



Nitrogen in Soil in Response to Cover Plants and Irrigation Levels in Semi-Arid

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Research article

Volume 4 Issue 3

Received Date: March 09, 2020

Published Date: April 06, 2020

DOI: 10.23880/jenr-16000195

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Abstract

The use of different species of cover plants and irrigation levels can affect the availability of nitrogen (N) and forms of N in the soil. In this study, total N and its inorganic forms in the soil were evaluated in the experiment with banana cultivation associated with cover plants and irrigation levels. The experiment was conducted in the state of Ceará in the Brazilian semiarid region with the design of randomized blocks and split plot with four replications. In the plots were evaluated four irrigation levels (50, 75, 100 and 125% of evapotranspiration of banana plants), were evaluated in the subplots four cover plants (*Pueraria phaseoloides* Benth, *Calopogonium muconoides* Desv., spontaneous vegetation and residue of banana plants) and sub-subplots two soil layers (0-5 cm and 5-10 cm) were evaluated. In general, the result of the leguminous *Pueraria phaseoloides* Benth showed a higher content of total N and its inorganic forms throughout the evaluation period in comparison to the other types of coverage. As for the effects of irrigation levels, it was found that the highest levels led to the lowest content of nitrate (N-NO₃-), compared to the levels of ammonium (N-NH₄+). Regarding the depth, was observed higher levels of total N and N-NO₃- in the most superficial layer and higher NH₄+ levels in the subsurface layer of the soil. Thus, the use of *Pueraria phaseoloides* Benth as a cover plant can improve the availability of N for a crop of agronomic interest, mainly in the most superficial layer of soil, with most of this N being in the form of NO₃-.

Keywords: Nutrient Cycling; Soil Protection; Plant Residues; Vegetable Biomass

Introduction

Nitrogen (N) is an essential chemical element for plant growth [1]. The most used soil management technique to increase N content is the mineral fertilization FAO [2] that can increase crop yields as well as crop profitability. However, mineral fertilizers can increase production costs Mahanta, et al. [3] and may represent an environmental risk in soils of tropical regions. Part of the nitrogen fertilizers applied in the soil is lost. The lost N has high pollutant potential and, once carried to ground waters, it may cause contamination of aquifers, rivers and lakes [4].

Markets and social movements claiming for agricultural sustainability have encouraged green manure as an alternative to nitrogen mineral fertilization, aiming the conservation of natural resources, the maintenance of soil quality in the agricultural systems and the reduction of production costs Lechenet, et al. [5].

Nitrogen input by plant material can reduce the use of mineral fertilizers. The N content in vegetal tissue is variable between plant species and leguminous usually have more N due the process of biological fixation of atmospheric N [6,7]. Returning plant residues to the soil is an alternative

and sustainable way of N fertilization and the main crop will benefit from N mineralization [8]. However, in tropical regions it also represents a risk of N losses due to the quick N mineralization that may not match with the period of high nutrient demand by the main crop, causing N losses in agroecosystems.

One alternative to use leguminous as N source is the intercropping between leguminous species and the main crop. This management promotes N availability for the main crop when it has the condition to absorb the mineralized nutrient after cutting leguminous plants [8].

According to Huygens, et al. [9], inorganic N can be found in the soil in two main forms: ammoniacal nitrogen (N-NH_4^+) and nitric nitrogen (N-NO_3^-). Proportions between inorganic N forms are influenced by soil management systems Tian [10] because the inorganic N form available in the soil may indicate aspects related to soil aeration [11].

Among the factors influencing inorganic N forms proportions there is the irrigation. Once its inadequate use may promote temporary flood, limiting N-NO_3^- availability [12]. In soils without oxygen restrictions N-NO_3^- is the predominant N form [13]. Nitrogen as nitrate is predominant in superficial soil layers where nitrification conditions are better [14]. On the other hand as soil depth increases oxygen content is reduced favouring N-NH_4^+ form [14]. In irrigated areas the predominance of N-NO_3^- in the soil solution may favour N losses by leaching and/or runoff. This strengthens the need to adopt adequate irrigation levels to avoid not only water losses, but also N losses.

This study was carried out to prove the following hypotheses: i) the traditional management of banana residues by growers and the presence of cover crop species contribute with N availability to the main crop; ii) irrigation levels decrease N-NO_3^- and increase N-NH_4^+ forms; and iii) the superficial soil layer has higher N amount than the deeper one.

Material and Methods

The study was developed in an experiment with banana trees installed in 2010 and conducted in the Vale do Curu Experimental Farm (Pentecoste, CE – Brazil). According to Köppen's classification system the climate of the region is BSW'h', which is semiarid with irregular rains, average annual rainfall of 797 mm, concentrated between January and April, and maximum and minimum annual temperature averages of 33.4°C and 22.4°C, respectively [15]. The soil of the experimental area was classified as Neossolo Flúvico [16]. The N content in the soil before the installation of the experiment was 0,65 g.kg⁻¹.

The experimental design was in randomized blocks and split-splitplot scheme with four replicates. The treatments evaluated in the plots were four irrigation levels corresponding to 50, 75, 100 and 125% of banana plants evapotranspiration. The plots (12 x 40 m) were constituted by four rows of banana tree cv. Prata Anã, planted in a simple row system with spacing of 3 x 2 m, consisting of 80 plants. In the subplots, four cover plants were evaluated: the leguminous *Pueraria phaseoloides* Benth, the leguminous *Calopogonium muconoides* Desv., spontaneous vegetation composed mainly by grasses *Panicum maximum* Jacq, and banana plant residues (conventional management used in this study as a control), totalizing 64 experimental units. Each plot was divided in four subplots (12 x 10 m) with twenty plants, the six central plants being considered as useful. The N contents (g m⁻²) of cover plants evaluated in this study were 24.2, 12.8, 12.3 and 11.7 for *Pueraria phaseoloides* Benth, *Calopogonium muconoides* Desv, spontaneous vegetation and banana plant residues, respectively. In the sub-subplots two soil layers (0-5 cm and 5-10 cm) were evaluated.

Evaluations related to this study were done from July 2012 after the first harvest of bananas and three cuts of cover plants. After cuts, the vegetal residues from cover plants were placed between the banana rows without incorporation.

Soil sampling was done six times based on the cover plant cuts in the same year of evaluation: 1) before the cut and deposition, 2) seven days after the cut and deposition, 3) 22 days after the cut and deposition, 4) 37 days after the cut and deposition, 5) 56 days after the cut and deposition, 6) 70 days after the cut and deposition. The soil was sampled in two layers (0-5 cm and 5-10 cm), in the banana rows where the plant residues were placed. The soil samples used to determine inorganic N forms were frozen until the chemical analysis.

The total N of the soil was determined using the method described in Teixeira [17]. The method is divided in two stages: sulfur digestion and distillation. In the digestion stage, a digestion mixture composed of Na_2SO_4 , CuSO_4 and H_2SO_4 was used in the soil sample, which was then placed in a digester block at a temperature of 350 °C. The distillation stage was made by in the steam distiller. The product of the distillation was titrated with H_2SO_4 solution until transformation of coloration blue or green for the pink coloration.

Nitrogen as nitrate (N-NO_3^-) and as ammonium (N-NH_4^+) in the soil were determined according to the method described in Teixeira *et al.* (2017). The extraction of these mineral N forms was done using KCl (1 mol L⁻¹) solution. The determination of N-NO_3^- and N-NH_4^+ was done by means of distillation of the solutions containing these forms of

mineral nitrogen. The product of the distillation was titrated with H_2SO_4 until the color change from blue or green to pink coloration.

The variables were statistically analysed using the software ASSISTAT Santos-Silva [18], which allowed the variance analysis by the F test, and then Tukey test was performed to compare means.

Results and Discussion

Total nitrogen

The evaluations to this study were realized after the third

cut of the cover plants. The total N in the soil was altered along the evaluation times which seems to be a consequence of the plant residues placed on the soil. Overall there was an increase in the availability of N along the time for all treatments, therefore, the cover plants proved to be efficient for this. Cover plants increase total nitrogen in soil Ramos [19], mainly through decomposition of plant residues. In time 1, before the deposition the cover plants, total N in soil was remaining of the previous cut and the inputs.

Total N content in response to the interaction between irrigation levels and cover plants is presented in Table 1. In the evaluation times 1, 2, 3 and 6, significant effects of this interaction were observed.

Time	Irrigation Level	Cover Plant				F value
		PP	CM	VS	BR	
		-----g Kg ⁻¹ -----				
1	1	1.31 aA	0.81 aC	1.13 aB	0.74 aC	0.2374*
	2	1.34 aA	0.80 aC	1.08 aB	0.70 aC	
	3	1.33 aA	0.78 aC	1.10 aB	0.69 aC	
	4	1.31 aA	0.74 aC	1.08 aB	0.71 aC	
2	1	2.11 bA	1.16 aB	1.14 aB	1.16 aB	5.1692**
	2	2.36 aA	1.13 aB	1.10 aB	1.01 bB	
	3	2.33 aA	1.10 aB	1.08 aB	0.99bB	
	4	2.31 aA	1.15 aB	1.06 aB	0.91 bC	
3	1	3.19 aA	2.20 aB	2.20 aB	1.91 aC	4.2402**
	2	3.00 abA	2.25 aB	2.29 aB	1.89 aC	
	3	2.88 bA	2.29 aB	2.39 aB	1.99 aC	
	4	2.93 bA	2.13 aB	2.23 aB	1.88 aC	
6	1	4.35 aA	2.35 aC	2.75 aB	2.84 aB	2.6568*
	2	3.99 bA	2.33 aC	2.79 aB	2.76 abB	
	3	3.88 bcA	2.21 abC	2.68 abB	2.65 bcB	
	4	3.76 cA	2.09 bC	2.53 bB	2.50 cB	

Table 1: Mean values of soil total N (g kg⁻¹) in response to the interaction between irrigation levels and cover plants. Time 1, 2, 3 and 6: sampling before cover plants deposition and at 7, 22 and 70 days after deposition, respectively. Irrigation Levels 1, 2, 3 and 4: 50, 75, 100 and 125% of the crop evapotranspiration. PP: Cover plant *Pueraria phaseoloides* Benth., CM: Cover plant *Calopogonium muconoides* Desv., VS: Cover plant with spontaneous vegetation and BR: Banana residues. Means followed by the same letters, lowercase in columns and uppercase in rows, do not differ statistically at 5% of probability, according to F and Tukey tests. *, ** statistically significant, at p level < 0.05 and < 0.01, respectively.

In the subplots with *Pueraria phaseoloides* Benth high mean values of total N were found for all irrigation levels and evaluation times. Many factors influence decomposition rate of plant residues, being their composition the main one. Depending on the interaction between climatic factors, macro and microbiological activities of the soil, quality and

quantity of plant residue, a decomposition and availability of nutrients can be fast and intense or slow and gradual [20].

The spontaneous vegetation in the experimental area was composed mainly of grasses (*Panicum maximum* Jacq.), which have distinct composition when compared with

leguminous, changing its decomposition rate. When grasses are used as cover plants, they provide high production of phytomass with high carbon (C) / nitrogen (N) ratio which decrease their rates of decomposition and release of nutrients [21]. In this study this is evidenced when comparing the total N levels in the subplots under spontaneous vegetation and under the *Pueraria phaseoloides* Benth leguminous. Throughout the experiment was observed that the subplots under spontaneous vegetation had lower levels of total N than the subplots under *Pueraria phaseoloides* Benth (Table 1). This may be a consequence of the higher C/N ratio that results in a slower decomposition of spontaneous vegetation and its composition. Espíndola [22] observed a C/N ratio of 79.3 for spontaneous vegetation also composed of *Panicum maximum* Jacq., and 23.5 for *Pueraria phaseoloides* Benth leguminous. About the composition, the authors observed a higher N content in the *Pueraria phaseoloides* Benth legume in relation to spontaneous vegetation and higher levels of cellulose and hemicellulose in spontaneous vegetation. Leguminous plants have higher amounts of phosphorus, potassium and calcium and lower C/N ratio than grasses, resulting in slower decomposition of grasses in comparison with leguminous [23].

Comparing the levels of total N in the subplots with the legume *Pueraria phaseoloides* Benth and in the subplots with banana plant residues (control) it was observed that the areas under banana plant residues resulted in lower amounts of total N throughout the experiment. Under the

same climate and soil conditions the speed of decomposition of the residues and the release of N are influenced by chemical characteristics especially the N content and C/N ratio [16]. Banana plant residues also have higher C/N ratio in comparison with *Pueraria phaseoloides* Benth residues, showing slow decomposition and nutrient liberation. Additionally to C/N ratio, plant residues decomposition is influenced also by contents of cellulose, hemicellulose, lignin and polyphenol, as well as by the lignin / N, polyphenol / N and lignin + polyphenol / N ratios [24].

The subplots with *Calopogonium muconoides* Desv. showed low levels of total N throughout the experiment when compared with the subplots under *Pueraria phaseoloides* Benth, although both species are leguminous. The low content of total N found in the subplots with the leguminous *Calopogonium muconoides* Desv. can be explained by the small input of biomass by that cover plant, because this leguminous was sensitive to cuts, showing reduced development. The highest total N content of soil found in subplots with *Pueraria phaseoloides* Benth is explained by the fact that this specific leguminous has higher N fixation capacity in its tissue when compared with other leguminous plants [25].

Analyzing the isolated effect of irrigation on total N content, it is possible to verify the influence of irrigation after the deposition of the cover plants residues on the soil (Table 2).

Irrigation Levels	Time					
	T1	T2	T3	T4	T5	T6
	-----g kg ⁻¹ -----					
1	1.0 a	1.4 a	2.4 a	3.9 a	3.7 a	3.1 a
2	1.0 a	1.4 a	2.4 a	3.9 a	3.7 a	3.0 b
3	1.0 a	1.4 a	2.4 a	3.8 b	3.6 b	2.9 c
4	1.0 a	1.4 a	2.3 a	3.8 b	3.5 b	2.7 d
F value	0.5725 ns	0.8835 ns	1.3091 ns	19.3032 **	17.3908 **	65.7599 **
Soil depth	Time					
	T1	T2	T3	T4	T5	T6
	-----g kg ⁻¹ -----					
1	1.3 a	1.7 a	2.8 a	4.3 a	3.9 a	3.2 a
2	0.6 b	1.0 b	1.8 b	3.4 b	3.3 b	2.6 b
F value	2478.0441 **	1090.7216 **	1935.0187 **	2613.1232 **	1876.5957 **	2325.6438 **

Table 2: Mean values of soil total N (g kg⁻¹) at different sampling times in response to irrigation levels and soil depths. Irrigation levels 1, 2, 3 and 4: 50, 75, 100 and 125 % of the crop evapotranspiration. Time 1, 2, 3, 4, 5 and 6: sampling before cover plants deposition and at 7, 22, 37, 56 and 70 days after the deposition, respectively. Soil depths 1 and 2 correspond to samples collected at 0-5 and 5-10 cm, respectively. Means followed by the same letters in columns do not differ statically at 5% of probability, according to F and Tukey tests. ^{ns} non-significant; ** statistically significant, at p level < 0.01.

The irrigation effects were observed 37 days after the deposition of the cover plants. Plots with low irrigation levels showed high contents of total N in the soil, this result corroborates with Reichmann [12], and they observed that soil inorganic N pools were lower with increased water availability compared to drought conditions. The authors still declare that the availability of inorganic N was inversely proportional to precipitation. The increased availability

of water can increase denitrification rates, creating anoxic conditions that stimulate the transformation of NO_3^- into N_2 and N_2O [12]. The highest mean of the total N in the soil were found at depth 1 (0-5 cm). Interaction between cover plants and soil layers was observed in all sampling periods (Table 3). In all situations the leguminous *Pueraria phaseoloides* Benth resulted in high content of total N in the soil.

Time	Cover plants	Soil depths		F value
		1	2	
		-----g kg ⁻¹ -----		
1	PP	1.71 aA	0.93 aB	32.1324 **
	CM	1.06 cA	0.51 cB	
	VS	1.57 bA	0.62 bB	
	BR	1.05 cA	0.37 dB	
2	PP	2.74 aA	1.82 aB	9.6082 **
	CM	1.46 bA	0.81 bB	
	VS	1.43 bcA	0.76 bB	
	BR	1.33 cA	0.71 bB	
3	PP	3.63 aA	2.36 aB	25.6147 **
	CM	2.74 bA	1.69 bB	
	VS	2.78 bA	1.78 bB	
	BR	2.27 cA	1.56 cB	
4	PP	6.29 aA	5.31 aB	35.4575 **
	CM	4.10 bA	3.12 bB	
	VS	3.68 cA	2.80 cB	
	BR	2.97 dA	2.41 dB	
5	PP	5.42 aA	4.69 aB	3.6028 *
	CM	3.23 dA	2.64 dB	
	VS	3.74 bA	3.08 bB	
	BR	3.46 cA	2.82 cB	
6	PP	4.34 aA	3.64 aB	9.8326 **
	CM	2.63 cA	1.86 cB	
	VS	3.00 bA	2.37 bB	
	BR	2.97 bA	2.41 bB	

Table 3: Mean values of soil total N (g kg⁻¹) in response to the interaction between cover plants and soil depths Time 1, 2, 3, 4, 5 and 6: sampling before cover plants deposition and at 7, 22, 37, 56 and 70 days after the deposition, respectively. PP: Cover plant *Pueraria phaseoloides* Benth., CM: Cover plant *Calopogonium muconoides* Desv., VS: Cover plant with spontaneous vegetation and BR: Banana residues. Soil depths 1 and 2 correspond to samples collected at 0-5 and 5-10 cm, respectively. Means followed by the same letters, lowercase in columns and uppercase in rows, do not differ statistically at 5% of probability, according to F and Tukey tests. *, ** statistically significant, at p level < 0.05 and < 0.01, respectively.

The high content of total N in the first soil layer (0-5 cm) is a consequence of cover plants management because plant residues were not incorporated into the soil. Additionally the superficial soil layer has better conditions of temperature, humidity and oxygen for microbial activity and high contents of total N [26].

The highest total N content in the soil presented in the subplots with the leguminous *Pueraria phaseoloides* Benth in the interaction between cover plants and soil layers throughout the entire sampling period and in all situations is a consequence of the higher biomass produced by this species in comparison with the leguminous *Calopogonium muconoides* Desv. and spontaneous vegetation. The biomass

production rate by the *Pueraria phaseoloides* Benth leguminous was 11.1 g m⁻² while for spontaneous vegetation it was 7.7 g m⁻² and *Calopogonium muconoides* Desv. 3.0 g m⁻². As well as result of the higher decomposition rate of *Pueraria phaseoloides* Benth in comparison to the banana plant residues.

Inorganic Nitrogen

Analyzing irrigation levels effects on the inorganic N forms in the soil (Table 4), was observed that high irrigation levels probably changed the nitrification dynamics that was difficulty by the higher level of irrigation, resulting in less accumulation of N-NO₃⁻.

Time	N forms	Irrigation levels				F value
		L1	L2	L3	L4	
		----- mg kg ⁻¹ -----				
T1	NO ₃ ⁻	8.63 a	6.89 ab	5.12 bc	3.90 c	18.2418 **
	NH ₄ ⁺	5.45 d	7.00 c	8.57 b	10.19 a	748.1049 **
T2	NO ₃ ⁻	11.01 a	9.97 ab	7.52 bc	5.91 c	14.7247 **
	NH ₄ ⁺	6.09 d	7.81 c	9.34 b	11.41 a	4407.0449 **
T3	NO ₃ ⁻	16.63 a	15.19 b	13.19 c	11.16 d	671.9400 **
	NH ₄ ⁺	9.98 d	11.90 c	13.95 b	15.85 a	3815.4578 **
T4	NO ₃ ⁻	26.75 a	24.54 b	22.68 c	20.53 d	562.9147 **
	NH ₄ ⁺	17.36 d	19.57 c	21.70 b	23.92 a	7256.9463 **
T5	NO ₃ ⁻	25.38 a	23.15 b	20.87 c	18.68 d	404.6841 **
	NH ₄ ⁺	16.80 d	18.60 c	20.49 b	22.74 a	13829.4583 **
T6	NO ₃ ⁻	23.07 a	20.55 b	18.21 c	15.98 d	1939.2259 **
	NH ₄ ⁺	14.70 d	16.98 c	18.78 b	21.44 a	4627.0752 **

Table 4: Mean contents of N-NO₃⁻ and N-NH₄⁺ (mg kg⁻¹) in soil collected at six evaluation times and subjected to four irrigation levels.

Irrigation levels 1, 2, 3 and 4: 50, 75, 100 and 125 % of the crop evapotranspiration. Time 1, 2, 3, 4, 5 and 6: sampling before cover plants deposition and at 7, 22, 37, 56 and 70 days after the deposition, respectively. Soil depths 1 and 2 correspond to samples collected at 0-5 and 5-10 cm, respectively. Means followed by the same letters in rows do not differ statistically at 5% of probability, according to F and Tukey tests. ** statistically significant, at p level of 1%.

The higher levels of irrigation may have generated an anaerobic condition making the action of nitrifying bacteria responsible for NO₃⁻ production difficult. For Reichmann [12] the increase in water availability promoted by irrigation reduces oxygen availability in the soil, reducing also N-NO₃⁻ whose presence is related to aerobic conditions. Paul [27] said that the water content directly affects the diffusion of different forms of inorganic N. Some studies have shown that

in soils without oxygen restriction the content of N-NO₃⁻ is high, since nitrification is favored under aerobic conditions [12,13].

Evaluating cover plants effects on inorganic N forms in the soil, the leguminous *Pueraria phaseoloides* Benth resulted in high contents of N-NO₃⁻ and N-NH₄⁺ throughout the study (Table 5).

Time	N forms	Cover plant				F value
		PP	CM	VS	BR	
		----- mg kg ⁻¹ -----				
T1	NO ₃ ⁻	8.51 a	4.93 c	6.21 b	4.89 c	153.0359 **
	NH ₄ ⁺	11.77 a	8.21 b	6.24 c	4.99 d	2.5980 *
T2	NO ₃ ⁻	15.08 a	7.23 b	6.57 c	5.54 d	976.1498 **
	NH ₄ ⁺	12.19 a	9.57 b	7.10 c	5.80 d	5761.0082 **
T3	NO ₃ ⁻	22.31 a	13.56 b	11.08 c	9.22 d	1835.4617 **
	NH ₄ ⁺	17.75 a	14.02 b	11.14 c	8.77 d	9827.5204 **
T4	NO ₃ ⁻	36.18 a	24.51 b	18.44 c	15.38 d	3887.0299 **
	NH ₄ ⁺	29.35 a	23.59 b	16.06 c	13.54 d	36713.9638 **
T5	NO ₃ ⁻	30.78 a	14.00 d	25.05 b	18.25 c	1850.5052 **
	NH ₄ ⁺	25.91 a	14.28 d	20.93 b	17.50 c	23709.8494 **
T6	NO ₃ ⁻	26.78 a	11.53 d	21.88 b	17.61 c	807.7282 **
	NH ₄ ⁺	23.47 a	13.27 d	19.28 b	15.88 c	20059.4148 **

Table 5: Mean contents of N-NO₃⁻ and N-NH₄⁺ (g kg⁻¹) at six evaluation times in response to cover plants.

PP: Cover plant *Pueraria phaseoloides* Benth., CM: Cover plant *Calopogonium muconoides* Desv., VS: Spontaneous vegetation, BR: banana residues. T1, T2, T3, T4, T5 and T6: sampling before cover plant deposition and at 7, 22, 37, 56 and 70 days after the deposition, respectively. Means followed by the same letters in columns do not differ statistically at 5% of probability, according to Tukey tests. *, ** statistically significant, at p level < 0.05 and < 0.01, respectively.

The high levels of N-NO₃⁻ and NH₄⁺ in the plots with the leguminous *Pueraria phaseoloides* Benth may be a consequence of the high biomass input promoted by this species, as previously presented. Interaction was found for N-NO₃⁻ between cover plants and soil layers during all evaluation times (Table 6). High content of N-NO₃⁻ was found in the superficial layer, mainly in the treatment with *Pueraria phaseoloides* Benth with decrease in this form as soil depth increases.

The high content of N-NO₃⁻ in the superficial layer mainly in the treatment with *Pueraria phaseoloides* Benth is explained by the better nitrification condition found in the superficial layer, mainly due to high aeration, once it is in contact with the atmospheric air. The high content of N-NO₃⁻ in the superficial layer of soils was found in other studies [28,29].

Time	Cover plants	Soil depths		F values
		1	2	
		-----mg Kg ⁻¹ -----		
1	PP	10.48 aA	6.54 aB	36.0653 **
	CM	5.54 cA	4.33 cB	
	VS	7.08 bA	5.34 bB	
	BR	5.51 cA	4.27 cB	
2	PP	20.86 aA	9.29 aB	322.2213 **
	CM	8.33 bA	6.13 bB	
	VS	8.31 bA	4.82 cB	
	BR	6.42 cA	4.67 cB	

3	PP	28.14 aA	16.48 aB	338.1026 **
	CM	16.03 bA	11.09 bB	
	VS	13.43 cA	8.73 cB	
	BR	11.96 dA	6.48 dB	
4	PP	42.00 aA	30.36 aB	234.9339 **
	CM	26.34 bA	22.67 bB	
	VS	20.79 cA	16.09 cB	
	BR	17.09 dA	13.67 dB	
5	PP	35.66 aA	25.89 aB	111.8785 **
	CM	16.33 dA	11.67 dB	
	VS	28.00 bA	22.09 bB	
	BR	20.53 cA	15.97 cB	
6	PP	28.89 aA	24.66 aB	5.1668 **
	CM	13.19 dA	9.88 dB	
	VS	23.08 bA	20.69 bB	
	BR	19.04 cA	16.19 cB	

Table 6: Levels of $N-NO_3^-$ ($mg\ kg^{-1}$) in response to the interaction between cover plants and soil depths.

Time 1, 2, 3, 4, 5 and 6: sampling before cover plants deposition and at 7, 22, 37, 56 and 70 days after the deposition, respectively. PP: Cover plant *Pueraria phaseoloides* Benth., CM: Cover plant *Calopogonium muconoides* Desv., VS: Cover plant with spontaneous vegetation and BR: Banana residues. Soil depths 1 and 2 correspond to samples collected at 0-5 and 5-10 cm, respectively. Means followed by the same letters, lowercase in columns and uppercase in rows, do not differ statistically at 1% of probability, according to F and Tukey tests. ** statistically significant, at p level < 0.01.

The $N-NH_4^+$ also showed interaction between cover plants and soil layers during all evaluation times (Table 7).

Time	Cover plants	Soil depths		F values
		1	2	
		-----mg Kg ⁻¹ -----		
1	PP	10,13 aB	13,42 aA	9,6943 **
	CM	6,78 bB	9,64 bA	
	VS	5,14 cB	7,34 cA	
	BR	4,17 dB	5,81 dA	
2	PP	10,83 aB	13,55 aA	27,6965 **
	CM	8,44 bB	10,69 bA	
	VS	6,00 cB	8,20 cA	
	BR	4,94 dB	6,66 dA	
3	PP	15,38 aB	20,12 aA	306,2940 **
	CM	12,84 bB	15,20 bA	
	VS	9,25 cB	13,04 cA	
	BR	7,98 dB	9,56 dA	

4	PP	26,92 aB	31,79 aA	213,7998 **
	CM	22,44 bB	24,74 bA	
	VS	14,60 cB	17,52 cA	
	BR	12,44 dB	14,68 dA	
5	PP	24,74 aB	27,08 aA	109,5261 **
	CM	13,04 dB	15,53 dA	
	VS	19,06 bB	22,81 bA	
	BR	16,34 cB	18,65 cA	
6	PP	22,29 aB	24,64 aA	84,6116 **
	CM	11,27 dB	15,28 dA	
	VS	17,51 bB	21,04 bA	
	BR	14,05 cB	17,72 cA	

Table 7: Levels of N- NH_4^+ (mg kg^{-1}) in response to the interaction between cover plants and soil depths. Time 1, 2, 3, 4, 5 and 6: sampling before cover plants deposition and at 7, 22, 37, 56 and 70 days after the deposition, respectively. PP: Cover plant *Pueraria phaseoloides* Benth., CM: Cover plant *Calopogonium muconoides* Desv., VS: Cover plant with spontaneous vegetation and BR: Banana residues. Soil depths 1 and 2 correspond to samples collected at 0-5 and 5-10 cm, respectively. Means followed by the same letters, lowercase in columns and uppercase in rows, do not differ statistically at 1% of probability, according to F and Tukey tests. ** statistically significant, at p level < 0.01.

The highest content of N- NH_4^+ in the deepest layer of the soil mainly in the plots with *Pueraria phaseoloides* Benth it may be explained by the worse nitrification condition of the deep layer in comparison with superficial layer. The high amount of N- NH_4^+ in deeper soil layers was found in other studies [30,14]. However, it is important to highlight that high amount of N- NH_4^+ was found in the superficial soil layer only in association with high irrigation levels that promoted low oxygen availability for nitrification.

In general most of total N in this study is in organic form, probably immobilized in microbial biomass. Soil microorganisms assimilate N to form the organic constituents of their cells and tissues [31]. The immobilization by soil biota is an important component of the N potentially mineralized, once the immobilization is temporary. As microorganisms die, they are mineralized, releasing nutrients and this process will be faster as the amount of N in microbial biomass increases [32].

Based on the findings of the present study verified that the hypothesis formulated were proved thus being accepted for the evaluated environmental condition. From a practical point of view, in a semi-arid climate condition, the use of *Pueraria phaseoloides* Benth leguminous as a cover plant is indicated since it can provide higher levels of inorganic N for the crop of economic interest and is also more resistant to cuts ensuring good biomass production [33].

Conclusion

The use of *Pueraria phaseoloides* Benth as a cover plant can improve nitrogen availability for the main crop because this species promoted high input of easily decomposed biomass. High irrigation levels (100 and 125% of the crop evapotranspiration) influenced inorganic N forms in the soil, being N- NH_4^+ the most abundant. The most superficial layer of the soil showed higher content of total-N and most of this N was in the form of NO_3^- .

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) and Northeast Bank (BNB). The authors would like to thank the staff of Vale do Curu Experimental Farm, which made field activities feasible.

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