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Enhancement of nitrogen use efficiency to increase yield and maize grain quality in no-till systems

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Introduction

The major challenge for sustainable agriculture in the humid tropics is identifying and reducing inefficient use of resources while simultaneously intensifying production, maintaining soil fertility and biodiversity and reducing offsite environmental consequences of agriculture. In the identification of soil resources, it is important to consider that they can be relatively mobile or immobile. Nitrogen, one of the resources required in large amounts by crops, is highly mobile mainly as nitrate, which is the dominant form of nitrogen in most agricultural soils (*Barber*, 1995). Efficient use of N by crops results in higher yields, increased grain protein content and increased return of stubble cover and maintenance of soil organic matter. Inefficient use of N by crops can result not only in increased emissions of potent greenhouse gases, including nitrous oxide (N_2O), but also in a loss of N from the root zone. Inefficient use of N fertilizer is clearly inconsistent with concepts of agricultural sustainability and ecological efficiency (*Hochman* et al., 2011).

Our hypothesis, adapted to an alley cropping system, was that combined use of residues leguminous trees of high and low quality in a sandy loam soil prone to cohesion would substantially enhance N use efficiency and increase grain yield, the grain protein content, and therefore the protein yield, of quality protein maize (QPM). Thus, the overall aim this study was to test these two hypotheses and identify an optimal combination of leguminous residues to increase the grain protein content and protein yield of maize.

Material and Methods

The experiment was conducted between 2009 and 2012 in Chapadinha, Maranhao, Brazil, 3°44’30”S and 43°21’37”W. The soil in the experimental area is an Arenic Hapludult, with 200 g kg^{-1} coarse sand, 480 g kg^{-1} fine sand, 70 g kg^{-1} silt and 260 g kg^{-1} clay. The legumes were planted with 0.05 m spacing in 10 x 4 m plots and in mixed rows so that each parcel received both types of residue.

In December 2011, samples were collected using a heavy-duty auger. The samples were composed of five sub-samples at four depth increments (0–5, 5–10, 10–15, 15–20 and 20-40 cm) for chemical and organic matter analysis. Each sample was analysed for pH (0.01 M $CaCl_2$ suspension, 1:2.5 soil/solution, v/v), organic carbon (Walkley-Black) and exchangeable K, Ca, Mg extraction by ‘exchangeable ions resin’ and potential acidity (H + Al) by SMP buffer solution (pH 7.0) (*van Raij* et al., 1986). Cation exchange capacity (CEC) was calculated as K + Ca + Mg + (H + Al); sum of bases (SB) was calculated as K + Ca + Mg and base saturation

percentage (BSP) was calculated as SB/CEC × 100. P, Ca, Mg and K measurements were obtained using a Varian 720-ES ICP Optical Emission Spectrometer.
Portions of samples 0-5 and 5-10 were mixed, and the organic matter was separated by physical soil fractionation based on a NaI solution density of 1.80 g cm^{-3} (determined by hydrometer), as described by *Sohi* et al. (2001). Wet oxidation with potassium dichromate was used for the carbon analysis of each soil fraction (*Tiessen* and *Moir*, 1993).
Immediately after the leguminous pruning still in January 2012, the QPM (Quality Protein Maize) variety BR 473 was sown in a no-tillage system. At planting all plots received 52 kg ha^{-1} P as superphosphate, 33 kg ha^{-1} of K in the form of potassium chloride (KCl) and 6.25 kg ha^{-1} Zn as zinc sulphate. The plots receiving mineral nitrogen fertilizer were fertilized with 45 kg ha^{-1}. In addition, 45 kg ha^{-1} of N was applied in the form of urea when the fourth pair of maize leaves emerged in the plots treated with N. The alley cropping experiment consisted of 10 treatments and four replicates arranged in randomised blocks: L+C+U, leucaena + clitoria + urea; L+A+U, leucaena + acacia + urea; G+C+U, gliricidia + clitoria + urea; G+A+U, gliricidia + acacia + urea; L+C, leucaena + clitoria; L+A, leucaena + acacia; G+C, gliricidia + clitoria; G+A, gliricidia + acacia; B+U, bare soil with urea; and control, bare soil without mineral fertilizer. The dry matter and nitrogen contents were measured at physiological maturity. The nitrogen concentration was determined following H_2SO_4-H_2O_2 digestion (Temminghoff and Houba, 2004).
Total plant N accumulation was determined by adding the grain and whole plant N accumulation values, calculated by multiplying the maize dry biomass by the respective maize tissue N concentrations. The grain N accumulation was determined for grain biomass by multiplying by the grain N concentration.
Recovery efficiency of inorganic nitrogen (REIN, %) = [(Δ plant N uptake on dry basis / total amount of inorganic N fertilizer applied] x 100.
Recovery efficiency of organic nitrogen (REON, %) = [(Δ plant N uptake on dry basis / total amount of N leguminous applied] x 100.
The Δ plant N uptake on a dry basis (0% moisture) is the plant N uptake (kg N ha^{-1}) for a treatment of N fertilizer minus the plant N uptake (kg N ha^{-1}) of the 0 N treatment on a per-unit-area basis.
Agronomic efficiency of inorganic applied N (AEIN, kg grain kg N $applied^{-1}$) = [(Δ grain yield (kg ha^{-1}) /total amount of N fertilizer applied.
Agronomic efficiency of organic applied N (AEON, kg grain kg N $applied^{-1}$) = [grain yield (kg ha^{-1}) in N added plots/total amount of leguminous N applied.
The Δ grain yield is the yield (kg ha^{-1}) of a treatment receiving organic or inorganic N minus the yield (kg ha^{-1}) of the 0 N treatment on a 145 g kg^{-1} moisture basis.
The weight of the ears, the number of grains per ear and the grain yield (GY) were determined, and all of the values were adjusted on a 145 g kg^{-1} moisture basis. The harvest index was determined as follows: Grain HI = [(GY at 14.5% /GY at 14.5% + stover yield) × 100.
The data were evaluated by analysis of variance (ANOVA) and the means compared using Tukey's post hoc test with a significance level of 0.05.

Results and Discussion

All residues greatly increased N recovery, such that plants under combinations of residues plus urea were around 45% more efficient at recovering applied inorganic N than plants in the B+U treatment plot (Fig. 1A). There were no significant differences among plants receiving residue treatments. The agronomic efficiency of inorganic N was significantly higher than the control only in the G+C+U treatment, although there was no significant difference between this treatment and L+A+U (Fig. 1B). The recovery efficiency of organic N was similar in all of the residue combinations, but the agronomic efficiency of organic N was higher for G+C than for L+A.
Both residues, as fertilizers, increased the N concentration in the plants (Table 1). Among the combinations of residues with urea, only the G+C+U and L+C+U treatments resulted in higher

plant N concentrations than L+A, which were not significantly different from B+U. All of the treatments with residues produced higher total N accumulation than the B+U treatment. The treatments consisting of residues plus urea led to higher N accumulation than the treatments with residues but without urea. The G+C+U treatment resulted in almost three-fold higher N accumulation than the B+U treatment (148.44 – 54.07), which was higher than the control. Additionally, the combination of residues and urea increased the N content in the grain, which was lower in the control than in all other treatments. Among the plants receiving residue treatments, the N content of the grain was higher with the G+C+U treatment than with the L+A treatment. There were no differences among the other treatments, which were not significantly different from either G+C+U or L+A. In contrast, the application of urea to bare soil did not significantly increase the total N accumulation in the maize grain. Grain N accumulation was higher in all of the residue-treated plots than in the B+U-treated or control plots, where total N accumulation did not differ. Among the treatments with residues, G+C+U and L+C+U produced significantly higher N accumulation in the maize grain than L+C, G+A and L+A. The application of residues also drastically increased the dry matter production, whereas the increase induced by urea was very low when compared with the control. Among the residue treatments, G+C+U and L+A+U resulted in higher dry matter production than all other treatments, with the exception of G+A+U.

Urea application did not increase ear weight. Only the treatments with G+C+U and L+C+U were superior to treatments without urea, with residues (Table 2). Among the treatments with residues L+A showed the lower ear weight. Differences in grain weight were small; the only significant difference was between L+C+U (28.75) and the control (23.75). The number of grains per ear ranged between 784 in G+C+U and 129 in the control. The number of grains was 180 in B+U, which was significantly lower than the number of grains for all of the treatments, with the exception of the control, including the G+C treatment, which even without urea produced 499 grains per ear.

The harvest index (HI) was also considerably affected by the use of residues; among these treatments, only L+A was not different from B+U. However, even in the G+C+U and L+C+U treatments where the HI was significantly higher than that in L+A+U, G+C, L+C, G+A and L+A, the harvest index was not higher than 0.40. There were many differences in yield among the treatments. The residues were more efficient than urea at enhancing maize yield, as all plots with residues gave higher yields than B+U. G+C+U was superior to all other treatments, followed by L+C+U, which was equal to G+A+U. Both the urea and the residues increased the quantity of the protein produced by maize. G+C+U and L+C+U treatments resulted in higher protein production than all other treatments, and L+A resulted in the lowest protein production among the residue treatments. In terms of protein production, G+A+U and L+A+U were superior only to G+A and L+A, among the residue treatments.

Conclusions and Outlook

Our study showed that soil cover is essential for increasing the efficiency of inorganic N use. Apart from other known advantages of mulch, such as its ability to preserve soil moisture, the light fractions of organic matter, also are important in improving the environment of the root zone in soil prone to cohesion. The enhancement of N nutrition promoted by the combination of the leguminous trees also increased the total biomass, grain population densities of the ear and the harvest index, thereby leading to higher grain yields for QPM maize.

These residue combinations also increased the protein yield. The increase in grain yield was more important than the influence of N nutrition on grain composition for achieving higher protein production. The great differences among residue treatments indicated that the higher N uptake and the higher yield of the gliricidia + clitoria + urea treatment could not be accounted for only by the physical and chemical improvements of the root zone. Other factors, such as antagonistic interactions between species, may also be involved and will require further attention in future research. Therefore, to increase the protein yield in cohesive soils of humid tropical regions, the alley cropping system is effective when tree species that do not interact antagonistically with the crops but rather provide nutrients and improve the root environment are used.

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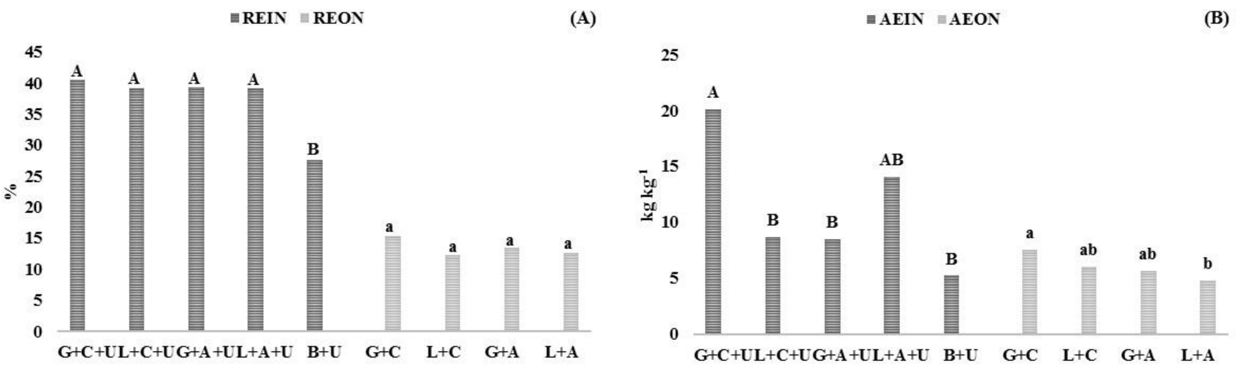

Fig. 1. Recovery efficiency of inorganic (REIN) and organic nitrogen (REON) (A); Agronomic efficiency of inorganic (AEIN) and organic applied nitrogen (AEON) (B). Upper-case for REIN and AEIN, lower-case for REON and AEON do not differ by Tukey's test at 5% probability. G+C+U = gliricidia + clitoria + urea; L+C+U = leucaena + clitoria + urea; G+A+U = gliricidia + acacia + urea; L+A+U = leucaena + acacia + urea; G+C = gliricidia + clitoria; L+C = leucaena + clitoria; G+A = gliricidia + acacia; L+A = leucaena + acacia; B+U = bare soil with urea

Table 1. Nitrogen concentration, contents, accumulation and dry matter stover in maize plants. Rows with same letters with each parameter do not differ by Tukey's test at 5% probability. G+C+U = gliricidia + clitoria + urea; L+C+U = leucaena + clitoria + urea; G+A+U = gliricidia + acacia + urea; L+A+U = leucaena + acacia + urea; G+C = gliricidia + clitoria; L+C = leucaena + clitoria; G+A = gliricidia + acacia; L+A = leucaena + acacia; B+U = bare soil with urea.

	G+C+U	L+C+U	G+A+U	L+A+U	G+C	L+C	G+A	L+A	B+U	Control
N concentration whole plant, g kg^{-1}	13.19 a	13.41 a	12.87 ab	12.48 ab	11.79 abc	11.58 abc	11.44 abc	11.10 bc	10.47 c	7.21 d
Total N accumulation, kg ha^{-1}	148.44 a	131.46 a	136.93 a	133.70 a	111.90 b	96.19 b	101.46 b	98.35 b	54.07 c	29.25 d
Grain N contents, g kg^{-1}	20.70 a	20.35 ab	19.12 ab	19.61 ab	18.81 ab	18.16 ab	18.37 ab	17.41 b	18.11 b	11.68 c
Grain N accumulation, kg ha^{-1}	68.73 a	58.64 a	54.15 ab	55.17 ab	54.21 ab	45.40 b	51.57 b	45.58 b	23.05 c	14.48 c
Dry matter stover, Mg ha^{-1}	6.29 a	5.35 b	5.78 ab	6.18 a	5.08 b	4.42 c	4.94 bc	5.00 b	2.99 c	2.40 d

Table 2. Yield parameters in the experiment.

	G+C+U	L+C+U	G+A+U	L+A+U	G+C	L+C	G+A	L+A	B+U	Control
Average weight of ears, g	219.0 a	210.5 a	185.9 ab	185.5 ab	149.7 bc	136.3 bc	141.4 bc	108.0 c	44.5 d	32.7 d
Weight of 100 grains, g	28.75 ab	33.75 a	31.25 ab	32.50 ab	30.0 ab	30.0 ab	31.25 ab	26.25 ab	25.0 ab	23.75 b
Grain number	784 a	638 b	599 b	576 bc	499 cd	454 d	460 d	421 d	180 e	129 e
Harvest Index	0.40 a	0.38 a	0.35 ab	0.30 b	0.31 b	0.36 ab	0.32 b	0.22 c	0.20 c	0.05 d
Grain yield, Mg ha^{-1}	4.12 a	3.29 b	3.06 bc	2.65 c	2.31 c	2.50 c	2.29 c	1.38 d	0.60 e	0.13 e
Protein, kg ha^{-1}	409.62 a	433.24 a	328.62 b	358.05 b	282.01 bc	282.95 bc	232.18 c	170.14 d	84.74 e	26.36 f

Rows with same letters with each parameter do not differ by Tukey's test at 5% probability. G+C+U = gliricidia + clitoria + urea; L+C+U = leucaena + clitoria + urea; G+A+U = gliricidia + acacia + urea; L+A+U = leucaena + acacia + urea; G+C = gliricidia + clitoria; L+C = leucaena + clitoria; G+A = gliricidia + acacia; L+A = leucaena + acacia; B+U = bare soil with urea