BIOLOGICAL NITROGEN FIXATION OF COMMON BEANS REDUCES EMISSION INTENSITY IN AN INTEGRATED CROP-LIVESTOCK SYSTEM ON A FERRALSOL OF THE BRAZILIAN SAVANNAH

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ABSTRACT
The objective of the study was to evaluate the effect of biological nitrogen fixation (BNF) and mineral nitrogen (N) on the emission of nitrous oxide (N_2O), volatilization of ammonia (NH_3) and production of common beans in an integrated crop-livestock system (ICL). The ICL system has about 8 ha, was implemented in 2011/2012 on a clay soil in an experimental area of Embrapa Rice and Beans, in the municipal area of Santo Antônio de Goiás, Goiás State, Central West region of Brazil. The treatments were without application of N (CONTROL); beans inoculated with N-fixing bacteria (*Rhizobium* sp.) and growth promoters (*Azospirillum* sp.), without the addition of mineral N (BNF); Mineral N (urea) applied according to standard recommendation (65 N); and mineral N (urea) applied according to the N sufficiency index criterion (102 N). N_2O and NH_3 were measured using static chambers, according to the method described by Alves et al. (2012) and Araújo et al. (2009), respectively. Emission and volatilization were calculated as the sum of fluxes throughout the common bean crop season, between October 2019 and January 2020. The cultivar used was BRS FC104. Emission intensity was calculated as the sum of the amount of N lost (N_2O + NH_3) per kg of grain produced. The emission of N_2O was significantly lower in the treatment BNF (0.69 kg ha^{-1}) than in the treatments 65 N and 102 N (1.44 and 1.25 kg ha^{-1}). The volatilization of NH_3 was significantly lower in BNF (1.31 kg ha^{-1}) than in 102 N (11.38 kg ha^{-1}). The grain yield did not differ between treatments and was in average high (3,109 kg ha^{-1}), as a result the emission intensity was significantly lower in the treatment BNF (0.90 g N kg grain^{-1}) than in the treatment with the highest dose of mineral N, 102 N (3.86 g N kg grain^{-1}) in the ICL system.
Key words: Nitrous Oxide; Ammonia; Mineral N

INTRODUCTION

Integrated farming systems are one of the main strategies of the Brazilian government to reduce or compensate for carbon emissions from agriculture with simultaneous improvement in production eficiency (OLIVEIRA et al., 2018). To achieve maximum potential of crop-livestock integration, the system should be adapted to regional demands and should be diversified. It is important to include staple foods in integrated systems because, besides diversification of production, this strategy may contribute to sustainable production of food in more resilient agricultural systems.

Nitrogen (N) fertilization is essential for the sustainability of agricultural systems, since N is the macronutrient required in greater quantity by agricultural crops. An important portion of the N required by the plants can be supplied through the N contained in the organic matter of the soil, organic fertilizers, plant residues, and through the excreta of faces and urine of animals (LIMA, 2018). However, the N present in the soil is not sufficient to sustain high yields, requiring the addition of nitrogen fertilizers (RAIJ, 2011).

Biological nitrogen fixation (BNF) is a natural process and is quite common in plants, mainly, but not exclusively, legumes. It allows some plant species to use molecular nitrogen (N_2) after its transformation by symbiotic bacteria in soil. BNF is a process widely used in soybean production and eliminates totally the need for the use of mineral N fertilizers. Common beans (*Phaseolus vulgaris* L.) is capable of BNF, however in commercial varieties this characteristic is suppressed. Therefore, the use of BNF for common bean production is a challenge.

Research results indicate that is possible for common beans to benefit from FBN in field conditions, reaching productivity levels of up to 3,425 kg ha^{-1} without using irrigation (HUNGRIA et al., 2000), and of up to 4,355 kg ha^{-1} with irrigation (Mendes et al., 2004). Brito et al. (2015), found that the productivity potential of common beans inoculated with rhizobia associated with supplementation with N as top dressing can reach 2,500 kg ha^{-1} in the Brazilian savannah ecosystem (Cerrado).

Due to the dynamic of N in soil-plant-atmosphere systems, losses through volatilization of ammonia (NH_3), nitrous oxide emission (N_2O) or leaching of mineral N (mainly nitrate, NO_3^-) must be considered. The use of mineral N fertilizers, such as urea, can result in increased production costs and environmental contamination (SANTOS et al., 2016).

The emission of N_2O is a result of denitrification and nitrification of N by soil microorganisms (CARVALHO et al., 2010). N_2O is a greenhouse gas (GHG) that has a global warming potential (PAG) about 310 times greater than the PAG of CO_2, over a period of 100 years in the atmosphere (IPCC, 2007). The use of mineral N fertilizers, decomposition of plant residues and manure are among the main sources of N_2O emissions from agricultural systems in Brazil (CARVALHO et al., 2006; ALVES et al., 2006).

In addition to the emission of N_2O, N can be lost as ammonia (NH_3) via the volatilization process. Losses via volatilization are extremely important because mineral N, usually urea, is mainly applied via top dressing, a perfect condition for hydrolyzation of urea and further losses of N as NH_3. Volatilized NH_3 is deposited again on Earth's surface via precipitation, being considered an indirect source of N_2O emission (CARVALHO et al., 2018).

The increasing concentration of GHG's in Earth's atmosphere generates concern on emissions from anthropogenic activities as the main cause of climate change. The growing demand for food production due to the increased urban population, can result in increased pressure on environment. Therefore, there is an urgent need to implement practices and process that can increase production efficiency of agricultural systems.

Common bean is a staple food for Brazilian population. Brazil is one of the largest producers and consumers of common beans. The proposition of technologies that can maximize production and reduce financial and environmental costs is essential for the Brazilian agricultural sector. Given the above mentioned, this research aimed to evaluate the effect of biological fixation of N and mineral fertilization of N on N_2O emission and NH_3 volatilization and grain yield of common beans cultivated under a crop-livestock system on a Ferralsol of the Brazilian savannah.

MATERIAL AND METHODS

Description of field experiment

The study was conducted in an integrated crop-livestock (ICL) system implemented in 2011/2012 in 8 ha at the research farm of Embrapa Rice and Beans, in Santo Antônio de Goiás, GO. The geographical coordinates of the study site were: 16 ° 29' 59 " to 16 ° 29' 44" W and 49 ° 17' 35 " to 49 ° 17' 54" S. The altitude of the area is 804 m and the slope is approximately 0.3%. The soil is a Rhodic Ferralsol (53-58% clay) (SANTOS et al., 2010). According to the Koppen classification (1936), the climate is a tropical savanna (Aw) with well-defined rainy (from October to April) and dry (May to September). The average annual precipitation of the last 33 years is 1,490 mm, and the average annual temperature is 23 ° C (AGRITEMPO, 2017).

Since 2011/2012 the ICL is a rainfed system including a rotation between a crop, such as soybean, rice, corn and sorghum cultivated alone or in consortium with Brachiaria grass, throughout the summer season, and a pasture formed by Brachiaria grass that serves to cover soil or to feed beef cattle throughout the dry season. In the summer season 2019/2020, common bean (*Phaseolus vulgaris* L.) was cultivated throughout the summer season (from October 2019 to January 2020). The cultivar used was BRS FC104 developed by Embrapa for integrated systems with a very short cycle of 60 days. Within the ICL, four treatments were implemented in strips: without application of mineral or biological fixation of N (CONTROL); the biological N fixation via inoculation of common beans (seeds and plants) with *Rhizobium* and *Azospirillum* (BNF); 65 kg ha^{-1} of mineral N applied as urea according to the standard recommendation for the culture (65 N); 102 kg ha^{-1} of mineral N applied as urea according to the sufficient index of N for common beans (102 N).

Volatilization of Ammonia (N-NH_3) from soil

Static free semi-open collecting chambers (SALE) were used to determine volatilized ammonia NH_3, according to Araújo et al. (2009) and Jantalia et al. (2012). The SALE was made from a transparent plastic bottle made of polyethylene terephthalate (PET), with a capacity of 2 L and covering an area of 0.008 m^2 on soil. A plastic flask with a capacity of 80 mL was placed inside each chamber, containing 60 mL of capture solution (1 mol L^{-1} sulfuric acid and 2% glycerin). A sponge of polyurethane 2.5 mm thick, 2.5 cm wide and 25 cm long was soaked in the capture solution. The sponge remained hanging vertically inside the SALE, with the lower part inside the plastic flask with the capture solution (Figure 1a). These SALE's containing the sponge and capture solution remained in the field since common beans was sown, throughout the entire crop season. Changes of sponges and capture solution were done constantly, at each 3 or 7 days. The capture solution of each SALE was diluted, followed by further analysis to quantify N using the "FIAlab" system (Flow Injection Analysis). Volatilization of N-NH_3 was determined in kg ha^{-1} as the sum of fluxes measured for the entire common bean season.

Emission of Nitrous oxide (N-N_2O) from soil

Nitrous oxide fluxes were measured using rectangular closed static chambers, according to Alves et al. (2012). These chambers are composed of two parts (top and bottom), which were coupled to measure the accumulation of N_2O in 3 times after closure, at 0, 15 and 30 minutes. The lower part, or base of the chamber consisted of a rectangular box made of metal with a hollow (40 cm x 60 cm), with walls 10 cm high, having a gutter (2 cm wide x 2 cm high) across the upper perimeter (Figure 1b). The base of the chamber was inserted 10 cm into the soil, so only the gutter was visible. The upper part, or top of the chamber, consisted of a rectangular metal box (40 x 60 cm and 15 cm high), equipped with connections and vials to extract air samples from inside the chambers. Before coupling the parts of the chamber for air sampling, the gutters were filled with water to seal the system. First air sample was collected as soon as the upper and lower parts were coupled, then at 15 and 30 minutes after. A volume of 60 mL of air was sampled using syringes. At the laboratory, syringes were coupled to an automated vacuum pump, and part of the sample was transferred to a 20 mL vial (headspace). A volume of 30 mL was initially discarded by purging the vacuum system. The concentrations of N_2O inside the vials was subsequently analyzed using an automatic gas chromatography. Sampling was carried out always in morning time between 8:00 and 10:00 in order to take an adequate representation of daily fluxes (ALVES et al. 2012). Frequency of sampling was daily or weekly throughout the entire common bean season. Total emission of N-N_2O was determined as the integration of measured fluxes.

Statistical analysis

Analyses were performed using the linear mixed model procedure (Proc Mixed) in SAS/STAT (SAS, 2008). Treatments (CONTROL, BNF, 65 N, and 102 N) were considered as fixed effects and repetitions (chambers) as random effect. F tests was applied for the main effects (treatments). Dunnett's test was applied to check for linear contrasts between means of BNF and other treatments.

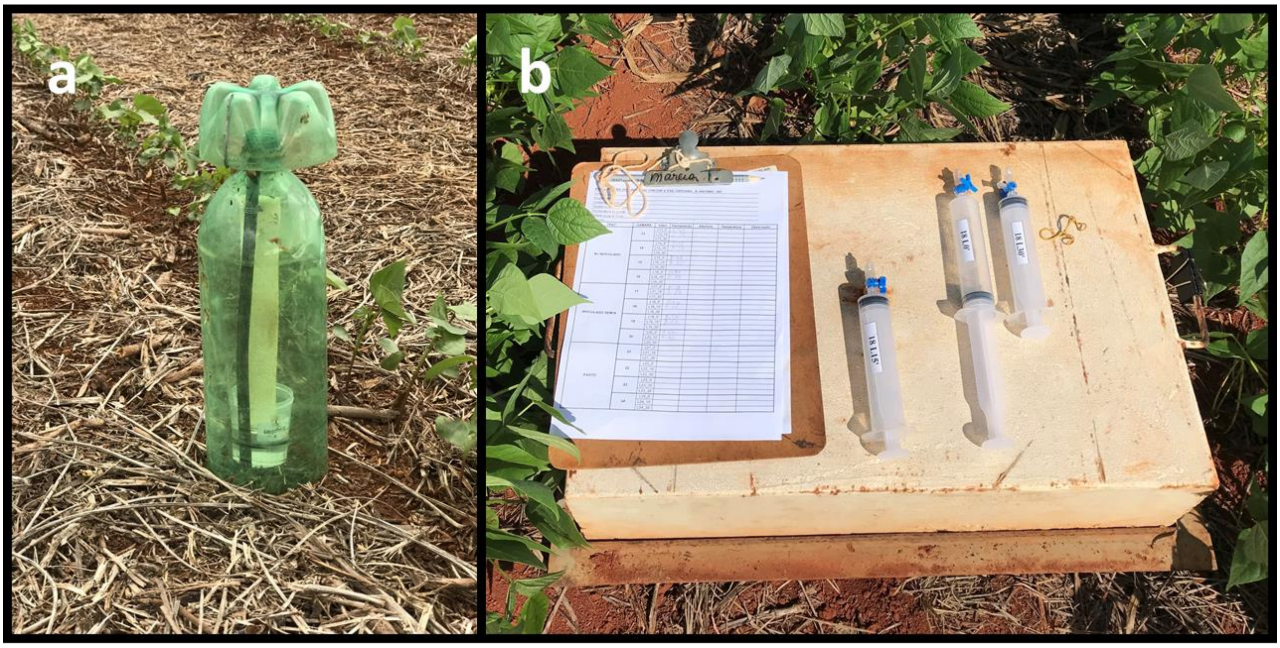

Figure 1. a. Static free semi-open collecting chamber (SALE) for ammonia, and b. static chamber for the collection of greenhouse gas fluxes from soil.

RESULTS AND DISCUSSIONS

The grain yield of common beans was similar for the respective treatments: 3,321.98 (CONTROL); 2,860.73 (BNF); 2,973.14 (65 N); and 3,279.53 (102 N) (Figure 2). The N-N_2O emission was, however, significantly lower for BNF treatment (0.69 kg N ha^{-1}) than for treatments with mineral N, 65 N (1.44 kg N ha^{-1}) and 102 N (1.25 kg N ha^{-1}). The N-NH_3 volatilization was also significantly lower for BNF treatment (1.31 kg N ha^{-1}) than for the treatment with highest dose of mineral N, 102 N (11.38 kg N ha^{-1}). As consequence, emission intensity was much lower for the treatment with biological N fixation, BNF (0.90 g N kg $grain^{-1}$) than for the treatment with highest dose of mineral N, 102 N (3.86 g N kg $grain^{-1}$). These results show that BNF can maintain high productivity of common beans and lower gaseous losses of N in the ICL system. High grain yield of rainfed common beans, regardless the treatment indicates that there is an improvement of soil quality along the years in the ICL system. The improvement of soil quality also contributed to a better response of common beans to inoculation with microorganisms. Further analysis can indicate correlations of soil properties with emission and volatilization of N in the ICL system.

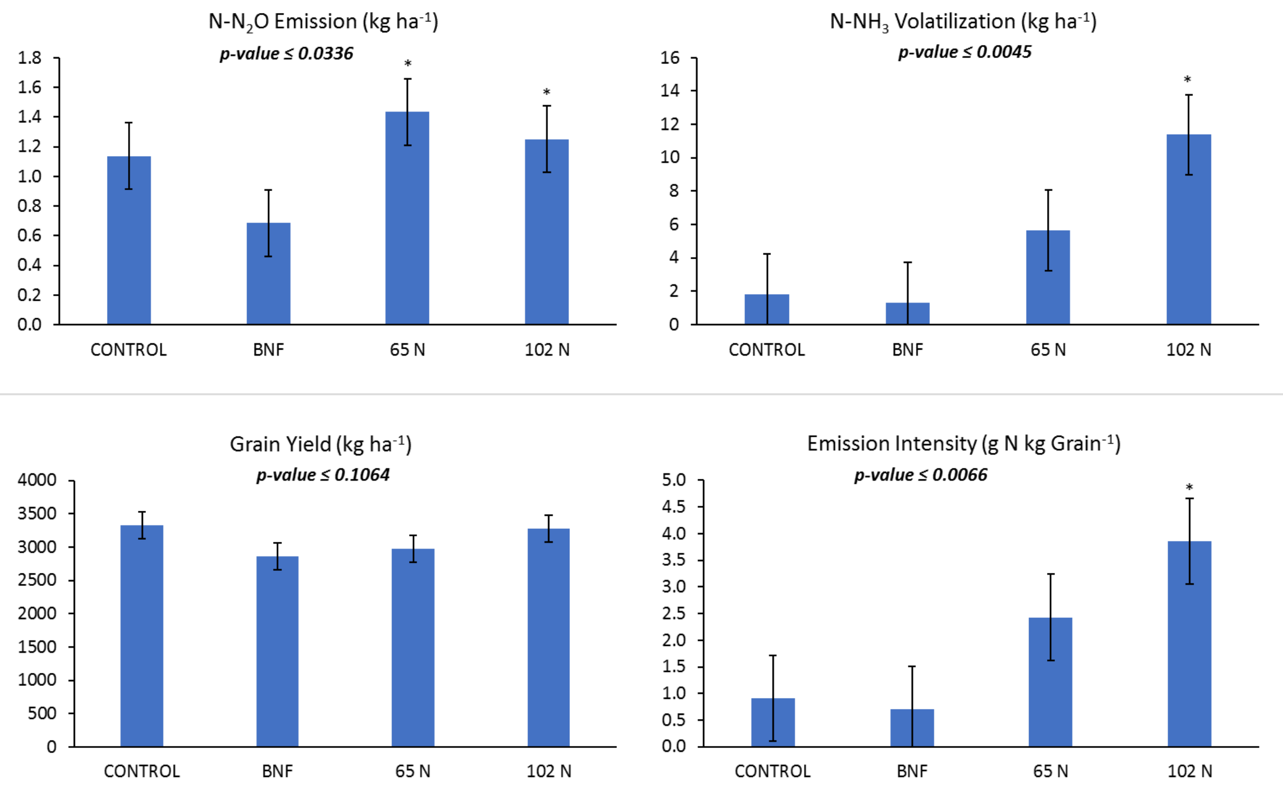

Figure 2. Effect of biological N fixation (BNF), mineral fertilization of N (65 N and 102 N), and soil without N fertilization (CONTROL) on N_2O emission, NH_3 volatilization, grain yield and emission intensity in one season of common beans cultivated under integrated crop-livestock system, from October 2019 to January 2020. P-values stands for nominal significance level of F-tests for the effect of treatments. Error bars are standard errors of means (n=4). *Means are significantly different from BNF treatment by Dunnett's test (p-value $\leq$ 0.05).

CONCLUSIONS

Results showed the low efficiency of mineral nitrogen fertilization in the ICL system, as it is accompanied by large losses of N in the form of NH_3 and N_2O. On the contrary, the biological N fixation in common beans proved to be efficient, matching levels of productivity to that when using mineral fertilizers, however, with less N_2O emission and NH_3 volatilization. Biological N fixation can contribute to the environmental and financial sustainability of the ICL system, as well as to the circularity of the production, as it reduces, or even eliminates, the necessity to apply mineral N as an external input.

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