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Green manure contributing for nutrients cycling in irrigated environments of the Brazilian semi-arid

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ABSTRACT

The green manure, through the simultaneous sowing of different species, can be a strategy to mitigate the environmental impact due to the use of fertilizers in irrigated environments in the Brazilian semi-arid. This study aimed to evaluate the dry matter production and the nutrients concentration and accumulation by phytomass of two types of plant mixture and natural vegetation cultivated between lines of a mango orchard, in two soil systems management, during five production cycles. The experiment was conducted in a complete randomized block design with four replications and treatments arranged in subdivided plots scheme. The plots consisted of two soil management systems (tillage and no-tillage), and the subplots consisted of 3 types of green manures: plant mixture 1 (PM1); plant mixture 2 (PM2) and spontaneous vegetation (SV). The dry matter, contents, and accumulation of N, P, K, Ca, Mg and S were evaluated. Plant mixture, independent of their composition, produced higher amounts of dry phytomass compared with natural vegetation and, consequently, accumulated higher amounts of nutrients. The N and P contents were lower in the phytomass of the spontaneous vegetation and the plant mixture with a predominance of grasses and oilseeds, respectively, in the tillage systems. The Ca contents were higher in the plant mixture with a predominance of grasses and oilseeds (PM2), and Mg in the plant mixture with a predominance of legumes (PM1) and the spontaneous vegetation (SV).

Keywords: Plant mixture, soil management, agricultural sustainability.

Introduction

Monocultures characterize the irrigated agricultural areas of the Brazilian semi-arid, high use of agricultural inputs and intensive use of the farm machine, causing soil degradation by erosion, salinization, and contamination by heavy metals and pesticides (Silva et al., 2012). Green manure allows the input of large amounts of biomass. Therefore it can be one of the alternatives to mitigate the impact of monocultures due to increasing the organic matter (D'Haene et al., 2009) and the nitrogen content (Salinas-Garcia et al., 2002) and nutrients cycling.

Simultaneous cultivation of different green manures species, called plant mixture, is an alternative to taking benefits promoted by different species (Summers et al., 2014). Legumes and grasses are the species most used in plant mixture, while few studies include oilseeds. The inclusion of different species is also necessary for the maintenance of biodiversity and effective sustainability of any agricultural activity (Wutke et al., 2014).

In Brazilian semi-arid region, there are reports of green manures phytomass additions ranging from 1.7 to 11 $Mg.ha^{-1}$ (Massad et al., 2013), related to the species, soil fertility, climatic conditions, C/N and lignin/total N, among others (Pariz et al., 2011; Teixeira et al., 2011). However, the minimum quantities of biomass were not defined for the positive balance of addition and accumulation dry matter, carbon and nitrogen in the soil, to increase the soil or agroecosystems quality.

The phytomass management of green manures, involving or not the residues incorporation into the soil, is another factor that influences the dynamics of the cycling and releasing of carbon and nutrients. According to Peche Filho et al. (2014), the maintenance of residues on the surface allows maximum protection to the soil and provides a lower decomposition rate in comparing to the incorporation, reducing the loss processes of the chemical elements in agroecosystems.

This study aimed to evaluate the dry matter production and accumulation of nutrients of the aerial phytomass of two types of plant mixtures and the spontaneous vegetation kept between the lines of a mango orchard, under two systems of soil management.

Material e Methods

The study was carried out in a long-term field experiment at the Bebedouro Experimental Farm of Embrapa Semiarid, located in the municipality of Petrolina, Pernambuco State, at the geographical coordinates 09°09'S, 40°22'W, and altitude 365.5 m. Data were collected from February 2009 to June 2014.

According to the classification proposed by Köppen, the climate of the region is BSwh, with the rainy period between January and April. The native vegetation is classified as hyper xerophilic caatinga. The means of precipitation, potential evapotranspiration reference, minimum and maximum temperature, during the five years of experiment, are presented in Figure 1.

The local soil is classified as Ultisol dystrophic plinthic, loamy/clayey plain relief (Table 1). The experiment was conducted in a subdivided plots scheme. Two soil management systems treatments as main plots had dimensions of 45 × 24 m. Conventional tillage plot (T) comprised of plowing and disking compared to no-tillage plot (NT). Three cropping systems were used to treat each sub-plot of 15 × 14 m: two different compositions of plant mixture and a spontaneous vegetation. Each treatment was performed on nine mango plants grown in the space of 5 × 8 m.

The plant mixture composition used with T and NT treatments were: PM1 = 75% legumes + 25% grasses and oilseeds; PM2 = 25% legumes + 75% grasses and oilseeds and SV - spontaneous vegetation. Fourteen species were included in the plant mixture composition, comprised of legumes, oilseeds and grasses, including the following species: Legumes - calopo (*Calopogonium mucunoide* Desv.), velvet bean (*Stizolobium aterrimum* L.), grey-seeded mucuna (*Stizolobium cinereum* Piper & Tracy), crotalaria (*Crotalaria juncea* L.), rattlebox (*Crotalaria spectabilis* Roth), jack beans (*Canavalia ensiformis* (L.) DC), lab-lab bean (*Dolichos lablab* L.); grasses: sesame (*Sesamum indicum* L.), corn (*Zea mays* L.), pearl millet (*Pennisetum americanum* (L.) Leeke) and milo (*Sorghum vulgare* Pers.); oilseed: pigeon pea (*Cajanus cajan* L.), sunflower (*Helianthus annuus* L.), castor oil plant (*Ricinus communis* L.). The predominant species composed the spontaneous vegetation: Benghal dayflower (*Commelina benghalensis* L.), purple bush-bean (*Macroptilium atropurpureum* (DC) Urban), Florida beggarweed (*Desmodium tortuosum* (Sw.) DC) and goat's head (*Acanthospermun hispidum* DC).

Plant mixtures were sown once a year for five consecutive cycles: December/2009; September/2010; April/2012; March/2013 and March/2014. The first line is located 100 cm from the base of the stem of the mango tree, totaling 13 lines of plant mixture between lines of a mango tree. To guarantee the uniformity of germination of the seeds, initially, the larger seeds were sown at 4 cm depth, and later, the smaller ones at 2 cm depth (Table 2).

A micro sprinkler irrigation system was installed, in total area, in the lines of mango trees, and drip irrigation for water supplementation in plant mixture, in the absence of rain. The irrigation depth was calculated using the average precipitation of the last 30 years, using the difference between the expected precipitation and the one that occurred. The mango tree irrigation management was carried out by monitoring soil water potential and water demand at the different stages of the crop using tensiometers installed at 10 cm from the base of the plant stem at depths of 20, 40, 60, 80 and 100 cm.

After 70 days of sowing the aerial phytomass production was evaluated and, in each subplot, it was carried out in three quadrants of 1 m^2 and then the soil management was carried out according to the treatments.

The dry phytomass was determined by weighing, after drying in a forced circulation greenhouse (65-70°C) until constant weight. Then, the samples were ground in a Willey-type mill (1 mm mesh) and submitted to digestion (nitric-perchloric) for determination of phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg) and sulfur (S) contents. The P was determined by colorimetry, S by turbidimetry, K by flame photometry, Ca and Mg by atomic absorption spectrophotometry (Donagema et al., 2011). The N content was determined by dry combustion using LECO elemental analyzer, TruSpec CHN-900. The nutrient concentration was multiplied by the dry matter production, with the data expressed in $kg.ha^{-1}$ to determine the number of nutrients accumulated in the aerial part of the plant mixture and the VE.

The results were submitted to analysis of variance, and the means were compared by the Tukey's test ($p < 0.05$) using SAS software (version 9.2).

Results

Dry phytomass productivity, K and S contents, and N, P, K, Mg and S accumulations were the variables that did not show a significant interaction between the soil management and green manures factors (Table 3). However, there is significant interaction for N, P, Ca and Mg contents and Ca accumulation (Table 4).

Considering the average of five years of cultivation, the plant mixtures (PM1 and PM2), regardless of their composition, produced a higher amount of phytomass in comparing to the spontaneous vegetation (SV). The maintenance of the SV, between lines of the mango tree orchard, allows the accumulation of 4.09 $Mg.ha^{-1}$ of phytomass, while PM1 and PM2 produced twice as high as SV (Table 3).There is a tendency to increase the phytomass productivity in all green manures throughout crop cycles (Figure 2).

The proportion of leguminous, grassy and oilseed species did not influence the amount of phytomass produced between PM1 and PM2. However, at all cycles, plant mixtures produced higher amounts of phytomass than spontaneous vegetation (Table 2).

No significant statistical differences were observed for N content as a function of the type of green manure evaluated (PM1, PM2, and SV) (Table 4). However, the accumulation of this nutrient in the phytomass was different among them (Table 3). Plant mixtures accumulated about three times more N than the SV, reaching 300 $kg.ha^{-1}$.

The N accumulation was superior in PM1, composed of a higher proportion of leguminous species, followed by PM2, with a predominance of grass and oilseed species, and at least spontaneous vegetation (Table 3). Considering that their contents are very similar, the quantity of phytomass produced by each green manure and natural vegetation was the determinant factor for the accumulation of this nutrient.

The soil tillage reduced the N content of SV but did not change in plant mixtures (PM1 and PM2) (Table 4). This result, considering the complexity of the biogeochemical cycle of N in the soil-plant system, and it can be attributed to the balance of this element, also considering the process of immobilization by the microbiota.

There was a significant interaction between green manures and soil management factors for P content (Table 4). The PM1 presents lowest P content, independent of the management system. However, the soil tillage reduces the P content in the PM2 phytomass, the plant mixture with a predominance of grasses (PM2). Nevertheless, PM2 presented the highest P content among green manures, in both soil management systems (Table 4). Considering the accumulation of this element, the plant mixtures (PM1 and PM2), regardless of their composition, accumulated higher amounts of P than the SV (Table 3), extracting 28.81; 30.32 and 15.15 $kg.ha^{-1}$, respectively.

The SV had higher K content when compared to PM1, not differing from PM2 (Table 3). However, PM1 and PM2 accumulated highest amounts of K when compared to the SV (Table 3).

The phytomass Ca content did not differ among green manures and spontaneous vegetation in a no-tillage system. However, PM2 and SV show the highest Ca levels with soil tillage, due to the presence of a higher proportion of grasses (Table 4).

In the no-tillage system, PM1 and PM2, regardless of their composition higher accumulation of Ca, (Table 4). On the other hand, in tillage system, the PM2 presented the highest Ca accumulation, followed by PM1 and SV (Table 4).

PM1 had the lowest Mg content, while SV had the highest values when there was no incorporation of the phytomass (NT). In the soil tillage (T), the Mg content is higher in the SV than in the plant mixtures, and PM1 and PM2 did not differ from each other. Green manures cultivated in soil tillage system presented higher Mg content when compared to those had grown in a no-tillage system.

The phytomass S contents were 3.21, 3.72 and 2.55 $g.kg^{-1}$ for PM1, PM2, and SV, respectively. Plant mixtures also present higher accumulation of Mg and S in comparing to SV (Table 3).

The N, P, K, Ca, Mg and S contents of the plant mixtures and the spontaneous vegetation of the five consecutive crop cycles are presented in Figures 3 and 4. The N contents were higher in the third and the fifth cycle. However, it has been observed that the increasing accumulation of this element in the plant mixtures throughout the cycles. About P, the highest levels were observed in the fourth cycle, in all plant mixtures and spontaneous vegetation, also reflecting the accumulated amount. On the other hand, the highest levels of K were observed in the first four cycles and the lowest levels in the fifth cycle. However, the accumulation of this element was higher in the plant mixtures compared to the spontaneous vegetation, standing out the fourth, cycle with the highest amounts accumulated in this element. The contents and accumulations of Ca and Mg had the same behavior throughout the five cycles, especially for the third cycle, with the highest levels of these elements for PM1 and PM2. There was no difference in the S contents during the five consecutive cycles of green fertilizer cultivations. However, the second cycle presented the highest contents of this element, however, in all cycles the plant mixtures accumulated more massive amounts of S than the spontaneous vegetation. In this study, species recommended as green manures were cultivated simultaneously, which in turn presented differences in the dynamics of nitrogen and other nutrients, reflecting too on the quality of the plant tissue. Therefore, plant mixtures allow differences in symbiotic capacity, root system depth and nutrient cycling in the same place at same time.

Discussion

The plant mixtures cultivation improves soil quality (Suzuki & Alves, 2006) due to increases the nutrients cycling, the organic matter content of the soil, resulting in increased infiltration, water storage, and aeration, as well as reduced soil mechanical resistance.

The amount of dry phytomass produced by plant mixtures was similar to green manure grown in other regions of the country. Menezes et al. (2009), in the Goiás State, in an experimental field evaluating dry phytomass production in single crops and intercropping, observed that the intercropping millet + crotalaria and millet + pigeon pea and spontaneous vegetation produced 9.18, 6.69 and 4.86 $mg.ha^{-1}$, respectively. Perin et al. (2010), in the Minas Gerais State, observed that crotalaria, millet, crotalaria + millet and spontaneous vegetation produced 9.34, 7.12, 8.04, and 4.49 $mg.ha^{-1}$ of dry phytomass, respectively. Cavalcante et al. (2012), in the Alagoas State, found that the phytomass production of the spontaneous vegetation (7.2 $mg.ha^{-1}$) resembled leguminous arboreal bean pigeon (8.7 $mg.ha^{-1}$), and was superior to *C. juncea* (3.0 $mg.ha^{-1}$), *C. spectabilis* (2.5 $mg.ha^{-1}$), lab-lab (3.2 $mg.ha^{-1}$), pork beans (3.0 $mg.ha^{-1}$), dwarf pigeon beans (4.0 $mg.ha^{-1}$) and black muna (4.2 $mg.ha^{-1}$). According to the researchers, this is because the SV is composed of plants adapted to region edaphoclimatic conditions. According to Perin et al. (2010), the prevailing edaphoclimatic conditions at each site can also influence the phytomass production of the green manure species.

The increase of the phytomass productivity in all green manures throughout the growing cycles is probably due to the improvement of soil quality previously mentioned.

The resemblance between the N contents in the phytomass plant mixtures was probably due to the dilution effect because of the higher vegetative growth. However, it is important to note that plant mixtures have oilseeds in their composition. As these species absorb significant amounts of N, it could be compensated the more significant presence of legumes in PM1 in comparing to PM2. Zobiole et al. (2010), in the establishment of macronutrient accumulation curves, in the sunflower crop in Paraná State, observed that N is the second most accumulated nutrient by oilseed crops, extracting about 150 $kg.ha^{-1}$.

Perin et al. (2004), evaluating the effects of isolated and intercropped *C. juncea* and millet (*P. americanum*) in the phytomass, nutrient content and accumulation, and biological nitrogen fixation (BNF), also observed that the content of this element in the SV was similar to the crotalaria. However, Lima et al. (2012) observed that crotalaria, pigeon pea, and black grouper had higher levels of N in the phytomass than the SV. Duarte Júnior & Coelho (2008) evaluated the green manures effects on the yield of sugarcane in the no-tillage system (SPD), in the Rio de Janeiro State. The authors observed that N content dry phytomass the pork beans (88%), mucunã (80%) and sunflower (44%) higher than the SV. The researchers attributed the lower N content of SV to the predominance of grass and Cyperaceae species. The differences observed in the studies on N levels of SV could be related to different edaphoclimatic conditions of the experimental sites, as well as to the phytosociological composition of the vegetation, as pointed out by Duarte Júnior & Coelho (2008). Cavalcante et al. (2012) also observed that the N content in the legumes was higher than the SV. It should be noted, however, that all cover crops or green manures, including spontaneous ones, have legumes that even in different proportions fix N atmospheric.

It was observed that the amount of N accumulated in SV in the present study was superior to those observed by Duarte Júnior & Coelho (2008) (43 $kg.ha^{-1}$) and Espíndola et al. (2006), in SV with predominance of colony grass

(*Panicum maximum* Jacq.) (36.2 and 47.2 kg.ha^{-1}). The values accumulated by PM1 and PM2 were similar to those observed by Duarte Júnior & Coelho (2008) who evaluated the crotalaria (320 kg.ha^{-1}), pig bean (297 kg.ha^{-1}) and black mucuna (230 kg.ha^{-1}) and higher than those observed by Espíndola et al. (2006) evaluating forage peanut (96.9 and 99.3 kg.ha^{-1}), tropical kudzu (125.8 and 126.1 kg.ha^{-1}), and siratro (65.2 and 90.3 kg.ha^{-1}), intercropped with banana, cultivated in the dry and rainy season, respectively.

Cantarella (2007) states that the mineralization-immobilization processes represent a subcycle within the N cycle in the soil and, therefore, the prevalence of one over the other, defines the availability of inorganic N for plants. According to the same author, the additions of organic materials to the soil, such as green manures, affect the balance between these two processes. However, continuous additions of organic material by green manures, over time, tend to form new balance and constant and stable N release to the plants.

The P contents observed in this study were in the range observed by other researchers in green manure studies. Duarte Júnior & Coelho (2008) observed higher levels of P, varying from 4.8 to 6.2 g.kg^{-1} in legumes and lower (2.3 g, kg^{-1}) in SV. In a study of nutrient extraction by cover plants, Cavalcante et al. (2012) observed levels of P varying from 2.0 to 3.5 g.kg^{-1} in the leguminous species evaluated, being the highest observed in the SV (4.0 g.kg^{-1}).

Similar P amounts were reported by Perin et al. (2010), whose accumulation of P was higher in the crotalaria (32.48 kg.ha^{-1}) than in SV (16.84 kg.ha^{-1}), although it did not differ from the accumulation of millet (28.84 kg.ha^{-1}) or the consortium with them (28.85 kg.ha^{-1}). Duarte Júnior & Coelho (2008) observed that *C. juncea*, pork beans, and black bean accumulated higher amounts of P than SV. However, it should be noted that the amounts of P accumulated by legumes were higher, varying from 49 to 85 kg.ha^{-1}, while SV accumulated around 50% of that observed in the present study. Green manure has an important role in P cycling and, in the present study, the highest accumulated amount of P was more related to the production of dry phytomass than to the content of this element in the phytomass.

Duarte Júnior & Coelho (2008), Fávero et al. (2000), and Perin et al. (2004) observed that some species of SV might present higher levels of K in comparing to the legumes. On the other hand, Perin et al. (2010) observed that even SV (277.70 kg.ha^{-1}), with lower dry phytomass production, accumulated similar amounts of K to the crotalaria (293.28 kg.ha^{-1}), millet (325.06 kg.ha-1), and crotalaria and millet (336,80 kg.ha^{-1}), due to the high content of this element in the phytomass of the SV. According to the same researchers, this type of vegetation can cycle amounts of K similar to the species used as green manures. Santos et al. (2008) emphasized that the contribution of K released by crop residues to the subsequent crop be around 80% for grass species and 90% of legumes species, thus having an important role in the cycling of this nutrient in the system. The incorporation of the plant mixtures and SV into the soil, with the higher proportion of grasses, can provide a greater quantity of K for the subsequent crop.

Duarte Júnior & Coelho (2008) observed that the contents of Ca in the aerial part of the legumes crotalaria, mucuna, and pork bean were 6,9; 9.5; 15.4 g.kg^{-1}, respectively, and higher than spontaneous vegetation (3.4 g.kg^{-1}). The same researchers observed a higher accumulation of Ca in the pork bean (197 kg ha^{-1}), while the crotalaria (123 kg.ha^{-1}) and the mucuna (95 kg.ha^{-1}) did not differ each other. However, these last two species accumulated on average nine times more Ca than the SV. The concentration of Ca in plants depends on the growth condition, of the species and organ evaluated, varying from 1 to 50 g.kg^{-1}. The amount of Ca required for monocotyledonous is lower than for dicotyledons (Hawkesford et al., 2012). Thus, in the present study, to interpret the effect of soil management and the types of plant mixture, it is important to perform an analysis of the contents and amounts of Ca accumulated by each species that compose them.

The need for Mg in the stages of plant growth varies between 1.5-3.5 g.kg^{-1} (Hawkesford et al., 2012). The Mg contents of PM1, PM2, and SV were higher than the values considered ideal for plant growth. Duarte Junior & Coelho (2008) observed that the Mg accumulation was higher in the *C. juncea*, pork bean, black mucuna comparing to spontaneous vegetation (57, 35, 29, and 7 kg.ha^{-1}, respectively).

According to Hawkesford et al. (2012), for a good growth of plants the content of S can vary between 1 to 5 g.kg^{-1} of their dry weight, being possible to occur differences in comparing to the requirement of this element according to the family to which the species belongs. According to the same authors, the requirement is greater for grasses followed by legumes and crucifers. Duarte Juníor & Coelho (2008) reported a higher accumulation of S in the *C. juncea*, pig bean, black mucuna, 69, 53, 41 kg.ha^{-1}, respectively, in relation to the spontaneous vegetation, 6 kg.ha^{-1}.

According to Carvalho et al. (2014), the diversity of N, P, K, Ca, Mg and S contents of the plant mixtures and the spontaneous vegetation of the five consecutive cycles of cultivation shows the importance of simultaneous seeding of more than one species or a mixture of these.

Conclusion

The plant mixtures, independent of their composition, produced larger amounts of dry phytomass in comparing to the spontaneous vegetation and, consequently, accumulated larger amounts of nutrients.

The N and P contents were lower in the phytomass of the spontaneous vegetation and in the plant mixture with predominance of grasses and oilseeds, respectively, when using the practice of incorporation of the vegetal residues.

The Ca contents were higher in the phytomass of the plant mixtures with predominance of grasses and oilseeds (PM2); and of Mg in the mixture with predominance of legumes (PM1) and in the spontaneous vegetation (SV).

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