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Economic Analysis of Maize Production and Nitrogen Use Efficiency in Rotation with *Brachiaria humidicola*

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Abstract

Among the essential macro elements for maize production, nitrogen (N) is the one limiting growth and yield the most. To maintain desired production levels, substantial amounts of N are required, mainly obtained through nitrogen fertilizer, a significant cost driver in maize production (13-18%). However, much of this fertilizer is lost after nitrification through leaching and denitrification processes under tropical humid conditions. Fertilizer lost to the environment produces considerable environmental damage (e.g., water pollution, emission of greenhouse gases) and generates economic loss to the producers. The International Center for Tropical Agriculture (CIAT), in collaboration with the University of Hohenheim (Germany) and Corpoica (Colombia), have conducted research on the phenomenon of biological nitrification inhibition (BNI) present in permanent plots of *Brachiaria humidicola* (Bh) (≥10 years established) to quantify the residual effects of BNI on subsequent maize cultivars. This residual effects of BNI result in greater nitrogen use efficiency (NUE) and therefore in higher maize grain yields. The trial was planted at the Research Center Corpoica-La Libertad, located in the eastern Plains of Colombia, during a period of three years (2013-2015). This article aims to evaluate the profitability of maize production on plots previously used for Bh and compares the results to conventional maize production (M). The analysis focused on measuring indicators of technical and economic efficiency with respect to NUE, yields and costs associated with each plot. Subsequently, profitability indicators were defined and a sensitivity analysis was performed to identify changes in yields, prices and expected costs. The results show that maize production on plots previously used for Bh (with residual BNI effect) is more profitable, with yields exceeding the ones obtained on conventional maize plots (no residual BNI effect) by up to 62%. This is accompanied by an increased technical and economic efficiency in NUE, lower unit costs (75%) and a superior cost-benefit ratio. However, the results are highly sensitive to variations in expected returns, and to some extent to maize sales prices and increased production costs. In general, crop rotation of *B. humidicola* and maize is an alternative to improve production efficiency and profitability, resulting from the residual effects of BNI related to Bh.

Keywords: Biological nitrification inhibition, *Brachiaria humidicola*, economic efficiency, improved forages, resource efficiency, rotation systems

Introduction

Among the essential macro elements, nitrogen (N) is a critical element in growth and yield of maize and in general for growth and development of plants. In order to maintain desired levels in yield, the plant requires large amounts of N, mainly obtained through nitrogenous fertilizers since it is hard to find enough N available in most soils (Below, 2002). This means that the N fertilization is one of the most widespread practices on agricultural production and constitutes an important item in the cost of production (Pires & Carlos, 2015).

However, up to 70% of this fertilizer is lost during nitrification and denitrification processes to the environment via nitrate leaching and nitrous oxide emissions (N_2O - a powerful greenhouse gas contributing to global warming) particularly under humid tropical conditions (Moreta et al., 2014). Thus, fertilizer that is not absorbed by plants causes on the one hand damage to the environment (Tubiello et al., 2014), and on the other hand economic loss in the range of US$ 90 billion annually (Subbarao et al., 2013), affecting directly sales prices and profit margins for producers. Therefore, the use of alternatives for a more efficient use of N fertilizers, would be the way to achieve better outcomes in productive, economic and environmental terms.

The International Center for Tropical Agriculture (CIAT), in collaboration with the University of Hohenheim (Germany) and Corpoica (Colombia), have conducted research on the phenomenon of Biological Nitrification Inhibition (BNI) present in permanent plots of *Brachiaria humidicola* (Bh) with 10 years of establishment, to quantify the residual effects of BNI on subsequent maize cultivars. This phenomenon has demonstrated to have a high potential for restoration of soil fertility, reduction of nitrogen pollution from agriculture and improvement of nitrogen use efficiency (NUE) (Moreta et al., 2014; Nuñez, 2015). The highest NUE in the Bh plots helps to achieve higher maize grain yields with lower amounts of nitrogen fertilization. Nevertheless, real economic benefits are unknown to the producer in those rotation systems, thus, this research aims to evaluate the profitability of maize production on plots previously used for Bh contrasting results with conventional maize production (M).

Material and Methods

This study was realized under the research project "*Climate-smart crop-livestock systems for smallholders in the tropics: Integration of new forage hybrids to intensify agriculture and to mitigate climate change through regulation of nitrification in soil*" funded by BMZ-GIZ.

The trial was established in the Eastern Plains of Colombia (Research Center Corpoica-La Libertad) and evaluated for maize grain yield during three consecutive production cycles (2013-2015). Maize yield was evaluated in three plots: a) productive *Brachiaria humidicola* (PBh), b) degraded *Brachiaria humidicola* (DBh), and c) conventional maize (M). On each plot, 3 doses of nitrogen (N) were applied (60, 120, and 240 kg N ha^{-1}) in order to determine the residual effect of BNI in N use efficiency leading to higher maize yield.

The analysis for this paper focused on measuring indicators of technical and economic efficiency with respect to NUE, yields, and costs associated with each plot. Finally, a sensitivity analysis and a Montecarlo simulation were carried out in order to determine the level of profitability and risk associated with *B. humidicola* (degraded and productive).

Results and Discussion

Yield per hectare was calculated based on kilograms of maize obtained and results presented by Karwat et al. (2016). When analyzing yield in the three options (Table 1), it can be observed that the lowest average yield obtained was in the M option with 3,049 kg of maize grain yield ha^{-1}, followed by the DBh with 4,080 kg, and PBh with 5,181 kg. This shows that yields in PBh and DBh increased their levels at an average of 32% and 62% respectively, compared to the M option.

These yield increases directly lead to income increases of 34% on average (987 to 1498 USD). The total average cost per hectare varied from 1,469 to 1,706 USD, depending on the applied fertilizer dose, which implies a minimum production to cover the total costs of production of 4,590, 4,834 and 5,331 kg of maize ha^{-1} in doses of 60, 120 and 240 kg N ha^{-1}, respectively. The results above indicate that maize production in the PBh option achieved the highest economic return, associated with increases in yield as well as reductions in the per unit product cost of 25% and 42% in the DBh and PBh plots, respectively.

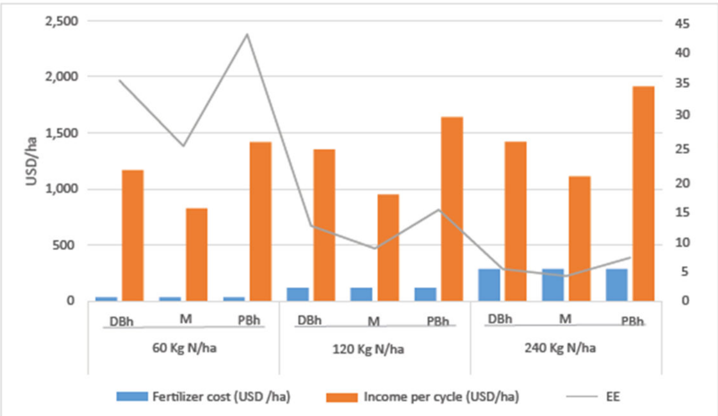
Table 1. Yield, costs, income and economic indicators of maize with respect to the N applied dose for each plot

Variables	M (Kg N/ha)			DBh (Kg N/ha)			PBh (Kg N/ha)		
	60	120	240	60	120	240	60	120	240
Maize yield (kg/ha)	2,592	2,993	3,564	3,575	4,134	4,533	4,366	5,168	6,009
Standard deviation of yield	428	1,141	1,249	758	1,198	1,048	981	1,878	602
Income (USD)	839	969	1,154	1,157	1,338	1,467	1,413	1,673	1,945
Variable costs[1]	32.9	110.8	269.5	32.9	110.8	269.5	32.9	110.8	269.5
Fixed costs[2]	1,436	1,436	1,436	1,436	1,436	1,436	1,436	1,436	1,436
Total product cost (USD)[3]	1,469	1,547	1,706	1,469	1,547	1,706	1,469	1,547	1,706
Utility (USD)[4]	-630	-578	-552	-312	-209	-239	-56	126	239
Break even point (kg maize)[5]	4,590	4,834	5,331	4,590	4,834	5,331	4,590	4,834	5,331
Unit product cost (USD)[6]	0.57	0.52	0.48	0.41	0.37	0.38	0.34	0.30	0.28

This is the average data of three years of evaluation (2013-2015), with three repetitions for each dose of nitrogen fertilizer. Prices were converted to dollars by using the average Representative Market Exchange Rate (RMER) for each of the years.
[1]Variable costs: include costs of N fertilizer; [2]Fixed costs: include costs of soil preparation, planting, control of pests and diseases; [3]Total product cost: the result of fixed costs plus variable costs; [4]Utility: the total income (sale price (0.32 USD) x yield) minus total costs; [5]Break even point: represents the minimum yield level to cover total production costs; [6]Unit product cost: obtained by dividing total product cost by total production.

A productivity analysis was performed based on the agronomic Nitrogen Use Efficiency (NUE) indicator, which is the additional yield per unit of fertilizer applied. The Economic Efficiency (EE) indicator was used to evaluate how much additional income would be obtained by investing in fertilizer application (Chavarria, 2013). These indicators show that highest efficiency could be obtained with the lowest N dose (60 kg N ha^{-1}) and suggests an efficiency decrease when increasing N levels. Therefore, the highest EE was reached in the PBh plot (Figure 1).

Figure 1 Economic Efficiency (EE) differences among three options



The best yields in the *B. humidícola* options (PBh and DBh) through the years of evaluation were subject to variations of up to 1,800 kg of maize per hectare (see Table 1), which means a high risk regarding the expected yield. On average, when changing all variables simultaneously, a positive NPV is obtained for the PBh option at fertilizer levels (kg N ha^{-1}) of 120 and 240, with a risk of obtaining negative results of 27% and 0.39%, respectively. For the dose of 60 kg N/ha, it can be observed a sufficiently high (78%) risk of resulting in an economic loss, which could reach a level of 1,998 USD in the case all variables in the simulation were in unfavorable ends for the 5,000 iterations. In the DBh option, the Net Present Value (NPV) resulted negative for different doses, with very low chances of reaching a favorable outcome (the probability that the NPV is above zero is 1%, 25%, and 31% at fertilizer levels (kg N ha^{-1}) of 60, 120, and 240, respectively).

Table 3 Montecarlo simulation results for simultaneous variations in key variables and their effect in the NPV

Variables	Productive Bh (N kg/ha)			Degraded Bh (N kg/ha)		
	60	120	240	60	120	240
NPV (Net Preset Value)[1]	-371.9	250.62	903.18	-986.73	-28.2	-373.42
NPV minimum[2]	-1,998	-1,163	-181	-2,212	-2,539	-1,976
NPV maximum[3]	1,359	1,996	2,207	285	1,648	1,717
prob NPV<0[4]	78%	27.8%	0.39%	99%	75%	69%
benefit/cost [5]	0.9	1.06	1.2	0.7	0.9	0.9

[1]Average value of NPV obtained in the simulation (5,000 iterations); [2]Maximum NPV that could be obtained (maximum profit); [3]Minimum value that the NPV indicator could take (maximum economic loss); [4]Probability of NPV (in relation average) to be below cero; [5]The total discounted benefits are divided by the total discounted costs.

In summary, the sensitivity analysis and the Monte Carlo simulation demonstrated the high risk associated to maize production. This is a result of the wide variations in yields observed during the three years of evaluation, the high production costs and the instability that might arise for input prices and maize sales prices.

Conclusions and Outlook

Crop rotation of *Brachiaria humidicola* and maize is an alternative to improve production efficiency and profitability (cost reduction, yield increase), resulting from the residual effects of BNI related to Bh. However, results are subject to high risks due to variations in expected returns for the three options and the high production costs of maize in Colombia.

Knowing about the economic benefits of such a rotation system serves as a decision making tool for livestock producers and can help in promoting the adoption of *B. humidicola* in livestock production systems.

Acknowledgments

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