with four replications. The treatments consisted of four forages: Palisade grass (*Urochloa brizantha* cv. Marandu), Congo grass (*Urochloa ruziziensis*), and two Guinea grass cultivars (*Panicum maximum* cv. Tanzânia and Áries); sown in three forage-maize intercropping methods: forage sown simultaneously with maize in the sowing furrow, mixed with fertilizer (furrow); forage sown by broadcasting, on the day of maize sowing (broadcast); and forage sown by broadcasting mixed with fertilizer sidedressed in the maize growth stage V4 (V4); and one control represented by maize monoculture. Each plot consisted of seven 18-m long maize rows, spaced 0.45 m apart and of traffic tracks of 15 m for the movement of vehicles and implements between the blocks. As useful area for evaluations, the three central rows were considered, disregarding a length of 4 m at either end of the plot.

On 10/05/2010, the plants of the experimental area were desiccated with glyphosate [(1.92 kg ha^{-1} of active ingredient (ai)]. On 05/19/2014, the early single-cross maize hybrid DKB 390 YG was sown to obtain a final plant population of 60,000 plants ha^{-1}. A precision planter with pneumatic seed distribution was used, with straight front cutting discs, furrowing rods for fertilization and mismatched double discs for seeding in seven rows, spaced 0.45 m apart. Maize seeds were treated with imidacloprid (2.6 g a.i. kg^{-1} seed) and thiodicarb (7.9 g a.i. kg^{-1} seed). Mineral fertilization in the planting furrow consisted of 24, 84 and 48 kg ha^{-1} of N, P_2O_5 and K_2O, respectively (300 kg ha^{-1} N-P-K fertilizer mixture 08-28-16).

Irrespective of the treatment (forage and sowing method), 510 points ha^{-1} of cultural value (10 kg ha^{-1} of forage seeds with cultural value of 51 %) were used. In the treatment furrow sowing, forage seeds were mixed with fertilizer and maize sown simultaneously at a soil depth of 0.08 and 0.06 m for the forages of the genera *Urochloa* and *Panicum*, respectively. In the treatment broadcast sowing, the forage seeds were distributed in the total area with a Vicon equipment (no incorporation into the soil) and later on that day maize was sown. In treatment V4, forage seeds were mixed with fertilizer and planted at a soil depth of 0.03 m.

On June 19, 2010, when maize reached stage V4 (four expanded leaves), 72 kg ha^{-1} K_2O (120 kg ha^{-1} KCl) and 135 kg ha^{-1} N (300 kg ha^{-1} agricultural urea) were sidedressed. A fertilizer vehicle for no-tillage sidedressing was used, with a chassis frame of 2.30 m, four mismatched double cutting discs (diameter 13" × 15"), and two 220-L recipients. Both fertilizations followed the recommendations of Cantarella et al. (1997) for maize.

On June 29, 2010, the herbicides atrazine and 2,4-D dimethylamine (1,000 and 161.2 g ha^{-1} a.i., respectively) were applied for weed control. On July 01, 2010, fall armyworm was controlled by the insecticides methomyl and triflumuron (172 and 29 g ha^{-1} a.i., respectively). On October 24, 2014, maize grain was mechanically harvested.

On November 12, 2010, the forage of the experimental area was desiccated with glyphosate [(2,4 kg ha^{-1} a.i.]. On November 20, 2010, the early-maturing soybean cultivar M-SOY 7908 RR with a determinate growth habit was sown for a final plant density of 200,000 plants ha^{-1}. The same precision planter as described above for maize was used, also with rows spaced 0.45 m apart. Soybean seeds were treated with carboxin and thiram (both at a rate of 60 g a.i. 100 kg^{-1} seed) and peat inoculum Masterfix Soja (100 g Masterfix 50 kg^{-1} seed). The mineral fertilizer sidedressed in the planting furrow consisted of 5, 50 and 50 kg ha^{-1} of N, P_2O_5 and K_2O, respectively (250 kg ha^{-1} N-P-K fertilizer 02-20-20).

Mineral sidedressing consisted of 60 kg ha^{-1} K_2O (100 kg ha^{-1} KCl), by broadcasting in the V4 stage. The same sidedresser fertilizer as described above for maize was used. Both fertilizations were applied as recommended by Ambrosano et al. (1997) for soybean.

On December 09, 2010, herbicide glyphosate [(1.44 kg ha^{-1} a.i.)] was applied for weed control. Caterpillars and bugs were controlled with insecticide applications as follows: December 09, 2010 methomyl (107 g ha^{-1} a.i.) at the beginning of infestation on January 07, 2011 beta-cyfluthrin and imadacloprid (6.25 and 50 g ha^{-1} a.i., respectively). Methomyl, beta-cyfluthrin and imidacloprid on January 24, 2011 (172; 6.25 and 50 g ha^{-1} a.i., respectively) and beta-cyfluthrin and imidacloprid on February 25, 2011 (12.5 and 100 g ha^{-1} a.i., respectively). Soybean rust was controlled with fungicide as follows: azoxystrobin and cyproconazole on January 07, 2011 and January 27, 2011 (140 and 56 g ha^{-1} a.i., respectively). On March 20, 2011, soybean grain was harvested mechanically.

At grain harvest, the residues of maize and forage plants were collected from a 13.5 m^2 area, weighed and a sample oven-dried at 65 °C for 72 h to determine dry weight. After forage desiccation, the same procedure was carried out. The total dry matter yield (TDMY) of maize and forage was calculated at both samplings and forage at the time of desiccation (FDMY), in kg ha^{-1}.

Later, the concentrations of N, P, K, Ca, Mg and S in forage residues were determined, according to the method proposed by Malavolta et al. (1997). The macronutrient contents were multiplied by FDMY, extrapolating the results to kg ha^{-1}, resulting in the amount of nutrients left on the soil surface after desiccation. The lignin contents were also determined, by the method described by Silva and Queiroz (2002), calculating the total lignin/N ratio.

After desiccation, forage fresh mass of each plot was exposed to decomposition in nylon bags (litter bags of 0.06 m^2, 0.3 × 0.2 m), proportionally to the amount per hectare (Pariz et al., 2011a). The litter bags were distributed and left on the ground in direct contact with the soil for 30, 60, 90, and 120 days. After desiccation (DAD), one litter bag per plot was removed to assess the remaining residues and determine the decomposition time for a period of 120 days. To this end, the fresh mass from each litter bag was collected, purified by sieving, and the dry weight determined (oven-dried at 65 °C to constant weight). Subsequently, the concentrations of N, P, K, Ca, Mg, and S of the remaining forage residue per litter bag were determined, according to the method proposed by Malavolta et al. (1997). The macronutrient contents were multiplied by the amount of remaining residues, calculating the respective release rates for a period of 120 days.

Before the mechanical harvesting of soybean grain, the final plant population (FPP) was determined by counting the plants of two central 3-m rows per plot and extrapolation to plants per hectare. Plant height (PH) was determined by measuring the distance between the plant collar and the apex tip on a graduated ruler (in cm). The insertion height of the first pod (IHFP) was determined by measuring the distance between the plant collar and the insertion height of the first pod with a cm ruler. The number of pods per plant (NPP) was determined by counting the pods per plant. For these determinations, 10 plants were randomly chosen, from the evaluated area of each plot during the evaluation of FPP. The weight of 1,000 grains (W1000) was determined as the mean of four samples of 1,000 grains per plot and the results were corrected to a moisture content of 13 %. The grain yield (GY) was determined in the plants of the three central rows harvested by hand, disregarding 4 m at either end of each plant row, resulting in an evaluated area of 13.5 m^2. After harvest, the plants were mechanically threshed, the grains weighed and GY calculated in kg ha^{-1}, corrected to a moisture content of 13 %.

The soil chemical and physical properties in the 0.0-0.2 m soil layer were determined according to the above methods for the initial soil analysis. Samples were collected after harvesting maize grain from monoculture or from intercrops with forage (October 29, 2010) and after soybean grain harvest (March 24, 2011).

Data were analyzed for normal distribution (Shapiro and Wilk, 1965) and subjected to ANOVA by the F test. The block effects were considered random and forage and sowing methods were considered fixed effects. When significant ($p \leq 0.05$), means were compared by the LSD test ($p \leq 0.05$). The variables of maize monoculture were compared with those of the intercrops by the test of orthogonal contrasts ($p \leq 0.05$). The residue decomposition and nutrient release rates were evaluated as suggested by Wider and Lang (1982) by the litter bag method, adopting the equation with highest determination coefficient (R^2) ($p \leq 0.05$). Statistical analyses were performed using statistical software Sisvar® (Ferreira, 1999).

RESULTS AND DISCUSSION

The total dry matter yield (TDMY) of maize and forage and the dry matter yield of forage (FDMY) at the time of desiccation were influenced by the interaction between forage and sowing methods (Table 1). The highest TDMY and FDMY of Guinea grass cv. Tanzânia sown by broadcasting, on the day of maize sowing (Table 2) was due to the better emergence of this grass in relation to the other sowing methods, as well as to the higher yield potential compared to other forages, given by the better weather conditions of early spring (Figure 1) (Pariz et al., 2011b). The lowest FDMY of Congo grass, sown in maize stage V4 without incorporation of seeds in the soil, can be explained by the shorter development time and lower plant density, requiring more time for tillering after maize harvest. This was also reflected in lower TDMY compared to furrow sowing, while Guinea grass cv. Áries also produced less TDMY when sown in maize stage V4, in comparison with broadcast sowing together with maize.

In the analyses of contrasts in all treatments, the TDMY exceeded the 11,393 kg ha^{-1} of residue deposited on the soil surface by maize monoculture (Table 1). Under the conditions of lowland *Cerrado* with dry and hot winters, due to the rapid decomposition of the plant residues left on the soil surface, annual residue amounts up to 12,000 kg ha^{-1} become necessary (Chioderoli et al., 2010, 2012; Pariz et al., 2011a). This amount can only be produced in systems that include the use of cover crops integrated in intercrops or crop rotation, as in this study, in which the amount of maize and forage plant residues exceeded 15,000 kg ha^{-1}. Autumn maize TDMY (late season) intercropped with forage analyzed in this study showed that such systems can be established under center pivot-irrigation in the soil and climatic conditions of lowland *Cerrado* (Tables 1 and 2). These yields were even higher than those recorded by Chioderoli et al. (2010, 2012) for the previous two autumn crops, all under the same soil and climatic conditions, using the same hybrid intercropped with tropical forages.

The accumulation of N, P, K, Ca, Mg, and S in residues at the time of desiccation was not affected by the forage type and sowing methods (Table 1). These results confirmed those of Torres et al. (2005), Costa et al. (2010), Pariz et al. (2011a), and Costa et al. (2014), demonstrating the ability of forage species of accumulating macronutrients, for biomass formation and nutrient cycling. Thus, the residues play a vital role in the consolidation and maintenance of NTS. The success of NTS depends strongly on the production and maintenance of residues on the soil surface (Macedo, 2009). In this context, late-season crops that ensure a soil mulch cover and nutrient cycling become fundamental in the diversification of sustainable agricultural production systems (Pariz et al., 2011a).

High accumulation of N and K (above 70 and 90 kg ha^{-1}, respectively) (Table 1), generally, was noteworthy. This confirms that these nutrients are the most absorbed and accumulated in the plant tissue of cover crops in the *Cerrado* region (Torres et al., 2005; Boer et al., 2007; Pariz et al., 2011a). Benefits of maize intercropping with Palisade grass in K recycling were reported by Garcia et al. (2008), raising the exchangeable form of this nutrient after forage desiccation. This explains the high K accumulations observed in this study, indicating that the evaluated forages extract high amounts of K from the soil, exceeding the amount of N (Costa et al., 2010).

The lignin/total nitrogen ratio (lig/N) of the residues was not influenced by the sowing method, but was lower in Congo grass than in the other forages (Table 1). These results may have been a consequence of the short period (18 days) between maize grain harvest and desiccation for biomass formation, in which new leaves prevailed, which usually have higher N and a lower lignin contents than grasses at more advanced phenological ages (Silva and Queiroz, 2002). In addition, Congo grass had fewer geniculate stems in the lower part formed from the base and from short stolons, reducing the lignin concentrations in plants (Silva and Queiroz, 2002). However, the lig/N ratio between 2.8 and 4.4 was similar to values reported by Pariz et al. (2011a), under similar conditions of season, soil and climate as in this study.

The lig/N ratio is positively correlated with the remaining residues (Aita and Giacomini, 2003). Thus, due to the lower lig/N ratio (Table 1), Congo grass was the only forage with a logarithmic decay rate of residues (Figure 2). These results indicate accelerated residue decomposition in the first 30 days after desiccation (DAD), with 50-60 % residual dry matter in this period. Due to the higher lig/N ratio, residue decomposition of the other

Table 1. Total dry matter yield (TDMY) maize exclusively or intercropping with forage sown in different methods, forage dry matter yield (FDMY), accumulation of nutrients and lignin/total nitrogen ratio (lig/N) in forage at the time of desiccation and significance of ANOVA in factorial and contrasts tests

	TDMY(1)	FDMY	N	P	K	Ca	Mg	S	Lig/N
	kg ha^{-1}								
Forages (F)									
Palisade grass	15,924	3,417	70 a	11 a	93 a	10 a	12 a	9 a	4.1 a
Congo grass	16,728	3,933	75 a	14 a	112 a	16 a	12 a	10 a	2.8 b
Guinea grass cv. Tanzânia	18,303	3,700	88 a	16 a	121 a	14 a	15 a	10 a	4.4 a
Guinea grass cv. Áries	17,162	3,400	92 a	16 a	142 a	16 a	15 a	12 a	4.0 a
Sowing method (SM)									
Furrow	17,593	3,750	91 a	16 a	128 a	15 a	14 a	10 a	3.7 a
Broadcast	18,254	4,338	75 a	12 a	115 a	13 a	13 a	9 a	4.0 a
V4	15,241	2,750	78 a	15 a	109 a	14 a	13 a	12 a	3.8 a
Maize monoculture	11,393	-	-	-	-	-	-	-	-
	ANOVA (p>F)								
Factorial									
F	0.1362	0.6064	0.4476	0.2619	0.1344	0.1898	0.2602	0.5591	0.0387
SM	0.0036	0.0012	0.4531	0.2469	0.5559	0.3419	0.6334	0.5232	0.4874
F × SM	0.0415	0.0482	0.5373	0.8863	0.1301	0.6677	0.7484	0.9155	0.7125
Contrasts(2)									
MM × M + PG FS	0.0011(3)	-	-	-	-	-	-	-	-
MM × M + PG BS	0.0133	-	-	-	-	-	-	-	-
MM × M + PG V4	0.0483	-	-	-	-	-	-	-	-
MM × M + CG FS	<0.0001	-	-	-	-	-	-	-	-
MM × M + CG BS	0.0095	-	-	-	-	-	-	-	-
MM × M + CG V4	0.0297	-	-	-	-	-	-	-	-
MM × M + GGT FS	0.0017	-	-	-	-	-	-	-	-
MM × M + GGT BS	<0.0001	-	-	-	-	-	-	-	-
MM × M + GGT V4	0.0141	-	-	-	-	-	-	-	-
MM × M + GGA FS	0.0019	-	-	-	-	-	-	-	-
MM × M + GGA BS	<0.0001	-	-	-	-	-	-	-	-
MM × M + GGA V4	0.0229	-	-	-	-	-	-	-	-

(1) TDMY: Total DMY of maize at grain harvest and of the forages in two stages (maize grain harvest and forage desiccation). (2) MM and M: maize monoculture and intercropped, respectively; PG, CG, GGT, and GGA: Palisade grass, Congo grass, Guinea grass cv. Tanzânia and Guinea grass cv. Áries, respectively; FS, BS and V4: forage sown in the furrow on the day of maize sowing; forage sown by broadcasting on the day of maize sowing; and forage sown by broadcasting in maize growth stage V_4, respectively. (3) Values of TDMY intercrops see table 2. Means followed by different letters differ from each other, by the t test (LSD) at 5 % probability.

Table 2. Partitioning of significant interactions of the total dry matter yield (TDMY) of maize intercropped with forage sown in different methods and forage dry matter yield (FDMY) at the time of desiccation

Forage	Sowing method		
	Furrow	Broadcast	V4
		TDMY[(1)] (kg ha^{-1})	
Palisade grass	17.280 aA	15.726 bA	14.765 aA
Congo grass	19.073 aA	15.952 bAB	15.160 aB
Guinea grass cv. Tanzânia	17.049 aB	22.171 aA	15.689 aB
Guinea grass cv. Áries	16.971 aAB	19.166 abA	15.350 aB
		FDMY (kg ha^{-1})	
Palisade grass	4.250 aA	3.150 bA	2.850 aA
Congo grass	4.150 aAB	4.650 abA	3.000 aB
Guinea grass cv. Tanzânia	3.550 aAB	5.600 aA	1.950 aB
Guinea grass cv. Áries	3.050 aA	3.950 bA	3.200 aA

(1) TDMY: Total maize DMY at the time of grain harvest and forage in two stages (at maize grain harvest and forage desiccation). Means followed by different lowercase letters in a column and uppercase letters in a row differed by the t test (LSD) at 5 % probability.

forages was exponential. Thus, except for Guinea grass cv. Tanzânia sown in maize growth stage V4, the other forages produced residue amounts exceeding 1,000 kg ha^{-1} dry weight 120 days after desiccation. This amount corresponded to more than 40 % of the residual dry weight, compared to the initial amount at the time of desiccation.

Weather conditions, in particular the high temperatures in the spring/summer in lowland *Cerrado* (Figure 1), accelerate residue decomposition (Figure 2). Logarithmic effects, with accelerated decomposition of Palisade grass residues 30 DAD, in early November, were stated by Pariz et al. (2011a). In this study, the high residue amount reduced the decomposition rate in most cases, since aside from accelerating the residue decomposition (Pariz et al., 2011a), a part of this material is also oxidized to CO_2 when in direct contact with the soil surface (Silva and Mendonça, 2007).

The release rate of the macronutrients N, P, K and Mg contained in the forage residues was logarithmic over the 120 DAD (Figures 3 and 4). The peak release of these nutrients occurred in the first 30 days. Nitrogen was the second most extracted nutrient by the forages and in general, the residues released more than 60 % of this nutrient in the 120 DAD. An intersection point was observed by Crusciol et al. (2005) when the amount of N accumulated in the residues was equal to the amount of N released into the soil, at 26 DAD. The authors stressed the evidence that, once fixed into organic compounds, N is available for cycling in the soil-plant residue complex of the agro-ecosystems. Therefore, the amount of N returning to the soil in the form of plant residues is a considerable portion of the total N absorbed by the subsequent plants, even in crops that are not N-fixing as soybean, compared to the small portion released from the roots and washed from the leaves by rain (Costa et al., 2012).

Although P is poorly soluble, high amounts can return to the soil under strong rainfall (Bromfield, 1961), since the intensity and duration of rainfalls also affect the amount of P that returns to the soil from residues (Costa et al., 2012). In this sense, the occurrence of high levels of rainfall after forage desiccation (Figure 1) may have favored the return of large amounts of P contained in the residues to the soil (Figure 3). In general, the residues released more than 80 % of this nutrient until 120 DAD.

The contribution of K released from the residues is worth highlighting: it is between 80 and 90 % for grasses and legumes and thus plays an important role in the cycling of this nutrient in the system (Santos et al., 2008). The nutrient release rate from crop residues during decomposition depends on the location and the form in which nutrients are contained in the plant tissue. Potassium, which is contained in non-structural components and in ionic form in the vacuole of plant cells, is released shortly after desiccation and, or,

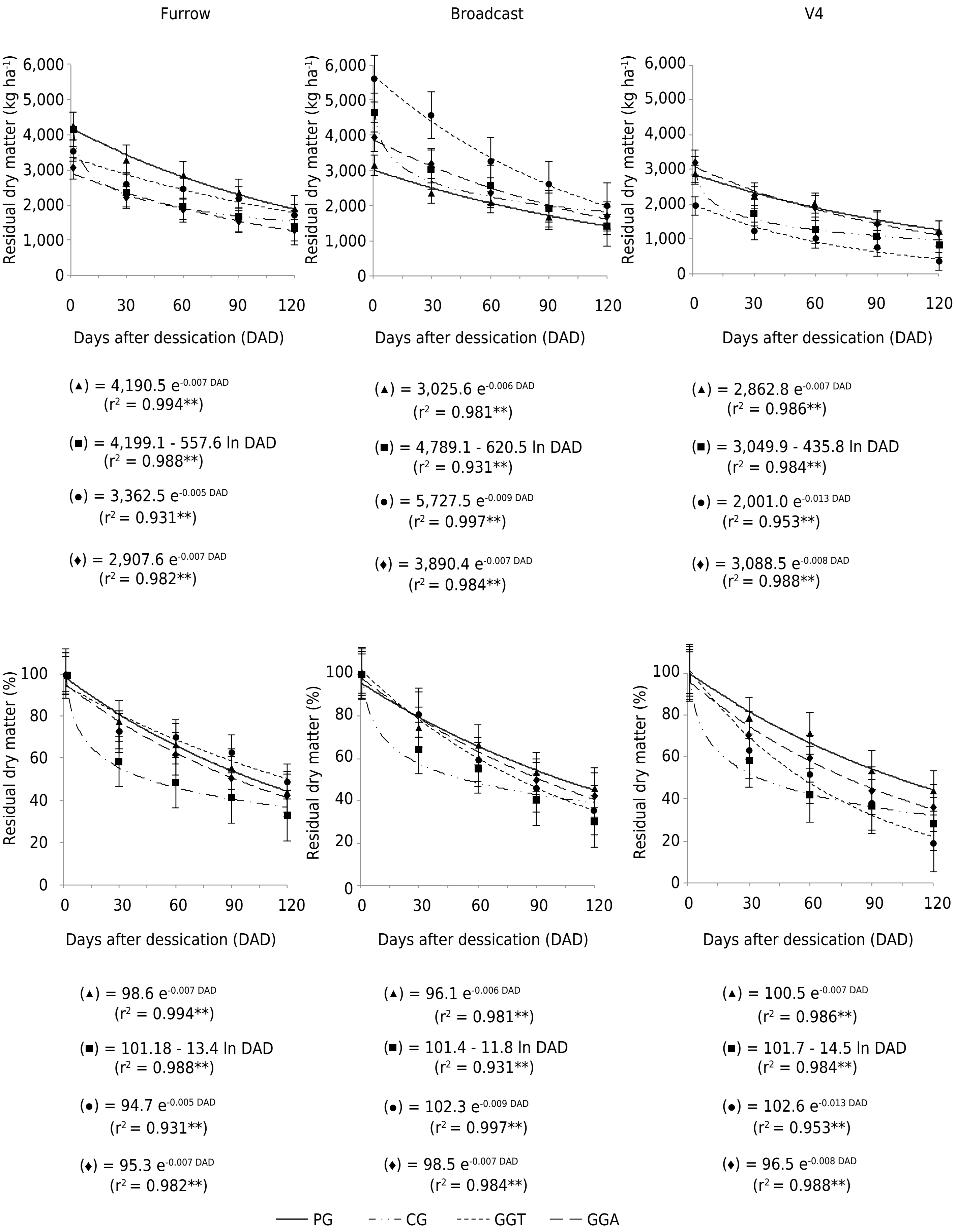
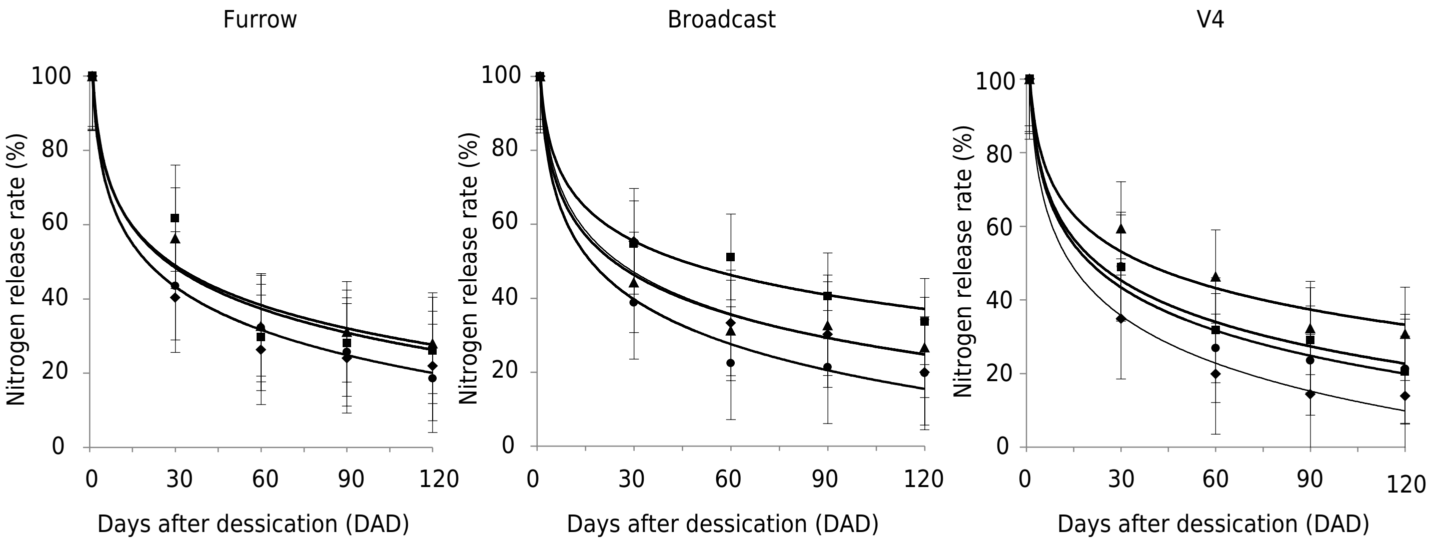
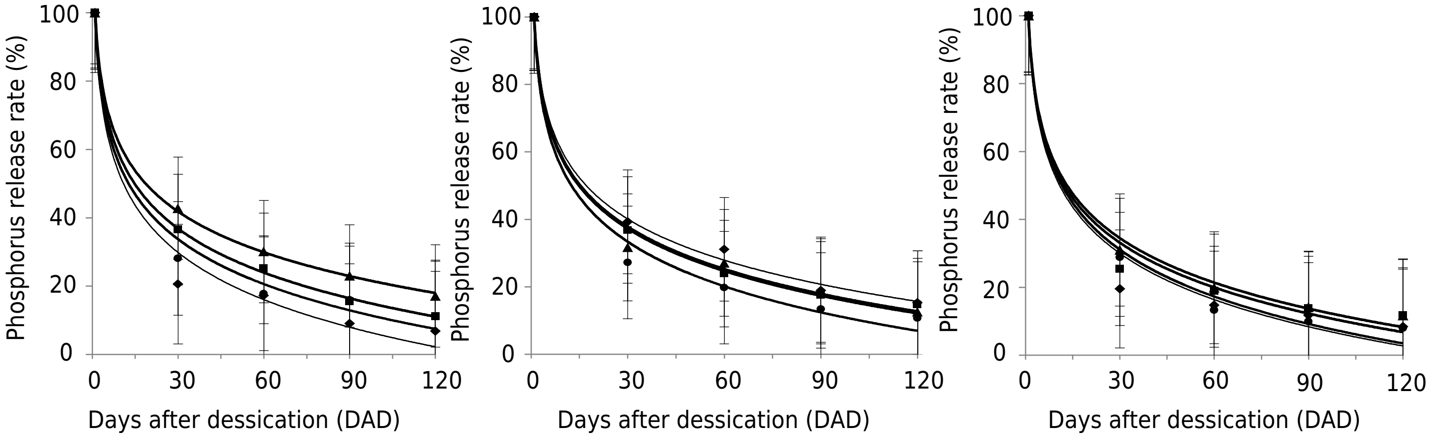


Figure 2. Residual dry matter (kg ha^{-1} and %) after desiccation (above and below, respectively), in three methods of sowing forage-autumn maize intercrops. PG, CG, GGT and GGA: Palisade grass, Congo grass, Guinea grass cv. Tanzânia and Guinea grass cv. Áries, respectively. **: significant at 1 %



Furrow	Broadcast	V4
(▲) = 101.273 - 15.3748 ln DAD (r^2 = 0.976**)	(▲) = 99.0075 - 15.4934 ln DAD (r^2 = 0.990**)	(▲) = 101.9768 - 14.353 ln DAD (r^2 = 0.974**)
(■) = 102.5669 - 15.926 ln DAD (r^2 = 0.939**)	(■) = 100.4737 - 13.2375 ln DAD (r^2 = 0.987**)	(■) = 100.8001 - 16.3125 ln DAD (r^2 = 0.994**)
(●) = 100.2066 - 16.7393 ln DAD (r^2 = 0.999**)	(●) = 99.05188 - 17.4503 ln DAD (r^2 = 0.990**)	(●) = 100.8671 - 16.894 ln DAD (r^2 = 0.987**)
(♦) = 99.08274 - 16.8521 ln DAD (r^2 = 0.993**)	(♦) = 102.1062 - 16.1861 ln DAD (r^2 = 0.975**)	(♦) = 99.26232 - 18.6715 ln DAD (r^2 = 0.995**)



Furrow	Broadcast	V4
(▲) = 100.3045 - 17.192 ln DAD (r^2 = 0.999**)	(▲) = 98.82911 - 18.1039 ln DAD (r^2 = 0.992**)	(▲) = 98.79843 - 18.9043 ln DAD (r^2 = 0.995**)
(■) = 100.04 - 18.58 ln DAD (r^2 = 0.999**)	(■) = 99.50813 - 18.1305 ln DAD (r^2 = 0.998**)	(■) = 97.72369 - 18.9892 ln DAD (r^2 = 0.984**)
(●) = 98.14521 - 18.9367 ln DAD (r^2 = 0.989**)	(●) = 98.22006 - 19.0647 ln DAD (r^2 = 0.990**)	(●) = 98.79934 - 19.9065 ln DAD (r^2 = 0.993**)
(♦) = 97.55432 - 19.9038 ln DAD (r^2 = 0.981**)	(♦) = 100.1086 - 17.6356 ln DAD (r^2 = 0.997**)	(♦) = 96.93528 - 19.6765 ln DAD (r^2 = 0.973**)

—— PG — · · — CG ----- GGT — — GGA

Figure 3. Nitrogen and phosphorus release rate from forage straw after desiccation, in three methods of sowing forage-autumn maize intercrops. PG, CG, GGT and GGA: Palisade grass, Congo grass, Guinea grass cv. Tanzânia and Guinea grass cv. Áries, respectively. **: significant at 1 %.

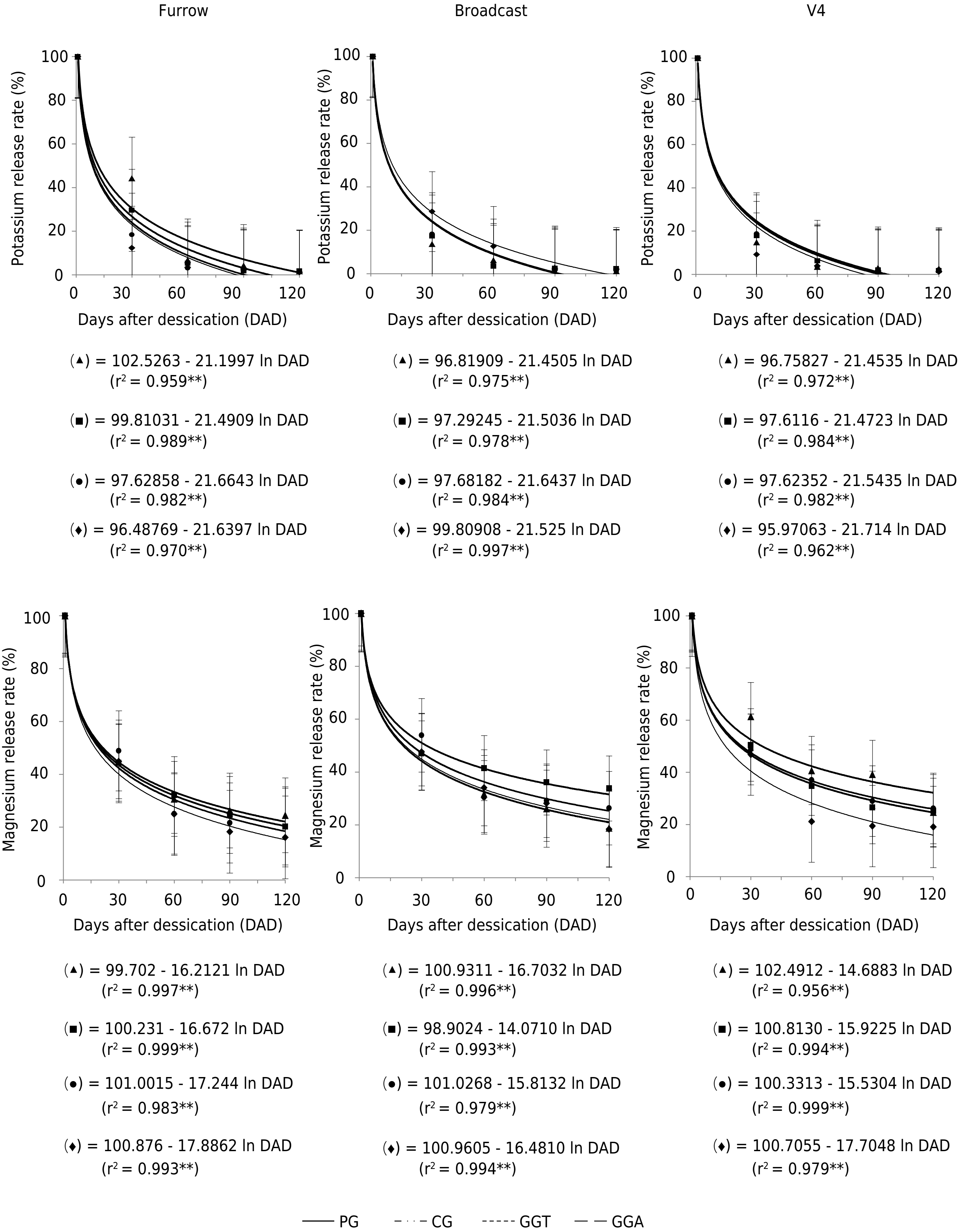


Figure 4. Potassium and magnesium release rate from forage straw after desiccation, in three methods of sowing forage-autumn maize intercrops. PG, CG, GGT and GGA: Palisade grass, Congo grass, Guinea grass cv. Tanzânia and Guinea grass cv. Áries, respectively. **: significant at 1 %.

cutting of the cover plants, and depends little on microbial processes (Giacomini et al., 2003). Thus, 90 DAD, K had been completely released from the forage residues (Figure 4).

The initial release of a large amount of Mg is because 70 % of this element is contained in the vacuole (Marschner, 1995). Most Mg is rapidly released, since this portion is not part of cell constituents. The remaining Mg (30 %) is subsequently released gradually, for being part of structural plant compounds (Crusciol et al., 2008). In this way, 30 DAD, about 50 % of the Mg contained in the forage residues had already been released (Figure 4). The release of the macronutrients Ca and S from the forage residues was exponential in the 120 DAD (Figure 5). In the first 30 days, the release of these nutrients was slower than that of the others (Figures 4 and 5), and 120 DAD, 40 to 60 % of the amount of Ca and S had been released from the forage residues.

The forages and sowing methods did not influence the yield components and soybean grain yield (Table 3). The final plant population (FPP) was similar to that reported by Chioderoli et al. (2012) when evaluating soybean sown on *Urochloa* residues intercropped with autumn maize, under similar soil and climatic conditions as in this study. The plant height (PH), insertion height of the first pod (IHFP), 1,000-grain weight (W1000), and grain yield (GY) of soybean were similar to those reported by Crusciol et al. (2012; 2014), of early soybean in intercrops with Palisade grass. However, these authors found higher FPP values and a lower number of pods per plant (NPP), resulting in the same yield potential.

In the analyses of contrasts, all treatments resulted in higher NPP, W1000 and GY than the crops following maize monoculture (Table 3). In general, the mean GY of 3,293 kg ha^{-1} was above the national average (2,854 and 3,002 kg ha^{-1}) in the growing seasons of 2013/2014 and 2014/2015, respectively (Conab, 2015). This GY was similar to the 3,270; 3,380 and 3,318 kg ha^{-1} reported by Andreotti et al. (2010), Silva et al. (2009) and Rosa Filho et al. (2009) in lowland *Cerrado* regions. On the other hand, the GY of soybean following maize monoculture was 2,782 kg ha^{-1}, corresponding to a difference of 511 kg ha^{-1}, compared to the mean GY of soybean following autumn maize intercropped with forage. Therefore, the residues of the forage combined with maize residues (Tables 1 and 2) protected the soil during the major part of soybean development (Figure 2), ensuring a lower variation in soil temperature, higher moisture and mainly more available nutrients (Table 1) during the process of residue decomposition (Figures 3, 4 and 5). This was reflected in higher NPP and heavier grains (higher W1000), resulting in a higher soybean GY.

The content of H+Al in the 0.0-0.2 m soil layer was higher after soybean cultivation, compared to sampling after autumn maize (Table 4). Consequently, base saturation (V) was lower after soybean cultivation. This demonstrates that forage intercropped with maize reduces the potential soil acidity. The content of soil organic matter (OM) was influenced by the interaction between sowing methods and sampling time. The OM content after maize cultivation was higher in the methods furrow and broadcast sowing, compared to method V4 (Table 5). Therefore, the higher TDMY in these sowing methods (Tables 1 and 2) increased OM mineralization (Torres et al., 2005). Regardless of the sowing methods, OM was higher after maize than after soybean cultivation. This can be explained by the presence of forage intercropped with maize, which has the capacity to raise the OM contents (Pariz et al., 2011a).

The K content (layer 0.0-0.2 m) was influenced by the interaction between forage and sampling time (Table 4). Due to the higher TDMY (Tables 1 and 2) after maize intercropping with Guinea grass cv. Tanzânia, there was a higher K soil content compared to intercrops with Guinea grass cv. Áries and Congo grass. After soybean cultivation however, the K levels in the soil from maize intercropped with Palisade grass were higher than in intercrops with Guinea grass cv. Tanzânia, and higher in intercrops with Congo grass than after maize cultivation. Thus, the release of nearly 100 % of this nutrient from forage residues (Figure 4) contributed to this increase. Results of Garcia et al. (2008) also showed that

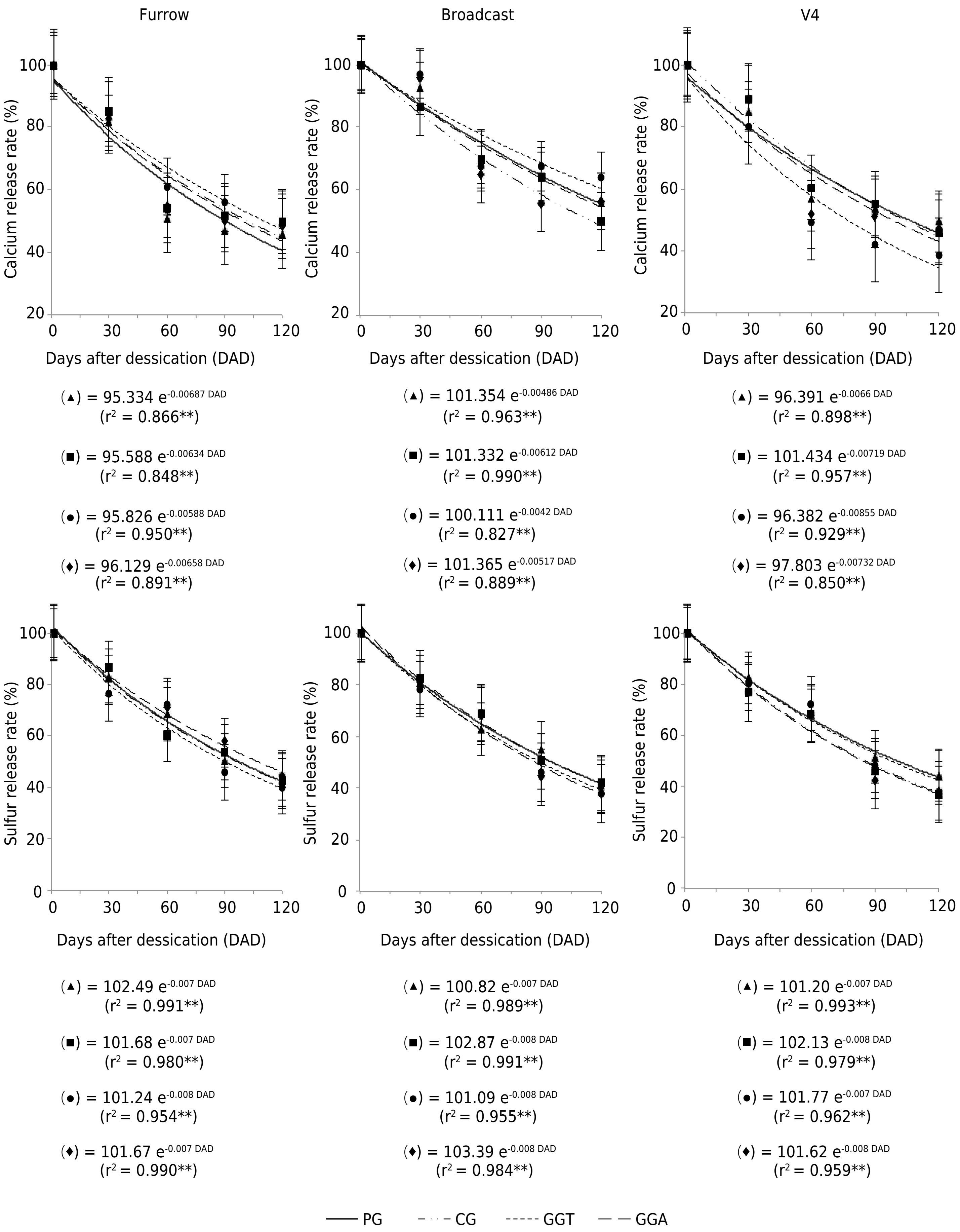


Figure 5. Calcium and sulfur release rate from forage straw after dessication, in three methods of sowing forage-autumn maize intercrops. PG, CG, GGT and GGA: Palisade grass, Congo grass, Guinea grass cv. Tanzânia and Guinea grass cv. Áries, respectively. **: significant at 1 %.

maize intercropping with Palisade grass was efficient in recycling K, a few months after forage desiccation, increasing the exchangeable form of this nutrient in the soil.

Forage-maize intercrops also increased P and K levels in the 0.0-0.2 m soil layer compared to maize monoculture in the sampling after maize grain harvest (Table 4). These results demonstrate the efficiency of the forages in providing these nutrients to the soil. Soils with Palisade grass had higher P levels in the labile fractions, increasing the absorption of this nutrient by plants (Silva et al., 2003). The OM in NTS also reduces the contact between soil colloids and the phosphate ion, reducing adsorption reactions, while residue decomposition (Figure 3) releases and redistributes organic, more mobile P forms that are less susceptible to adsorption reactions in the soil (Mesquita Filho and Torrent, 1993). It is also noteworthy that the maize stalks left on the soil surface after grain harvest are important K recyclers in the system (Jaremtchuk et al., 2006). Thus, the decomposition

Table 3. Final plant population (FPP), plant height (PH), insertion height of first pod (IHFP), number of pods per plant (NPP), thousand grain weight (W1000) and grain yield (GY) of soybean after maize in monoculture or intercropped with forages sown in different methods and significance of ANOVA in factorial and contrast tests

	FPP	PH	IHFP	NPP	W1000	GY
	nº ha^{-1}	m	m	nº	g	kg ha^{-1}
Forage (F)						
Palisade grass	197,037 a	0.83 a	0.18 a	77 a	123.9 a	3,331 a
Congo grass	199,951 a	0.81 a	0.18 a	74 a	123.7 a	3,298 a
Guinea grass cv. Tanzânia	198,766 a	0.79 a	0.19 a	75 a	125.0 a	3,232 a
Guinea grass cv. Áries	196,605 a	0.83 a	0.18 a	74 a	125.5 a	3,311 a
Sowing method (SM)						
Furrow	197,982 a	0.81 a	0.18 a	72 a	126.9 a	3,326 a
Broadcast	196,278 a	0.81 a	0.19 a	73 a	123.9 a	3,281 a
V4	200,009 a	0.83 a	0.18 a	73 a	122.7 a	3,271 a
Maize monoculture	200,630	0.85	0.18	61	113.0	2,782
Anova (p>F)						
Factorial						
F	0.3548	0.1466	0.6239	0.0003	0.8855	0.8156
SM	0.2487	0.4149	0.1310	0.5852	0.1820	0.1705
F × SM	0.4854	0.1085	0.1258	0.5376	0.9352	0.1453
Contrast(1)						
MM × M + PG FS	0.2504	0.3518	0.1830	0.0001(2)	0.0097(3)	0.0015(2)
MM × M + PG BS	0.1845	0.6806	0.1553	0.0005	0.0106	0.0010
MM × M + PG V4	0.5821	0.2257	0.1229	0.0001	0.0456	0.0008
MM × M + CG FS	0.2845	0.5416	0.1981	0.0002	0.0037	0.0029
MM × M + CG BS	0.2548	0.2246	0.1606	0.0061	0.0177	0.0008
MM × M + CG V4	0.6854	0.3646	0.3151	0.0010	0.0494	0.0005
MM × M + GGT FS	0.2487	0.1114	0.1785	0.0247	0.0045	0.0008
MM × M + GGT BS	0.2358	0.1981	0.1870	0.0145	0.0178	0.0449
MM × M + GGT V4	0.7014	0.1107	0.1570	0.0090	0.0106	0.0001
MM × M + GGA FS	0.4012	0.1825	0.1337	0.0017	0.0005	0.0049
MM × M + GGA BS	0.3487	0.3393	0.1622	0.0006	0.0307	0.0010
MM × M + GGA V4	0.6852	0.9403	0.1490	0.0007	0.0190	0.0001

(1) MM and M: maize monoculture and intercropped, respectively; PG, CG, GGT, and GGA: Palisade grass, Congo grass, Guinea grass cv. Tanzânia and Guinea grass cv. Áries, respectively; FS, BS and V4: forage sown in the furrow on the day of maize sowing; forage sown by broadcasting on the day of maize sowing; and forage sown by broadcasting in maize growth stage V$_4$, respectively. (2) Values of NPP and GY of the intercrops see table 4. (3) Values of W1000: M + PG FS; M + PG BS; M + PG V4; M + CG FS; M + CG BS; M + CG V4; M + GGT FS; M + GGT BS; M + GGT V4; M + GGA FS; M + GGA BS; M + GGA V4 = 125.0; 124.9; 121.7; 126.7; 123.9; 120.5; 126.3; 123.9; 124.9; 129.7; 122.9 and 123.8 g., respectively. Means followed by different letters differed from each other, by the t test (LSD) at 5 % probability.

of maize monoculture residues increased P and K levels in the 0.0-0.20 m soil layer, with no difference from the intercrops with forage after soybean grain harvest.

Forage-maize intercrops and soybean cultivation maintained the soil fertility found in the initial soil analysis, including a slight increase in P content, which was initially 25 mg dm^{-3} (Tables 4 and 5). In maize monoculture however, P and K decreased, especially after maize grain harvest, while potential acidity (H+Al) increased and base saturation (V) decreased after cultivation of subsequent soybean.

Changes in the soil chemical properties, especially after maize harvest and intercrops compared with maize monoculture (Tables 4 and 5), resulted from the high accumulation of forage residues left on the surface during the experiment. By the decomposition process of the residual plant biomass, the soil was supplied with nutrients, stimulating the biological activity and leading to changes in fertility (Costa et al., 2015).

Table 4. Soil chemical properties in the 0.0-0.2 m layer, after harvest of maize in monoculture or intercropped with forages sown in different methods and after the harvest of subsequent soybean and significance of ANOVA in factorial and contrast tests

	$\text{pH(CaCl}_2\text{)}$	OM	P (resin)	H+Al	K^+	Ca^{2+}	Mg^{2+}	V
		g dm^{-3}	mg dm^{-3}			mmol$_c$ dm^{-3}		%
Forage (F)								
Palisade grass	4.8 a	22.0 a	29.3 a	36.7 a	2.5	14.9 a	9.6 a	42.4 a
Congo grass	4.8 a	22.4 a	26.1 a	35.9 a	2.1	15.0 a	10.0 a	43.0 a
Guinea grass cv. Tanzânia	4.8 a	21.2 a	27.5 a	34.4 a	2.3	14.9 a	9.9 a	44.1 a
Guinea grass cv. Áries	4.8 a	21.7 a	26.6 a	36.2 a	2.1	14.0 a	9.7 a	41.6 a
Sowing method (SM)								
Furrow	4.8 a	22.3	30.6 a	35.4 a	2.3 a	15.6 a	10.0 a	44.1 a
Broadcast	4.8 a	22.1	25.1 a	36.2 a	2.3 a	14.4 a	9.7 a	42.2 a
V4	4.8 a	21.0	26.4 a	35.7 a	2.2 a	14.1 a	9.8 a	42.2 a
Season (S)								
After maize	4.8 a	23.2	26.7 a	32.1 b	2.1	15.2 a	9.9 a	45.9 a
After soybean	4.8 a	20.4	28.0 a	39.4 a	2.4	14.2 a	9.7 a	40.0 b
After maize monoculture (MM)	4.9	22.3	15.8	32.8	1.5	16.3	10.9	46.7
After soybean following MM	4.6	21.0	21.8	42.1	2.1	14.3	8.8	37.4
				Anova (p>F)				
Factorial								
F	0.8774	0.1567	0.7727	0.3574	0.0480	0.7638	0.8453	0.5312
SM	0.8537	0.0158	0.1399	0.8152	0.6429	0.2266	0.7415	0.4646
S	0.8952	0.0004	0.5747	0.0003	0.0150	0.2057	0.7807	0.0002
F × SM	0.1674	0.4084	0.5178	0.1163	0.1253	0.1982	0.1151	0.1421
F × S	0.7340	0.8309	0.1782	0.3048	0.0270	0.3956	0.8671	0.5740
SM × S	0.6299	0.0152	0.1644	0.4879	0.7589	0.8775	0.5932	0.8737
F × SM × S	0.7727	0.1240	0.2901	0.6785	0.7673	0.4825	0.6030	0.5529
Contrast								
After maize monoculture (MM)								
× intercrops	0.6176	0.3232	0.0421	0.7993	0.0490	0.5783	0.6816	0.9999
After soybean following MM								
× intercrops	0.4945	0.5319	0.2828	0.2546	0.3338	0.9956	0.6895	0.5599

Means followed by different letters differed from each other, by the t test (LSD) at 5 % probability.

Table 5. Partitioning of significant interactions of organic matter (OM) and potassium (K^+) of the soil in the 0.0-0.2 m layer, after harvest of maize in monoculture or intercropped with forages sown in different methods and after the harvest of subsequent soybean

	Season	
	After maize	**After soybean**
	OM (g dm^{-3})	
Sowing method		
Furrow	24.4 aA	20.2 aB
Broadcast	23.6 aA	20.6 aB
V4	21.7 bA	20.3 aB
	K^+ ($mmol_c$ dm^{-3})	
Forage		
Palisade grass	2.2 abB	2.8 aA
Congo grass	1.8 bB	2.4 abA
Guinea grass cv. Tanzânia	2.5 aA	2.1 bA
Guinea grass cv. Áries	1.9 bA	2.3 abA

Means followed by different lowercase letters in a column and capital letters in a row differed from each other, by the t test (LSD) at 5 % probability.

The forages and sowing methods did not influence the macro- (MA), micro- (MI), and total porosity (TP), and bulk density (BD) in the 0.0-0.2 m soil layer (Table 6). Soybean cultivation however increased soil MA in relation to maize. Similarly, cultivation of soybean after forage- maize intercrops raised MA in comparison with maize monoculture. Thus, the effective root system of forage was possibly responsible for these results. After maize harvest, the forage roots were still not fully decomposed, due to the lower temperatures in that period (Figure 1). After the period between maize harvest (October) and soybean harvest (March), the decomposition of forage roots was already more advanced, coinciding with the time of occurrence of higher temperatures.

Increase in MA values after soybean (Table 6) probably occurred because the soil was exploited by different root systems (grasses and legumes), which, after decomposition of the root mass, contribute to the formation of an architecture of permanent pores, resulting in greater MA of the soil (Costa et al., 2015). This behavior was also observed by several other authors in the same study region, who stated improvements in this soil property by crop rotation, in particular by intercropping of maize with tropical forages and subsequent soybean (Chioderoli et al., 2012; Mendonça et al., 2013; Costa et al., 2015). The values of MA, MI, TP and BD reported by these authors were very similar to those in this study, under the same soil and climatic conditions.

The increase in macropores is the most important aspect of a proper soil management for conservation, and a MA value of less than 0.10 m^3 m^{-3} can be critical (Spera et al., 2009). However, as reported by Costa et al. (2015), MA values below 0.10 m^3 m^{-3}, as in this study, did not affect maize and soybean productivity either. Thus, for tropical soils with irrigated crops, this threshold of 0.10 m^3 m^{-3} may not be the real limiting value for agricultural production. The succession maize – soybean improved soil MA, regardless of the use of forage – maize intercrops (Mendonça et al., 2013; Costa et al., 2015), which is the crop rotation system indicated for NTS in the *Cerrado* region to improve this soil physical property.

Consequently, the better MA indicates the importance of forages for soil aggregation, structure and permeability, and can favor root development and allow a greater exploration of the soil profile by roots, increasing water infiltration and nutrient absorption, improving crop production (Chioderoli et al., 2012), aside from reducing erosion and, consequently, maintaining the system stability (Costa et al., 2015). Therefore, these results may also

Table 6. Macroporosity (MA), microporosity (MI), total porosity (TP) and soil density (BD) in the 0.0-0.2 m layer, after harvest of maize in monoculture or intercropped with forages sown in different methods and after harvest of subsequent soybean and significance of ANOVA in factorial and contrast tests

	MA	MI	TP	BD
		m^3 m^{-3}		Mg m^{-3}
Forage (F)				
Palisade grass	0.067 a	0.347 a	0.414 a	1.54 a
Congo grass	0.066 a	0.344 a	0.410 a	1.55 a
Guinea grass cv. Tanzânia	0.063 a	0.328 a	0.391 a	1.58 a
Guinea grass cv. Áries	0.069 a	0.348 a	0.417 a	1.54 a
Sowing method (SM)				
Furrow	0.065 a	0.340 a	0.405 a	1.56 a
Broadcast	0.063 a	0.343 a	0.406 a	1.56 a
V4	0.070 a	0.342 a	0.412 a	1.54 a
Season (S)				
After maize	0.061 b	0.351 a	0.412 a	1.57 a
After soybean	0.072 a	0.333 a	0.405 a	1.54 a
After maize monoculture (MM)	0.060	0.328	0.388	1.59
After soybean following MM	0.061	0.330	0.390	1.57
		Anova (p>F)		
Factorial				
F	0.5199	0.8317	0.6991	0.4043
SM	0.1560	0.9917	0.9415	0.7706
S	0.0006	0.2894	0.6567	0.1175
F × SM	0.5397	0.2754	0.1863	0.1567
F × S	0.8674	0.3219	0.2808	0.3568
SM × S	0.5164	0.2580	0.3332	0.5703
F × SM × S	0.1407	0.4497	0.5034	0.3832
Contrast				
After maize monoculture (MM) × intercrops	0.9141	0.5888	0.5697	0.6074
After soybean following MM × intercrops	0.0426	0.9432	0.7343	0.4840

Means followed by different letters differ from each other, by the t test (LSD) at 5 % probability.

explain the higher NPP, W1000 and soybean GY compared to crops following maize monoculture (Table 3). It is also noteworthy that the presence of forage maintained MI, TP, BD, and improved MA after soybean, as shown in comparison with the initial soil analysis.

CONCLUSIONS

The forage sowing methods in the furrow and by broadcasting raised the total amount of residues in autumn maize compared to method V4, especially when sowing Guinea grass cv. Tanzânia in the broadcast method. However, regardless of the forage and sowing method, intercropping increased the amount of residue in relation to maize monoculture.

Forage and sowing methods did not influence nutrient accumulation in the residues at the time of desiccation and the lowest ratio of lignin/total N in Congo grass residues led to a logarithmic decay rate.

Forage and sowing methods did not influence the macronutrient release rate from residues within 120 days after desiccation; the release of N, P, K and Mg was logarithmic and the release of Ca and S was exponential.

Forage and sowing methods in intercropping with maize did not influence the yield components and productivity of subsequent soybean. However, intercropping raised grain yield in subsequent soybean, compared to maize monoculture, apart from preserving the soil chemical and physical properties.

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