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Decomposition and Nutrient Release of Cover Crops in Mango Cultivation in Brazilian Semi-Arid Region

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ABSTRACT: Knowledge of the decomposition dynamics of aboveground phytomass and its release of nutrients in mixtures of cover crops as well as the impact on the soil tillage system is fundamental for the sustainable management of agroecosystems. This work aimed to evaluate whether soil tillage and the choice of cover crops cultivated in the interrows can be technological strategies to increase dry biomass production, increase the capacity to add carbon, and improve macronutrient cycling in a mango (*Mangifera indica* L.) orchard in a semi-arid environment. The field experiment (sixth year) consisted of two soil tillage systems (NT-no tillage and CT-conventional tillage) combined with three plant mixtures (PM1-75 % leguminous + 25 % grasses and oilseed species, PM2-25 % leguminous + 75 % grasses and oilseed species, and SV - spontaneous vegetation). Phytomass production and nutrient accumulation were not affected by the soil tillage system, but PM1 had the highest phytomass production and accumulations of C, N, and K, and it was significantly superior to SV. Regardless of the type of plant mixture, cultivated or spontaneous, soil tillage increased the rates of phytomass decomposition and nutrient release evaluated for 315 days after the cover plant management. The PM1 had the highest rates of decomposition and release of P and K, followed by PM2 and SV. There was no difference between the mixtures for the release of N, Ca, and Mg. The use of a mixture of cover crops, regardless of the predominance of leguminous or non-leguminous species, and a no-tillage system were technological strategies that could be adopted to favor the addition of soil carbon and nutrient cycling in fruit agroecosystems in the Brazilian semi-arid region. Spontaneous vegetation, due to its capacity to accumulate nutrients and the recalcitrant characteristics of its phytomass, has the potential to cycle nutrients and keep the soil covered. In addition, spontaneous vegetation should be better investigated because it is a low-cost strategy in agroecosystem designs.

Keywords: macronutrients, plant mixtures, decomposition rate, *Mangifera indica* L.

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INTRODUCTION

No-tillage and minimum tillage systems are types of soil management that, when associated with the use of cover crops, whether in intercropping or succession with a main crop, have been utilized as conservation practices in several agricultural environments (Conceição et al., 2013; Xavier et al., 2013; Garcia-Franco et al., 2015). Absence of soil tillage or minimal tillage allows carbon (C) to accumulate in the soil due to the reduction in the organic matter decomposition rate (Conceição et al., 2013). Utilization of cover crops without soil tillage is significant because of the maintenance of soil cover, addition of nitrogen, cycling of nutrients, and reduction of soil erosion (Perin et al., 2004; Gomes et al., 2005; Lal et al., 2007; Blanco-Canqui, 2013), as well as the mitigation of greenhouse gases emissions (Bayer et al., 2015), increase in water efficiency and productivity, and increase in biological diversity, among other reasons (Espíndola et al., 2004; Almeida et al., 2016), so they can be parts of sustainable multifunctional agricultural systems.

However, cover crops and no-tillage are not commonly adopted in semi-arid regions due to the difficulty in developing strategies adapted to these environments. In general, the high temperatures intrinsic to the semi-arid climate, when combined with the availability of water and nutrients through fertigation, accelerates the decomposition of organic residues (Giongo et al., 2011; Freitas et al., 2012). The high rate of decomposition of plant residues in the soil can generate asynchrony between the nutrient release and nutritional requirements of fruit crops during their life cycle. In addition, management of cover crops combined with the traffic of machines used in the harvest operations and cultivation practices, has the potential to interfere with phytomass and organic matter decomposition dynamics.

Phytomass decomposition, nutrient cycling, and organic matter stabilization in the soil are complex processes regulated by three variables: the environment, residue quality, and decomposer organisms (Aita and Giacomini, 2003; Moreira and Siqueira, 2006). Temperature and rainfall regime are dominant factors in the phytomass decomposition rate. When these factors, along with edaphic conditions, are ideal, or at least not limiting, phytomass quality and the mutualistic relations between macro- and microorganisms drive the rates of decomposition and nutrient cycling (Lavelle et al., 1993). Soil tillage influences intrinsic decomposition factors, which changes the dynamics of this phenomenon.

Several phytomass quality indices have described as good predictors of decomposition and the release of nutrients. The phytomass of leguminous species, mainly due to the high N content, has a fast decomposition and nutrient release, especially in regions with high temperatures (Gama-Rodrigues et al., 2007), and these qualities may be intensified by soil tillage. On the other hand, the phytomass of grass species has lower N content, which is not adequate for the prompt establishment of the decomposer microbiota, and often leads to the temporary unavailability of nutrients to crops of economic interest (Teixeira et al., 2010). In general, materials that are poor in N and P with high contents of lignins and polyphenols as well as high C/N, C/P, polyphenol/N, lignin/N, lignin/P, and (lignin + polyphenol)/N ratios are assumed to have slower decomposition rates (Palm and Sanchez, 1991; Aita and Giacomini, 2003; Moreira and Siqueira, 2006).

The use of different plant species as cover crops and in no-tillage systems has been used to improve the synchronism between phytomass decomposition and nutrient release as well as the requirements of crops and soil cover maintenance (Aita and Giacomini, 2003; Teixeira et al., 2010). Associations of leguminous and grass species (Teixeira et al., 2010) and leguminous, grass, and oilseed species (Giongo et al., 2011) supply phytomass with intermediate C/N ratios, thus equilibrating decomposition rates, plant material permanence time in the soil, and availability of nutrients.

Few studies provide alternatives for multifunctional fruit agroecosystem designs under semi-arid conditions in terms of a simultaneous use of different cover crop species, soil management, cycling of carbon and nutrients. Therefore, alternate cultivation of a mixture of leguminous, grass, and oilseed species, as well as the use of spontaneous vegetation, without soil tillage, in irrigated perennial crops in a semi-arid region, could be an important alternative for maintaining equilibrium between carbon addition and decomposition rates and for the nutrient cycling in these agroecosystems.

Therefore, this study aimed to evaluate whether soil tillage and the type of plant mixture altered phytomass production, accumulation of nutrients, and decomposition rates, as well as the release of C, N, P, K, Ca, and Mg of cover crops cultivated in the interrows of a mango orchard.

MATERIAL AND METHODS

Field experiment

The study was conducted in a long-term field experiment with mango trees (*Mangifera indica* L., cv. Kent), at Embrapa Semi-Arid (Brazilian Agriculture Research Corporation), in Petrolina, Pernambuco, Brazil (09° 09' S, 40° 22' W, altitude 366 m a.s.l.). The soil of the area was classified as *Argissolo Vermelho Amarelo eutrófico plíntico* (Santos et al., 2018) and Ultisol (Soil Survey Staff, 2014), medium/clay texture, on flat terrain. The climate of the region is BSwh' (Köppen classification system), semi-arid, with mean annual rainfall of 567 mm and mean annual air temperature ranging between 24.2-28.2 °C.

The area, originally under native hyperxerophilic Caatinga vegetation, was converted to an agricultural system in 1972, and cultivated for 16 years with corn (*Zea mays* L.), common beans (*Phaseolus vulgaris* L.), and watermelons (*Citrullus lanatus* L.), under a conventional soil tillage system, followed by date palm (*Phoenix dactylifera* L.) for 20 years. Our experiment started in December 2009.

Treatments consisted of two soil tillage systems [no-tillage (NT) and conventional tillage (CT)], combined with three mixtures of cover crops [75 % leguminous species + 25 % grass and oilseed species (PM1); 25 % leguminous species + 75 % grass and oilseed species (PM2); and spontaneous vegetation (SV)]. The experimental design was a split-plot randomized block design, in four replicates, with soil tillage systems in the plot and mixtures of cover crops in the subplots. Each subplot was composed of three rows, with three mango trees, totaling 27 trees per plot, at 8 × 5 m spacing, with a total area of 360 m^2 and interrow area (where mixtures of cover crops were sown) of 270 m^2 (18 × 15 m). The mixtures of cover crops were grown in 6 m long strips in the interrows, leaving a free border of 1 m on each side of the mango tree rows.

The PM1 and PM2 contained 14 species, which included oilseeds, grasses, and leguminous plants, but at different proportions (Table 1). Spontaneous vegetation was composed mainly of *Desmodium tortuosum* (Sw.) D.C., *Macroptilium lathyroides* (L.) Urb., *Digitaria bicornis* (Lam.) Roem. Schult., *Dactyloctenium aegypitium* (L.) Willd., *Commelina difusa* Burm. f., *Acanthospermum hispidum* DC., *Euphorbia chamaeclada* Ule, *Waltheria rotundifolia* Schrank, *Waltheria sp*. L., *Tridax procumbens* L., *Ipomoea mauritiana* Jacq., *Ipomoea bahiensis* Willd. Ex Roem. Schult., and *Amaranthus deflexus* L.

In the NT system, cover crops were managed using a manual mower, at the full flowering of most of the species, approximately 70 days after sowing. Plants were cut at 5 cm above the soil surface and their aboveground phytomass was deposited on the soil in the mango interrows. In the CT system, the phytomass was incorporated with disc plow to 0.20 m depth, followed by superficial harrowing, with a light open-disc harrow.

Table 1. Proportion of seeds used in the composition of two mixtures of cover crops in mango interrows: PM1 (75 % leguminous species + 25 % grass and oilseed species) and PM2 (25 % leguminous species + 75 % grass and oilseed species)

Cover crops species	PM1	PM2
	kg ha^{-1}	
Oilseed		
Helianthus annuus L.(sunflower)	3.1	9.3
Ricinus communis L (castor oil plant)	30.0	90.0
Sesamum indicum L.(sesame)	1.0	3.0
Grass		
Zea mays L.(Corn)	15.0	45.0
Pennisetum americanum (L.) Leeke (pearl millet)	1.0	3.0
Sorghum vulgare Pers. (sorghum)	2.5	7.5
Leguminous		
Crotalaria spectabilis Roth (rattlebox)	5.2	1.7
Crotalaria juncea L. (rattlepod)	13.5	4.5
Canavalia ensiformis (L.) DC. (jack bean)	187.5	62.5
Calopogonium mucunoide Desv. (calopo)	3.7	1.2
Mucuna pruriens Piper & Tracy. (black velvet bean)	101.2	33.7
Cajanus cajan (L.) Millsp. (pigeon pea)	12.7	4.2
Dolichos lablab L. (lab-lab bean)	60.0	20.0
Mucuna cochinchinensis (Lour.) A.Chev. (grey-seeded velvet bean)	101.2	33.7

Since the beginning of the experiment, the cover crops were cultivated for six cycles: 2009/2010, 2010/2011, 2012, 2013, 2014, and 2015. The present study was carried out in the sixth cycle, and the cover crops in PM1 and PM2 were manually sown on February 23 and 24, 2015, in approximately 0.05 m deep furrows spaced by 0.50 m, totaling 36 cultivation rows per subplot. Some soil chemical properties measured before sowing the cover crops of this cycle are presented in table 2.

Irrigation was performed using a drip system, with emitters spaced at 0.50 m and with a flow rate of 1.6 L h^{-1}, distributed in the interrows. Irrigations were performed based on reference evapotranspiration (ETo), calculated by the Penman-Monteith method, from daily data collected at a weather station installed close to the experimental site. The crop coefficient to determine crop evapotranspiration (ETc) was proposed by Doorenbos and Pruitt (1977). From the sowing to the cutting of cover crops, irrigation was only applied in the interrows. After management of the cover crops, irrigation was completely suspended in order to cause the water stress necessary to paralyze mango vegetative growth, and reestablished in September, after the flowering of 50 % of the orchard.

Evaluations of cover crop aboveground phytomass

To determine the quantity of aboveground phytomass and macronutrients produced by the cover crops, three samples were collected along each subplot in areas of 1 m^2 each. Cover crops were cut close to the soil and weighed to obtain the fresh phytomass. To determine the moisture content, approximately 400 g of these materials were separated and dried in a forced air circulation oven at 65 °C until mass stabilization, which also allowed dry phytomass production to be calculated.

For phytomass chemical characterization, oven-dried samples were ground in a Wiley-type mill and passed through 1-mm mesh sieves. Carbon (C) and nitrogen (N) contents were obtained by dry combustion in an elemental analyzer. Phosphorus (P) was determined using the extract obtained by dry digestion in muffle furnace at 550 °C (Melo and Silva, 2008) and analyzed by molecular absorption spectrophotometry in vanadate yellow. Potassium

Table 2. Soil chemical properties after five years under two tillage systems (no-tillage - NT) and conventional tillage - CT), combined with three mixtures of cover crops in mango interrows (PM1 - 75 % leguminous species + 25 % grass and oilseed species; PM2 - 25 % leguminous species + 75 % grass and oilseed species; and SV - spontaneous vegetation and before sowing of sixth cycle cover crop mixtures, February 2015 in the municipality of Petrolina, Pernambuco State

Treatments	CE	pH(H_2O)	P	K^+	Ca^{2+}	Na^+	Mg^{2+}	Al^{3+}	H+Al	SB	CEC
	dS m^{-1}		mg dm^{-3}				cmol$_c$ dm^{-3}				
						0.00-0.05 m					
NT-PM1	0.36	7.08	48.94	0.40	2.88	0.07	1.23	nd	0.75	4.55	5.30
NT-PM2	0.35	7.10	35.57	0.57	2.88	0.10	1.25	nd	0.65	4.80	5.45
NT-SV	0.50	7.10	37.68	0.44	3.10	0.06	1.25	nd	1.15	4.88	6.03
CT-PM1	0.45	6.78	33.71	0.30	2.70	0.08	1.18	nd	0.80	4.28	5.05
CT-PM2	0.34	6.88	42.52	0.42	2.40	0.08	1.20	nd	0.63	4.10	4.73
CT-SV	0.38	6.75	40.58	0.36	2.23	0.06	1.08	nd	0.73	3.75	4.43
						0.05-0.10 m					
NT-PM1	0.35	6.60	28.72	0.64	1.65	0.06	0.80	nd	1.13	3.15	4.30
NT-PM2	0.29	6.80	33.73	0.48	1.70	0.06	0.78	nd	1.00	3.03	4.00
NT-SV	0.27	6.93	30.87	0.45	1.98	0.06	0.78	nd	1.30	3.25	4.53
CT-PM1	0.36	7.08	42.20	0.49	2.48	0.08	1.15	nd	0.80	4.23	5.00
CT-PM2	0.37	7.13	39.50	0.46	2.00	0.08	1.08	nd	0.93	3.60	4.55
CT-SV	0.33	7.08	40.43	0.37	2.05	0.07	1.08	nd	0.95	3.58	4.53
						0.10-0.20 m					
NT-PM1	0.44	6.05	27.07	0.46	1.20	0.06	0.60	nd	1.88	2.30	4.20
NT-PM2	0.24	6.28	28.76	0.41	1.35	0.05	0.70	nd	1.88	2.53	4.40
NT-SV	0.28	6.53	23.17	0.38	1.33	0.05	0.68	nd	1.45	2.45	3.88
CT-PM1	0.30	6.63	30.31	0.45	1.65	0.07	0.90	nd	1.25	3.05	4.33
CT-PM2	0.31	6.65	27.24	0.37	1.43	0.07	0.68	nd	1.33	2.55	3.88
CT-SV	0.28	6.90	31.96	0.35	1.63	0.06	0.80	nd	0.83	2.83	3.65
						0.20-0.40 m					
NT-PM1	0.30	5.63	27.27	0.36	2.05	0.06	0.83	0.03	2.40	3.30	5.70
NT-PM2	0.33	5.63	21.84	0.34	1.50	0.05	0.80	0.03	2.80	2.68	5.50
NT-SV	0.34	5.88	14.52	0.38	1.55	0.06	0.65	0.01	2.15	2.65	4.80
CT-PM1	0.32	6.00	17.43	0.30	1.45	0.06	0.73	nd	2.08	2.53	4.60
CT-PM2	0.30	6.28	26.95	0.34	1.73	0.06	0.85	nd	1.65	2.95	4.60
CT-SV	0.17	6.28	18.00	0.31	1.53	0.07	0.75	nd	1.80	2.65	4.45

pH in H_2O at a ratio of 1:2.5 v/v. Ca^{2+}, Mg^{2+}, and Al^{3+} extracted with KCl solution (1 mol L^{-1}); P and K extracted with Mehlich-1; H+Al = SMP buffer solution - pH 7.5; CEC at pH 7.0; nd = not detected; SB = sum of bases.

(K), calcium (Ca), and magnesium (Mg) contents were determined after digestion in a nitric-perchloric acid solution (5:1); K contents were determined by flame photometry, while Ca and Mg contents were determined by atomic absorption spectrophotometry (Silva et al., 2009). The accumulation of nutrients in aboveground dry phytomass was calculated by multiplying the respective contents by the phytomass production.

Hemicellulose, cellulose, and lignin contents were also determined. Hemicellulose was determined by the difference between the contents of neutral detergent fiber (NDF) and acid detergent fiber (ADF), obtained by the non-sequential method, according to techniques described by Robertson and Van Soest (1981). Cellulose was destroyed using 72 % sulfuric acid (van Soest, 1994); lignin was obtained by the weight difference, subtracting the ashes produced during the burning in the muffle at 600 °C (Anderson and Ingram, 1993), and cellulose was obtained by the weight difference between ADF and lignin.

Cover crops phytomass decomposition and release of nutrients

For 315 days (from May 28, 2015 to April 7, 2016) after management of the cover crops, at 14 evaluation times (0, 8, 15, 30, 45, 60, 90, 120, 150, 180, 210, 240, 270, and 315 days after management), the decomposition of the aboveground phytomass deposited on the soil surface (NT) or incorporated to the soil (CT) in each mixture of cover crops was evaluated by the litter-bag method. Nylon litter bags (2 mm mesh) with dimensions of 0.30 × 0.30 m were filled with 280 g of aboveground dry phytomass of the plant mixtures, representing approximately the average fresh phytomass (31.73 Mg ha^{-1}) and dry phytomass (7.36 Mg ha^{-1}) of all mixtures. In each subplot, 13 litter bags were randomly distributed (one for each time of evaluation, except the time zero). In NT plots, the litter bags were put in direct contact with the soil surface, whereas in CT plots they were buried at a 0.20-m depth, simulating incorporation.

The litter bags collected at each time of evaluation were manually cleaned to remove adhered soil particles. The remaining phytomass was dried in forced air circulation oven at 65 °C until constant weight, to obtain the remaining dry phytomass (REMP). For the chemical analyses of the remaining phytomass, the oven-dried samples were ground in Wiley-type mill and passed through 1-mm mesh sieves. At each time of evaluation, ash content was determined in the remaining phytomass for a 1 g sample, which was incinerated in a muffle furnace at 550 °C for 4 h. Then, REMP values were corrected by the ash content in order to be expressed free from soil particle contamination (Christensen, 1985). At each time of evaluation, C, N, P, K, Ca, and Mg contents were also determined in the remaining phytomass, following the same analysis methodologies described previously. The percentage of nutrients (REMN) in the remaining dry phytomass was calculated by multiplying the respective contents by the REMP. At six times of evaluation (8, 15, 30, 45, 60, and 315 days after management), hemicellulose, cellulose, and lignin contents were determined in the remaining phytomass, using the same methods described previously, and were used to obtain the Pearson's correlation coefficients with percentages of remaining phytomass and nutrients.

At each time of evaluation, soil samples were collected from each subplot to monitor soil moisture using a gouge auger at 0.00-0.05 and 0.15-0.20 m layers.

Decomposition and nutrient release rates were estimated by fitting nonlinear regression models to the observed values, according to Wieder and Lang (1982). The single-exponential model (Equation 1) is single-compartment, with only one decomposition rate, *k*. The asymptotic model (Equation 2) assumes that only the labile compartment is decomposed at a rate, *ka*, and that the recalcitrant compartment does not change in the evaluated period. In the double-exponential model (Equation 3), the remaining phytomass and nutrients of labile and recalcitrant compartments decreased exponentially at different rates.

Single-exponential: *REMP* or *REMN* (%) = Ae^{-kt} Eq. 1

Asymptotic: *REMP* or *REMN* (%) = $Ae^{-kt} + (100 - A)$ Eq. 2

Double-exponential: *REMP* or *REMN* (%) = $Ae^{-k_a t} + (100 - A)e^{-k_b t}$ Eq. 3

in which, *REMP* (%) is the percentage of remaining dry phytomass, *REMN* (%) is the percentage of nutrient remaining in the phytomass (C, N, P, K, Ca, and Mg), *k* is the decomposition rate, k_a is the decomposition rate of the labile compartment, k_b is the decomposition rate of the recalcitrant compartment, and *t* is the time in days.

The half-life time ($t_{1/2}$) of the remaining phytomass or remaining nutrient quantities, which expresses the time necessary for half of the phytomass to decompose or for half of the nutrients to be released, was calculated according to the equation 4, described by Rezende et al. (1999):

$$t_{1/2} = \ln \frac{2}{k}$$ Eq. 4

During the period of phytomass decomposition and nutrient release evaluations, soil moisture, rainfall, and air temperature were also measured by a weather station close to the experiment (Figure 1).

Statistical analysis

The measured variables were subjected to different analyses of variance. Aboveground dry phytomass production and nutrient accumulation were subjected to analysis of variance by an F test at a 0.05 significance level, and the degrees of freedom (DF) for the experimental factors (soil tillage and plant mixtures) that had significant F values were compared by the Tukey test ($p<0.05$). A second analysis of variance was conducted for the study of decomposition. The DF relative to time was further analyzed by nonlinear regression. The models tested, when significant, were compared by the values of AIC (Akaike's Information Criterion), and the one with lowest AIC was selected. In addition, analyses of simple linear correlations of REMP and REMN with the properties of the remaining phytomass over time were also carried out.

RESULTS AND DISCUSSION

Aboveground phytomass, contents, and accumulation of nutrients

Soil tillage did not influence aboveground phytomass production or nutrient accumulation in the mixtures of cover crops. However, there was a significant difference ($p<0.05$) between the mixtures of cover crops for aboveground phytomass production (Table 3). Only PM1, the mixture with a predominance of leguminous species, had a higher phytomass production (8.18 Mg ha^{-1}) than SV (6.52 Mg ha^{-1}). Phytomass production in

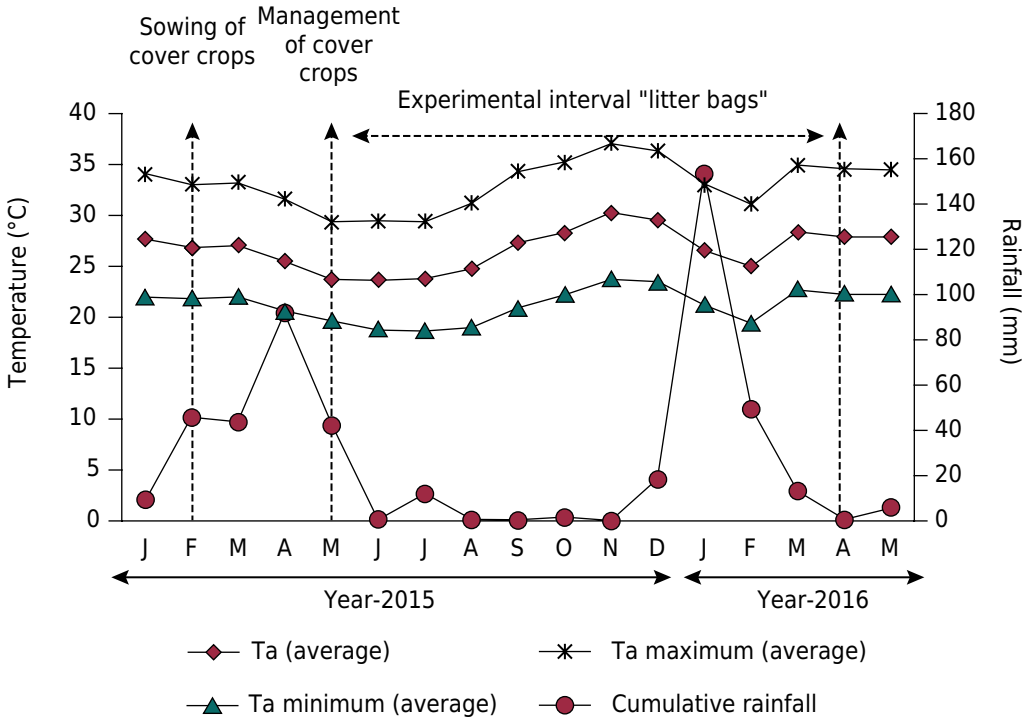

Figure 1. Monthly average air temperature (minimum, mean, and maximum) and cumulative rainfall during the growth period and after management of the cover crops (February 2015 to April 2016). Data of the Agrometeorological Station of Embrapa Semi-Arid Agriculture, Petrolina, Pernambuco, Brazil.

PM2 (7.83 Mg ha^{-1}) was similar to that of the other plant mixtures evaluated. In PM1, the greater proportion of leguminous species probably increased phytomass production compared to the spontaneous vegetation, due to their potential for phytomass production and N fixation (Xavier et al., 2013). Possibly, the greater proportion of grasses in PM2, with high photosynthetic capacities and the production of C-rich phytomass (Taiz and Zeiger, 2013), as well as of oilseed species, which are efficient at nutrient cycling (N and P) (Giacomini et al., 2003), contributed to the lack of significant difference between this mixture and both PM1 and SV.

Soil tillage had no influence on most of the chemical properties evaluated, and only C, P, and Ca content as well as the C/P ratio varied among plant mixtures (Table 4). The mixtures PM1 and PM2 resulted in the highest C contents, and were significantly different from SV. The mixture PM2 had the highest mean P content (3.50 g kg^{-1}), significantly different from the PM1 and MP3 mixtures, and consequently having the lowest mean C/P ratio (132.18). The SV had the highest mean Ca content (15.75 g kg^{-1}), which was approximately 44 % higher than those of the other mixtures were (Table 4).

In regard to the chemical composition of the plant mixtures, cellulose was the most abundant compound in all of them, followed by lignin and hemicellulose (Table 4), but there was no significant difference for any of these properties between the plant mixtures.

Both the mixtures of cultivated cover crops and the spontaneous vegetation had the following order of nutrient accumulations: C> K> N > Ca> Mg> P. Carbon and N accumulations showed the same trend for dry phytomass (Table 3). The presence of oilseed species in PM2 possibly favored N accumulation, and it did not differ from PM1. Giacomini et al. (2003), when testing the contribution of oilseed species to the N cycling

Table 3. Means and means squared of the aboveground phytomass production and accumulation of macronutrients of different mixtures of cover crops cultivated in interrows of a mango agroecosystem in the municipality of Petrolina, Pernambuco State

Mixtures of cover crops	Dry phytomass	C	N	P	K	Ca	Mg
	Mg ha^{-1}					kg ha^{-1}	
PM1	8.18a	3761.20a	157.00a	24.94ab	219.64a	89.32a	42.28a
PM2	7.83ab	3580.46ab	122.96ab	27.31a	220.30a	86.07a	42.16a
SV	6.52b	2916.84b	100.94b	19.94b	175.74b	103.18a	36.85a
Soil tillage systems							
NT	7.55a	3433.94a	128.48a	23.31a	206.70a	89.79a	39.82a
CT	7.47a	3405.06a	125.45a	24.81a	203.75a	95.92a	41.04a
Source of variance			Means Squared				
Block	3.01^{ns}	679401^{ns}	1683.56^{ns}	31.36^{ns}	1236.00^{ns}	373.83^{ns}	139.05^{ns}
Soil tillage (A)	0.03^{ns}	5005.38^{ns}	55.39^{ns}	13.53^{ns}	52.25^{ns}	225.08^{ns}	8.91^{ns}
Error (A)	1.57	331967	2117.54	23.58	982.44	172.11	65.82
Mixtures of cover crops (B)	6.12*	1581323.00*	63.82*	113.07*	5217.64**	660.26^{ns}	77.04^{ns}
AxB	2.15 ns	441769^{ns}	285.91^{ns}	8.56^{ns}	480.35^{ns}	316.68^{ns}	89.93^{ns}
Error (B)	1.29	292085	1273.92	16.82	712.76	550.56	36.03
CV 1 (%)	16.68	16.85	36.24	20.18	15.27	14.13	20.07
CV 2 (%)	15.12	15.8	28.11	17.04	13.01	25.27	14.85

Carbon and nitrogen determined by dry combustion in an elemental analyzer. Phosphorus determined by spectrophotometry in vanadate yellow in extract obtained by dry digestion in muffle furnace at 550 °C (Melo and Silva, 2008). Potassium, calcium, and magnesium were determined after digestion in a nitric-perchloric acid solution (5:1); K contents were determined by flame photometry; Ca and Mg contents were determined by atomic absorption spectrophotometry (Silva et al., 2009). NT = no-tillage; CT = conventional tillage; PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; SV = spontaneous vegetation; CV = coefficient of variation; ^{ns} = not significant; * = significant by test F ($p<0.05$); ** = significant by test F ($p<0.01$). Means followed by the same letters within each column, between the mixtures of cover crops and between soil tillage systems, have no statistical difference by Tukey test ($p<0.05$) and by the F test ($p<0.05$), respectively.

of cover plant mixtures, observed that the mixtures of oats + oilseed radish and oats + common vetch accumulated similar amounts of N, and did not differ from the single crops of common vetch and oilseed radish; however, the authors pointed out that the treatments were superior to the single crop of oats.

Phosphorus accumulation in PM2 (27.31 kg ha^{-1}) was higher than that of SV (19.94 kg ha^{-1}), and did not differ from that of PM1 (24.92 kg ha^{-1}) (Table 3). Plant species vary inter- and intraspecifically in their capacity to absorb and accumulate nutrients. In general, grasses, due to their extensive root systems, are highly efficient at P cycling (Rao et al., 1995). By contrast, leguminous (Franchini et al., 2004) and oilseed species (Wang et al., 2008) can be efficient at transporting P from subsurface layers, contributing to the cycling of this element.

The PM1 and PM2 plant mixtures were more efficient in extracting and cycling K from the soil than SV in the mango production system (Table 3), indicating that the cultivation of cover crops is an important strategy to mitigate losses of this element through leaching and erosion. For Ca and Mg accumulation, no differences were observed between the plant mixtures and SV, highlighting the importance of the spontaneous vegetation for nutrient cycling strategies in managed agroecosystems.

Phytomass decomposition and nutrient release

Residue decomposition kinetics was influenced by soil tillage ($p<0.01$), the mixture of cover crops ($p<0.01$), time ($p<0.01$), and by the interaction of soil tillage and time ($p<0.01$). However, since there was single effect of the mixtures, the decomposition models were fitted for each mixture of cover crops, considering each system of soil tillage.

Table 4. Means and mean squared of the chemical properties aboveground phytomass of different mixtures of cover crops cultivated in interrows of a mango agroecosystem in Petrolina, Pernambuco State

Cover crops	C	N	P	K	Ca	Mg	Lig	Hemi	Cel	C/N	C/P	N/lig	(Lig+Celu)/N	Lig/P
	g kg^{-1}													
PM1	459.91a	19.34a	3.04b	26.96a	10.92b	5.14a	118.37a	77.88a	298.79a	25.01a	153.12a	6.38a	22.51a	39.59a
PM2	457.04a	15.58a	3.50a	28.47a	11.10b	5.43a	108.19a	70.93a	298.82a	30.18a	132.18b	7.11a	26.84a	31.36a
SV	445.95b	15.38a	3.10b	27.35a	15.75a	5.65a	122.21a	50.06a	339.33a	31.64a	145.71ab	8.30a	33.11a	39.60a
Soil tillage systems														
NT	454.18a	16.73a	3.09a	27.60a	12.16a	5.29a	126.59a	77.21a	388.76a	29.72a	147.77a	7.95a	33.71a	41.01a
CT	454.42a	16.81a	3.33a	27.59a	13.02a	5.53a	105.92a	55.37a	235.87b	28.16a	139.58a	6.57a	21.26b	32.68a
Source of variance	Mean Squared													
Block	82.34^{ns}	13.39^{ns}	0.34^{ns}	7.19^{ns}	1.34^{ns}	0.61^{ns}	339.88^{ns}	113.78^{ns}	2901.32^{ns}	79.35^{ns}	778.93^{ns}	2.03^{ns}	81.01^{ns}	69.17^{ns}
Soil tillage (A)	0.33^{ns}	0.04^{ns}	0.35^{ns}	0.00^{ns}	4.39^{ns}	0.33^{ns}	2561.371^{ns}	2859.90^{ns}	140245.00*	14.74^{ns}	402.60^{ns}	11.36^{ns}	929.25*	416.23^{ns}
Error (A)	15.05	20.40	0.15	3.82	3.12	0.59	391.29	586.22	5336.42	50.62	289.63	1.75	54.02	88.21
Mixtures of cover crops (B)	434.89**	39.95^{ns}	0.49**	4.93^{ns}	59.99**	0.52^{ns}	420.01^{ns}	1677.12^{ns}	4378.64^{ns}	97.22^{ns}	901.62*	7.52^{ns}	227.00^{ns}	180.84^{ns}
A×B	0.98^{ns}	13.77^{ns}	0.14^{ns}	30.51^{ns}	1.67^{ns}	0.22^{ns}	316.56^{ns}	474.17^{ns}	3341.70^{ns}	60.21^{ns}	244.19^{ns}	2.65^{ns}	42.51^{ns}	5.22^{ns}
Error (B)	49.11	17.54	0.05	9.79	3.71	0.26	537.47	1118.25	1686.95	66.93	161.54	2.78	73.73	48.22
CV 1 (%)	0.85	26.94	12.06	7.08	14.03	14.20	17.01	36.52	23.39	24.58	11.85	18.22	26.75	25.49
CV 2 (%)	1.54	24.98	6.97	11.34	15.30	9.43	19.93	50.44	13.15	28.27	8.85	22.96	31.25	18.84

Carbon and N determined by dry combustion in an elemental analyzer; P determined by spectrophotometry in vanadate yellow in extract obtained by dry digestion in muffle furnace at 550 °C (Melo and Silva, 2008); K, Ca, and Mg were determined after digestion in a nitric-perchloric acid solution (5:1); hemicellulose was determined by the difference between the contents of neutral detergent fiber (NDF) and acid detergent fiber (ADF), obtained by the non-sequential method (Robertson and Van Soest, 1981); cellulose was destroyed using 72 % sulfuric acid (van Soest, 1994); lignin was obtained by the weight difference, subtracting the ashes produced during the burning in the muffle at 600 °C (Anderson and Ingram, 1993), and cellulose was obtained by the weight difference between ADF and lignin. NT = no-tillage; CT = conventional tillage; PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; SV = spontaneous vegetation; CV = coefficient of variation; ^{ns} = not significant; * = significant by test F ($p<0.05$); ** = significant by test F ($p<0.01$). Means followed by the same letters within each column, between the mixtures of cover crops and between soil tillage systems, have no statistical difference by Tukey test ($p<0.05$) and by the F test ($p<0.05$), respectively.

The no-tillage (NT) type of soil management led to lower rates of decomposition of the cover crop mixtures compared to the soil tillage (CT) management (Figure 2). In NT, for all mixtures, the single-exponential model had the higher capacity to predict the percentage of remaining phytomass (Figure 2a), with decomposition rates of 0.00304, 0.00268, and 0.00222 per day as well as half-life times of 228, 258, and 312 days for PM1, PM2, and SV, respectively. However, in the CT management, only the remaining dry matter of SV fitted to the single-exponential model, with decomposition rate of 0.0045 per day and a half-life time of 154 days. However, PM1 and PM2 data fitted to the double-exponential model, so the easily decomposable compartment of these mixtures, which represented 61 and 58 % of their total dry matter, respectively, had a decomposition rate of 0.148 per day and half-life time of only 4 days (Figure 2b). By contrast, without soil tillage the half-life times estimated for PM1 and PM2 were 228 and 258 days, respectively (Figure 2a).

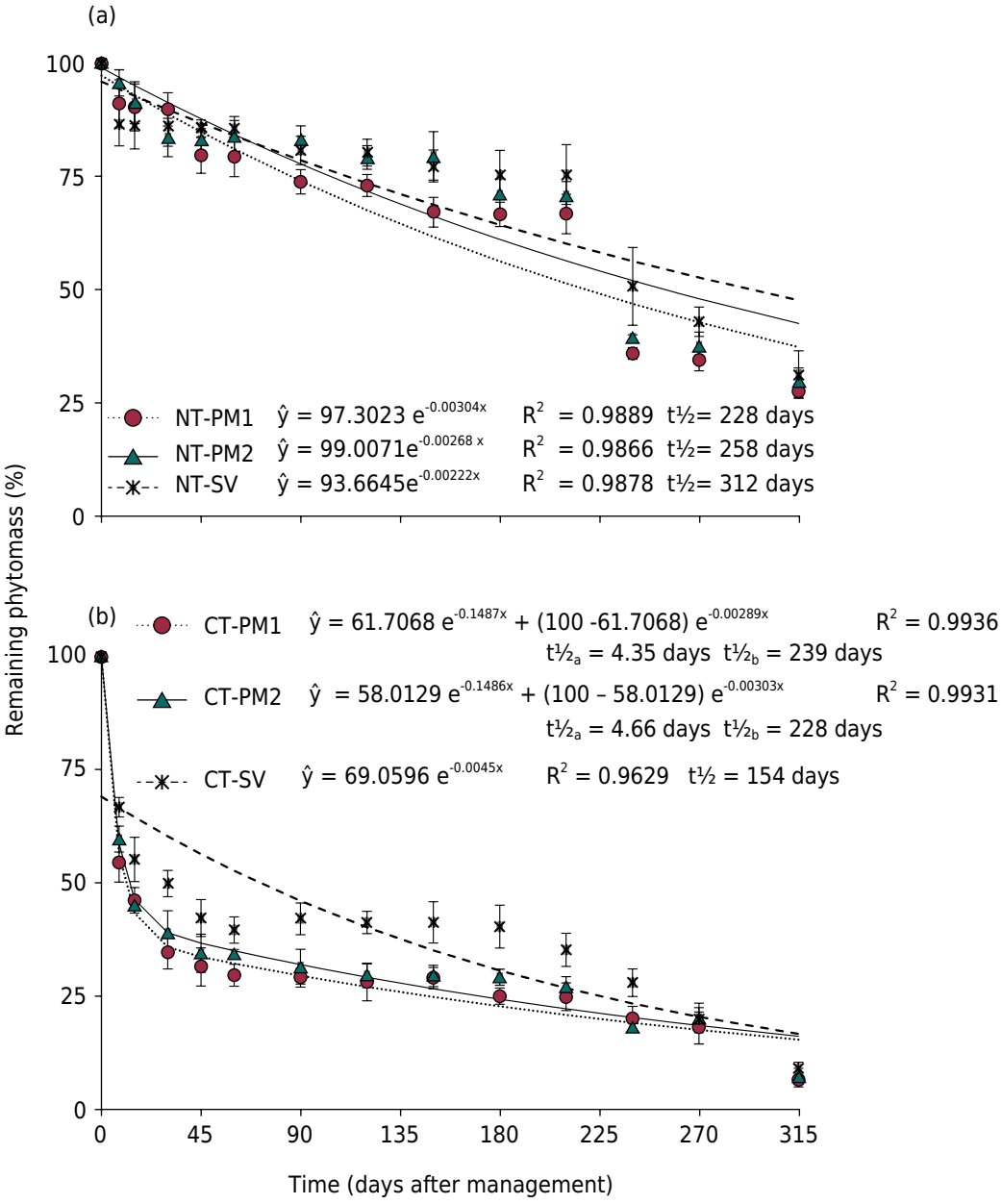

Figure 2. Remaining aboveground phytomass after management of three mixtures of cover crops in mango interrows in Petrolina, Pernambuco State, Brazil. PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; and SV = spontaneous vegetation combined with two soil tillage systems (NT = no tillage (a); CT = conventional tillage (b); t ½ = half-life time; $t½_a$ = half-life time of labile compartment; and $t½_b$ = half-life time of recalcitrant compartment. Bars represent the standard error of the mean.

Soil tillage usually exposes organic residues to oxidizing conditions (temperature, humidity, and aeration), accelerating microbial activity, and thus elevating the decomposition rate (Thönnissen et al., 2000; Gómez-Muñoz et al., 2014). Zibilske and Materon (2005) observed that, under semi-arid conditions, incorporation to 0.10 m depth reduced the remaining phytomass percentage in the soil, from 75 to 45 % after one year, compared to its deposition on the surface. Gómez-Muñoz et al. (2014) also observed that *Vicia sativa* aboveground phytomass, incorporated to a 0.05-0.10 m layer in the interrows of an olive orchard in southern Spain, had a higher decomposition rate than the phytomass left on the soil surface.

Thus, the higher decomposition rates for all mixtures of cover crops with soil tillage in mango interrows corroborates the immediate impacts of plant residue incorporation on the decomposition rate, release of nutrients, and C losses to the atmosphere.

In all types of plant mixtures, higher mass losses were observed in the initial phase, mainly in the first 45 days, followed by a slower one for the rest of the study period. In the CT system, where conditions were more favorable to decomposition, the losses of easily decomposable compounds occurred immediately after phytomass incorporation to the soil (Figure 2b).

Faster mass loss in the first days is a typical trend attributed to the loss of easily decomposable components, such as soluble carbohydrates or nutrients (Sall et al., 2003; Moreira and Siqueira, 2006), which could be associated with photo oxidation processes, microbial attack, activity fragmentation by macro and mesofauna, etc., as well as minor rainfall events during this period (Figure 1). The period of slower mass loss is probably associated with the proportional increase in the content of more recalcitrant compounds, such as lignin and polyphenols, which tend to reduce the decomposition rate (Moreira and Siqueira, 2006). Additionally, lower water contents in the soil from 45-200 days after cutting and managing the plant mixtures (Figure 3), due to the suspension of irrigation water for the management of mango flowering were associated with the dry period in the region (Figure 1), and also contributed to reducing the decomposition rates.

The VE had a lower decomposition rate compared to PM1 and PM2 under both types of soil management, and had a higher percentage of remaining phytomass at the end of the evaluation period.

Lower mass loss in PM1 over time, compared to SV, could be compensated for by the greater amount of phytomass produced (8.18 compared to 6.52 Mg ha^{-1} of SV, Table 3). Thus, at 315 days after phytomass management, when the soil tillage was adopted, the remaining dry phytomass estimated by the fitted models was 16.17 % for PM1 and 16.73 % for SV (Figure 2b), which corresponded to about 1.32 and 1.10 Mg ha^{-1}, respectively. In the management with no tillage, the estimated remaining phytomass was 37.35 % for PM1, 42.56 % for PM2, and 47.69 % for SV (Figure 2a), which corresponded in absolute terms to 3.05, 3.33, and 3.11 Mg ha^{-1}, respectively.

Carbon decomposition kinetics was similar to that of dry phytomass, since C represented more than 40 % of the aboveground phytomass production of each mixture. Because of that, it was decided not to present its release curves.

Nitrogen, Ca, and Mg release rates did not vary among the types of plant mixtures, but varied with soil tillage ($p<0.01$). The variability of remaining N during the experimental interval may have contributed to the lack of differences between the plant mixtures. Nitrogen is frequently immobilized by the microbial biomass, depending on the quantity and quality of oxidizable C available (Moreira and Siqueira, 2006; Xu et al., 2017). Therefore, a possible variation between the processes of mineralization and immobilization may be associated with this result.

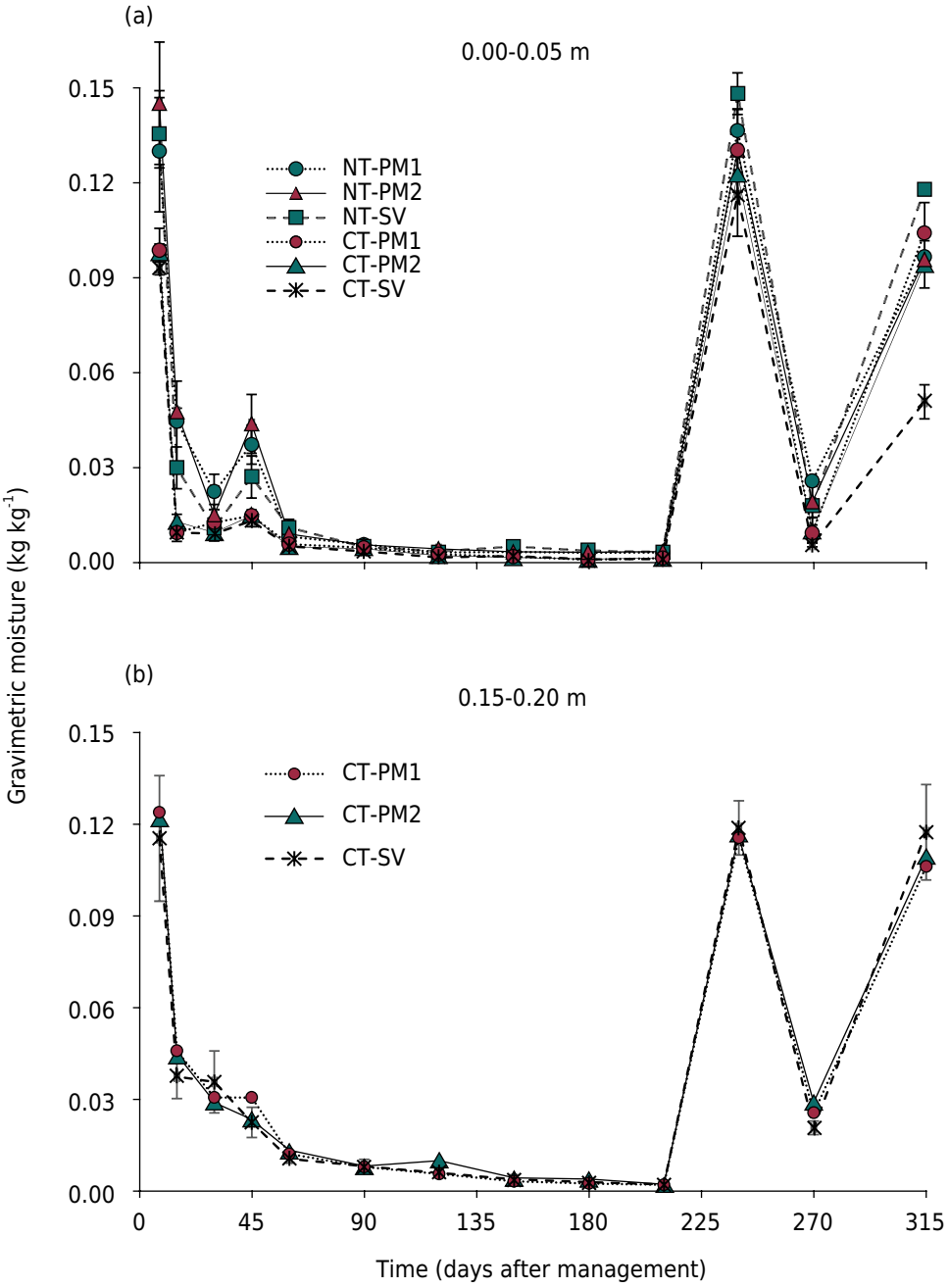

Figure 3. Gravimetric moisture in the 0.00-0.05 and 0.15-0.20 m layers of a *Argissolo Vermelho Amarelo* (Ultisol) under two soil tillage systems (NT = no tillage; CT = conventional tillage) and after management of three mixtures of cover crops in mango interrows (PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; and SV = spontaneous vegetation). Bars represent the standard error of the mean.

In relation to the treatment without soil tillage, the single-exponential and asymptotic models had the highest capacities for predicting N (Figure 4) and Ca release kinetics (Figure 5), respectively. From the fitted models, the estimated release rates of these nutrients were 0.00220 and 0.00216 per day, with half-life times of 315 and 320 days for N and Ca, respectively. However, when phytomass was incorporated to the soil in the treatment with soil tillage, the double-exponential model in two fractions (easily decomposable and recalcitrant) had the highest prediction capacity for both nutrients. Soil tillage increases the release rates of N (Figure 4) and Ca (Figure 5), so that in the easily decomposable compartment 45.98 % of N and 40.03 % of Ca were released at rates of 0.2853 and 0.4738 per day, with half-life estimated at only 2.42 and 1.46 day,

respectively. In contrast, in the recalcitrant compartment, the release rates of N and Ca were 0.00220 and 0.00249 per day with half-life of 315 and 278 days, respectively, and these values were lower than that of the easily decomposable component and similar to those obtained by the fitted models for the treatment without soil tillage.

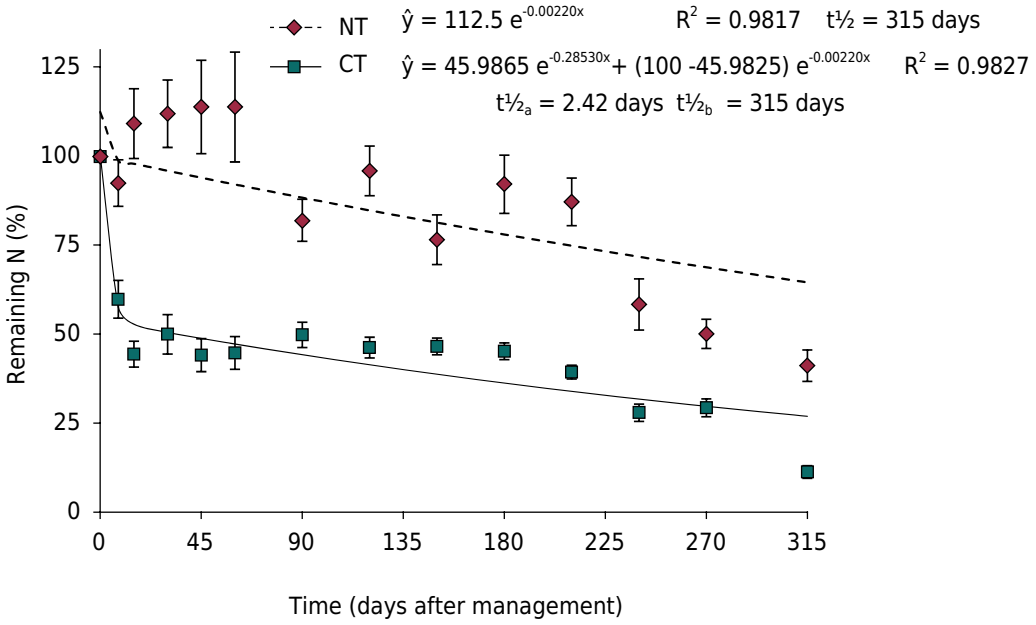

Figure 4. Means of remaining nitrogen of aboveground phytomass after management of three mixtures of cover crops in mango interrows in Petrolina, Pernambuco, Brazil (PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; and SV = spontaneous vegetation) under two soil tillage systems (NT = no tillage; CT = conventional tillage); t ½ = half-life time; $t½_a$ = half-life time of more easily decomposable compartment; $t ½_b$ = half-life time of recalcitrant compartment. Bars represent the standard error of the mean.

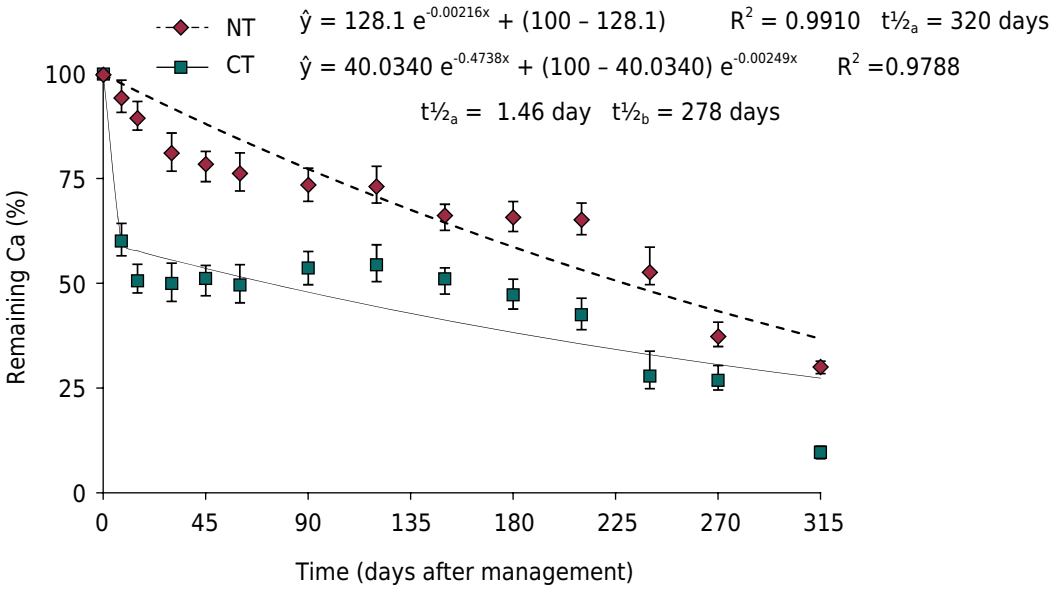

Figure 5. Means of remaining calcium of aboveground phytomass after management of three mixtures of cover crops in mango interrows in Petrolina, Pernambuco, Brazil (PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; and SV = spontaneous vegetation) under two soil tillage systems (NT = no tillage; CT = conventional tillage); t ½ = half-life time; $t½_a$ = half-life time of more easily decomposable compartment; $t ½_b$ = half-life time of recalcitrant compartment. Bars represent the standard error of the mean.

Nitrogen, Ca, and Mg release kinetics did not vary among the plant mixtures ($p>0.01$), being represented by only one model for each type of soil tillage. However, since there was greater N accumulation in PM1 (157.00 kg ha^{-1}) compared to SV (100.94 kg ha^{-1}) (Table 3), at the end of the evaluation period, and considering the models fitted for each soil tillage (Figure 4), it can be inferred that PM1 released 55.51 and 114.59 kg ha^{-1} of N, whereas SV released 35.70 and 73.68 kg ha^{-1} of N, in the treatments with and without soil tillage, respectively. These results highlight the importance of including leguminous species in mixtures of cover crops cultivated for the addition and cycling of N in the interrows of perennial fruit crops.

Magnesium release, described by the single-exponential and asymptotic models in the treatments with and without soil tillage, respectively, had a fast initial phase (Figure 6). Fast release of Mg from the phytomass to the soil occurs because this element is present in the plant in ionic compounds or soluble molecules (Taiz and Zeiger, 2013). Approximately 25 % of this nutrient present in the plant is found in the form of chlorophyll, 5-10 % is bound to pectates on cell walls or precipitated as soluble salts in the vacuoles, and 60-90 % is found in water-soluble forms (Vitti et al., 2006). Magnesium release rates were 0.00574 and 0.07930 per day and the half-life times were 120 and 9 days in the treatments with and without soil tillage, respectively (Figure 6). The treatments with and without soil tillage, at the end of the evaluations (315 days), released approximately the same amount of Mg, 30 kg ha^{-1} or 80 % of the Mg contained in the phytomass (Table 3).

Phosphorous and K release was influenced by soil tillage ($p<0.01$), the mixture of cover crops ($p<0.01$), and time ($p<0.01$), as well as by the interactions between soil tillage and time ($p<0.01$) and between the mixture of cover crops and time ($p<0.01$). Besides these interactions, K varied with the soil tillage while interacting with the mixture of cover crops ($p<0.05$).

In the treatment without soil tillage, P release from the cover crop mixtures fitted to the single-exponential model, in which PM1 had the highest nutrient release rate (0.00356 per day), followed by PM2 (0.00329 per day), and SV (0.00241 per day), with half-life times of 194, 211, and 287 days, respectively (Figure 7a). For the treatment with soil tillage, P release data of PM1 and PM2 fitted to the asymptotic model. Phosphorous

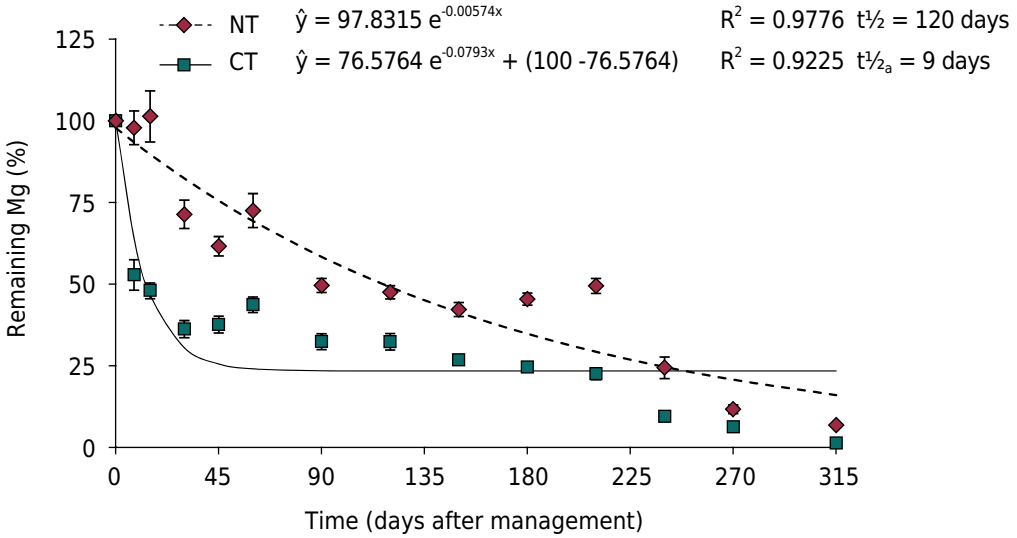

Figure 6. Means of remaining magnesium of aboveground phytomass after management of three mixtures of cover crops in mango interrows in Petrolina, Pernambuco, Brazil (PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; and SV = spontaneous vegetation) under two soil tillage systems (NT = no tillage; CT = conventional tillage); t ½ = half-life time, $t½_a$ = half-life time of more easily decomposable compartment. Bars represent the standard error of the mean.

associated with the easily decomposable compartment was released at rates of 0.22570 per day in PM1 and 0.12830 per day in PM2, with half-life times of 3 and 5 days for PM1 and PM2, respectively. For SV, P release fitted to the single-exponential model with a rate of 0.00339 per day and a half-life time of 204 days (Figure 7b).

During the evaluation period, in the treatment without soil tillage, the K release rate was constant (single-exponential model) and with values of 0.00583, 0.00488, and 0.00473 per day for PM1, PM2, and SV, respectively (Figure 8a). In the treatment with soil tillage, PM1 and PM2 showed similar release rates (0.09900 and 0.09110 per day, respectively), which were higher than that of SV (0.01700 per day) (Figure 8b). The highest release rates estimated to the mixtures of cultivated cover crops, independent of the soil management, contributed to the lowest half-life times of K.

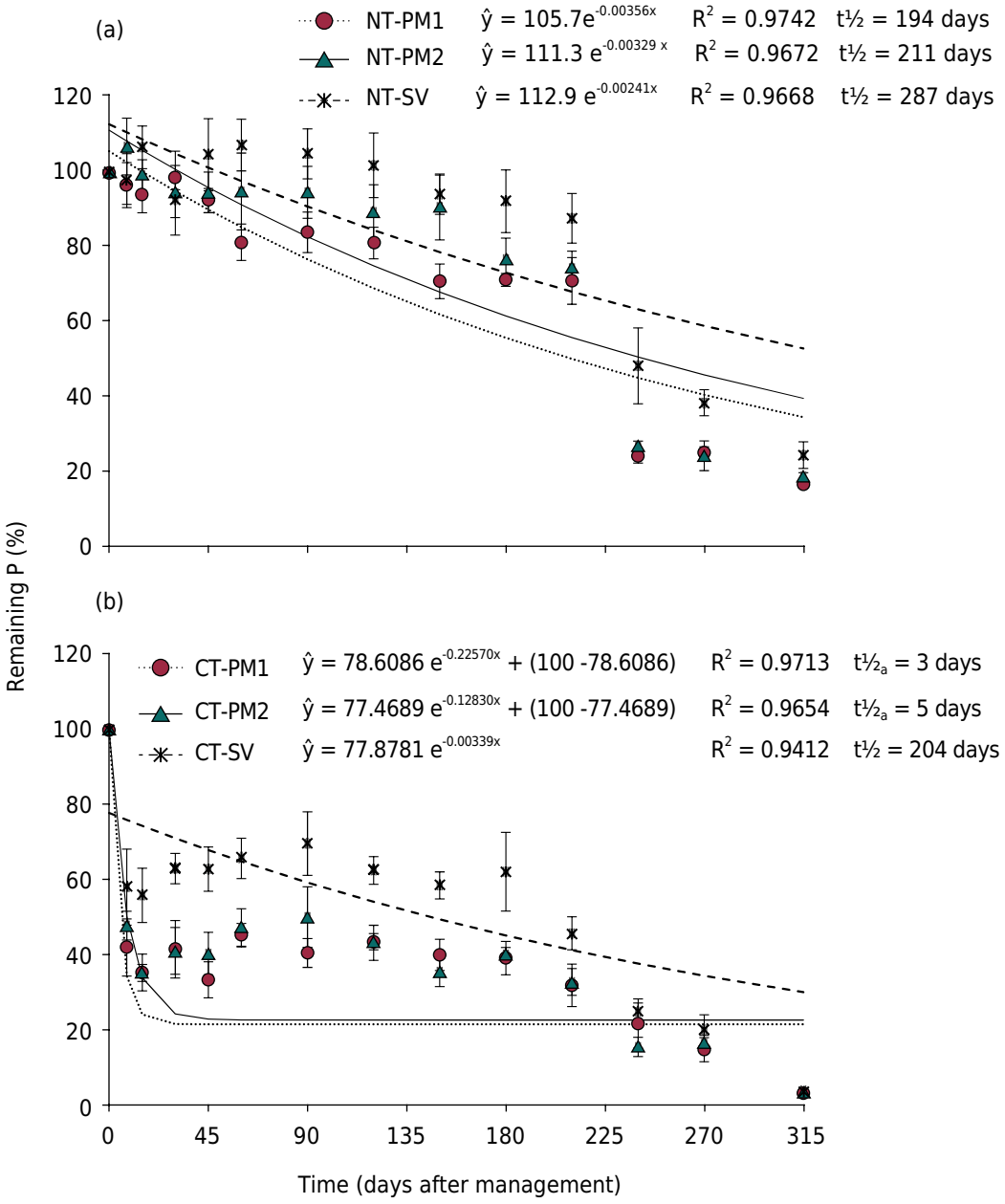

Figure 7. Remaining phosphorus of aboveground phytomass after management of three mixtures of cover crops in mango interrows in Petrolina, Pernambuco, Brazil (PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; and SV = spontaneous vegetation) under two soil tillage systems (NT = no tillage (a); CT = conventional tillage (b); t½ = half-life time; $t½_a$ = half-life time of more easily decomposable compartment. Bars represent the standard error of the mean.

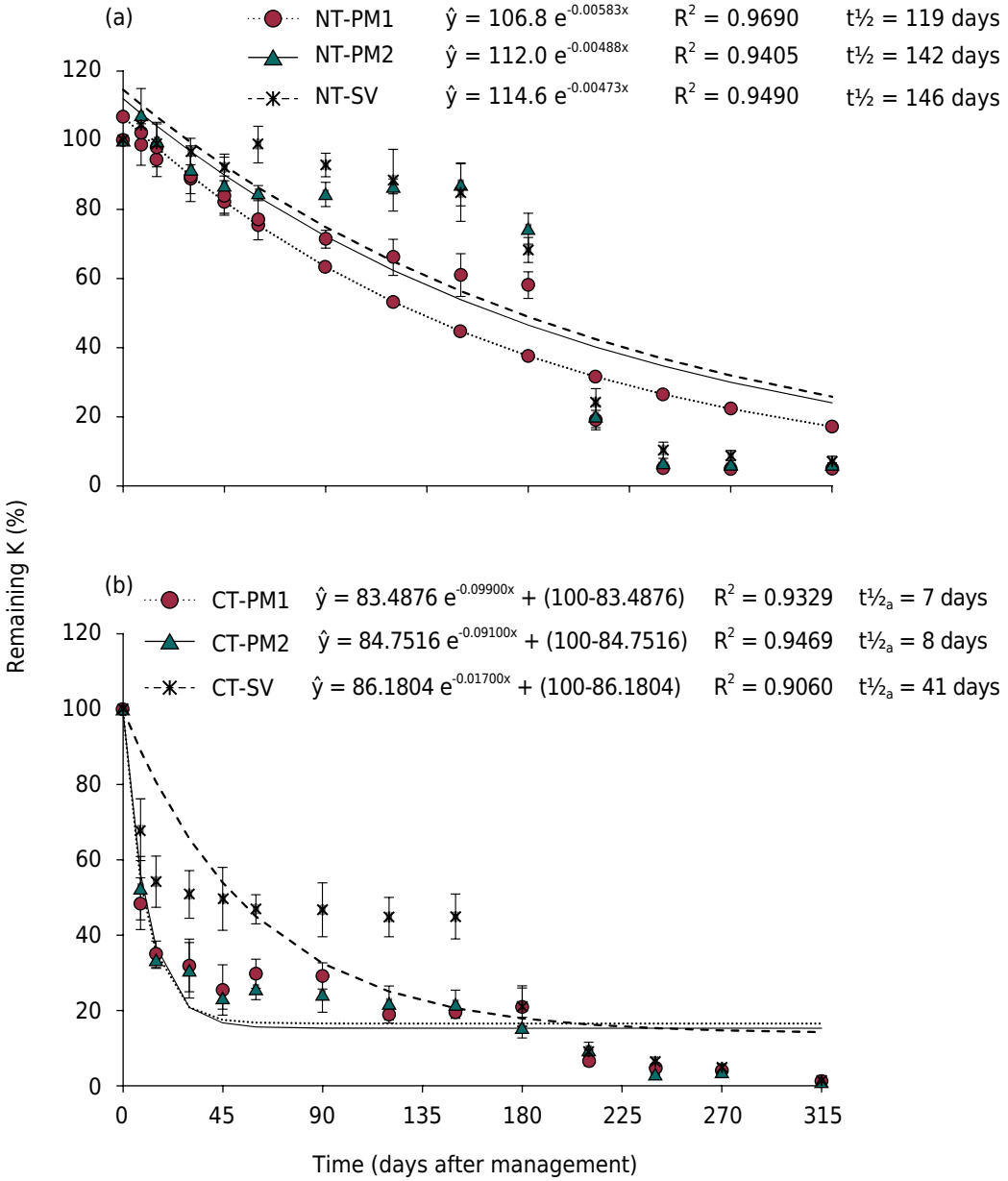

Figure 8. Remaining potassium of aboveground phytomass after management of three mixtures of cover crops in mango interrows in Petrolina, Pernambuco, Brazil. (PM1 = 75 % leguminous species + 25 % grass and oilseed species; PM2 = 25 % leguminous species + 75 % grass and oilseed species; and SV = spontaneous vegetation) under two soil tillage systems (NT = no tillage (a); CT = conventional tillage (b); t½ = half-life time; $t½_a$ = half-life time of more easily decomposable compartment. Bars represent the standard error of the mean.

There were differences in K release between both types of soil management and among mixtures of cover crops. The values of K remaining in the phytomass estimated by the equations, at the end of the evaluation period, were 17 % in PM1, 24 % in PM2, and 25 % in SV (Figure 8a) in the treatment without soil tillage, and 16 % in PM1, 15 % in PM2, and 14 % in SV in the treatment with soil tillage (Figure 8b). Thus, virtually all the K contained in the phytomass of the plant mixtures (Table 3) was supplied to the soil after 315 days of evaluation. Leite et al. (2010), evaluating K release in cover crops, observed that there were differences between treatments for the remaining values at almost all times of collection, except at the last one (100 days), when the treatments did not differ.

Studies evaluating phytomass decomposition describe a fast release of K in the initial phase of the process (Aita and Giacomini, 2003; Gama-Rodrigues et al., 2007; Leite, 2010; Teixeira et al., 2010; Gómez-Muñoz et al., 2014; Xavier et al., 2017). The fast

loss of K could be related to the fact that this element does not integrate into "stable" organic structures (Marschner, 1995; Gama-Rodrigues et al., 2007; Taiz and Zeiger, 2013; Gómez-Muñoz et al., 2014). One of the main mechanisms driving K release is leaching, so mineralization is not a pre-requisite for its transfer to the soil (Gama-Rodrigues et al., 2007). Nonetheless, in the present study the lower release of K from residues left on soil surface could be associated only with the effect of its content in the remaining mass, where the amount of water was possibly not sufficient for its leaching.

The correlation analysis (Table 5) of remaining phytomass (REMP) and remaining percentage of nutrients (REMN), with some properties of the residues of the mixtures, demonstrated that REMP and REMN were inversely proportional to N, Ca, and lignin contents as well as Lignin/N and Lignin/P ratios. Additionally, they were directly proportional to the C, K, Mg, hemicellulose, and cellulose contents as well as the C/N ratio. Phosphorous was positively correlated only with the remaining percentages of P, K, Ca, and Mg. The remaining percentages of these nutrients were also inversely proportional to the C/P ratio.

These results indicate that, with the reduction of N and Ca in the phytomass of the residues, and with the increase in C, cellulose and hemicellulose contents, and the C/N ratio, there was a reduction in the rates of decomposition and nutrient release. Low availability of N and an increase of C in recalcitrant forms, as well as an increase in the C/N ratio, have been commonly cited as properties for the prediction of decomposition and nutrient release (Giacomini et al., 2003; Gama-Rodrigues et al., 2007). Cellulose represents an important source of C to decomposer microbial communities, constituting about one third of the total plant biomass (Somerville, 2006). However, this biopolymer may exhibit higher recalcitrance than other organic compounds, due to its internal composition of glucose subunits linked by β-1,4 glycosidic bonds, resulting in structures of long fibrils (Perez et al., 2002). Thus, its interconnection with lignin, forming the complex called "lignocellulose", may contribute to the reduction of decomposition when at high contents.

The phytomass quality of cover crops is considered to be the most important controlling factor of decomposition at local scales, and the variations in decomposition rates between different types of cover has been commonly related to the initial contents (and proportions) of nutrients (Vaieretti et al., 2005). Inverse relationships between lignin

Table 5. Pearson correlation coefficients between percentage of phytomass and remaining nutrients, with some properties of the remaining dry phytomass over the time of decomposition

Property	Remaining percentage					
	Remaining phytomass	N	P	K	Ca	Mg
C	0.56**	0.49**	0.61**	0.53**	0.53**	0.50**
N	-0.42**	-0.08^{ns}	-0.34**	-0.38**	-0.24**	-0.29^{ns}
P	0.00^{ns}	0.09^{ns}	0.30**	0.11*	0.20*	0.10^{ns}
K	0.65**	0.52**	0.74**	0.85**	0.67**	0.69**
Ca	-0.51**	-0.41**	-0.33**	-0.36**	-0.14**	-0.29**
Mg	0.27**	0.22**	0.37**	0.38**	0.49**	0.60**
Lig	-0.75**	-0.58**	-0.61**	-0.68**	-0.61**	-0.61**
Hem	0.17^{ns}	0.28**	0.21**	0.18*	0.09^{ns}	0.05^{ns}
Cel	0.52**	0.45**	0.54**	0.53**	0.41**	0.35**
C/N	0.56**	0.27**	0.53**	0.51**	0.38**	0.42**
C/P	-0.04^{ns}	-0.11^{ns}	-0.28**	-0.13*	-0.20*	-0.12*
lig/N	-0.50**	-0.57**	-0.42**	-0.45**	-0.43**	-0.43**
lig/P	-0.63**	-0.53**	-0.69**	-0.62**	-0.65**	-0.59**

^{ns} = not significant; * and ** = $p<0.05$ and $p<0.01$, respectively; Lig = lignin; Cel = cellulose; Hem = hemicellulose.

contents, lignin/N ratios, lignin/P ratios, and the percentages of remaining mass and most nutrients indicate the progressive increase of recalcitrant materials. Thus, when the percentages of remaining phytomass and nutrients are lower, the lignin content, lignin/N, and lignin/P ratios are higher.

CONCLUSIONS

Soil tillage had no influence on phytomass production or the accumulation of nutrients with the different plant mixtures.

Soil tillage increased the phytomass decomposition rates of the mixtures of cover crops, drastically reducing the half-life time of the easily decomposable compartment.

Regardless of the type of soil management, the rates of decomposition and release of P and K showed the following order: PM1 (greater proportion of leguminous species) > PM2 (greater proportion of grass and oilseed species) > spontaneous vegetation (SV).

A mixture of cover crops with a predominance of leguminous species (PM1) can be a viable option, compared to spontaneous vegetation, when the main strategy of the agroecosystem is higher nitrogen addition.

In multifunctional agroecosystems in the semi-arid region, in order to increase the half-life time, soil cover time, and promote the gradual release of nutrients, it is fundamental that phytomass not be incorporated.

The use of mixtures of cover crops, regardless of the composition, associated with a no-tillage system, is a technological strategy that can be adopted to favor carbon accumulation in the soil and cycling of nutrients in fruit agroecosystems in the Brazilian semi-arid region.

Spontaneous vegetation has potential for nutrient cycling due to the accumulation of nutrients and the recalcitrant properties of its phytomass. Therefore, it should be better investigated because it could be a low-cost strategy in sustainable, multifunctional agroecosystem designs.

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