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Original article

Management of bioproducts and NPK fertilization in maize grown on Eutric Nitisols in Cuba

Manejo de bioproductos y fertilización NPK en maíz cultivado sobre suelos Ferralíticos Rojos Lixiviados en Cuba

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ABSTRACT: Maize is an important food source for both humans and livestock. In Cuba, its production is limited by insufficient nutrient supply; however, various bioproducts have been developed that either provide nutrients or enhance their utilization efficiency. This study aimed to evaluate the effectiveness of the combined application of several bioproducts in relation to fertilizer doses and the maximum experimental yields of maize grown on Eutric Nitisols. Three experiments were conducted with different cultivars during the 2009-2015 period. Randomized block designs were used to assess various combinations of the bioproducts EcoMic®, Biobras-16®, Fitomas-E®, Quitomax®, and Dimargon®, with up to four bioproducts applied in the presence of different NPK fertilizer doses, as well as treatments with fertilizer alone. A beneficial response to the combined application of bioproducts was observed, depending on the fertilizer dose and the maximum yield obtained. For yield levels between 3 and 4 t ha^{-1}, applying 50 % NPK was sufficient. When yield increased to 5 t ha^{-1} and in soils with high available phosphorus content, the dose should be increased to 75 % NK, while maintaining phosphorus at 50 %, since applying 75 % P reduced the yield of the bioproduct combination. The application of bioproducts in the presence of 50 % NPK fertilization consistently achieved yields similar to those obtained with 100 % NPK.

Key words: *Azotobacter chroococcum*, brassinosteroid analog, chitosan, mycorrhizal inoculant.

RESUMEN: El maíz es un alimento importante para el hombre y el ganado. En Cuba, su producción se encuentra limitada por un deficiente suministro de nutrientes; no obstante, se han desarrollado diferentes bioproductos, los cuales aportan nutrientes o incrementan la eficiencia en la utilización de estos. Este trabajo se realizó con el objetivo de evaluar la efectividad de la aplicación conjunta de varios bioproductos, en relación con las dosis de fertilizantes y los rendimientos máximos experimentales del maíz cultivado sobre suelos Ferralíticos Rojos Lixiviados. Se ejecutaron tres experimentos con diferentes cultivares, durante el periodo 2009-2015. Se estudiaron en bloques al azar diversas combinaciones de los bioproductos EcoMic®, Biobras-16®, Fitomas-E®, Quitomax® y Dimargon® con un máximo de cuatro bioproductos en presencia de diferentes dosis de fertilizante NPK, además de tratamientos en los que solo se aplicaron fertilizantes. Se encontró una respuesta beneficiosa a la aplicación conjunta de estos bioproductos, dependiente de la dosis de fertilizante aplicada y del rendimiento máximo obtenido. Para niveles de rendimientos entre 3 y 4 t ha^{-1} fue suficiente aplicar el 50 % NPK. Cuando el rendimiento se incrementó hasta 5 t ha^{-1} y en suelos con contenidos altos de fósforo disponible, la dosis debe aumentar a 75 % NK, pero manteniendo el fósforo en 50 %, ya que aplicar 75 % P redujo el rendimiento de la combinación de bioproductos. La aplicación de los bioproductos en presencia del 50 % de la fertilización NPK siempre alcanzó rendimientos similares a los obtenidos al fertilizar con 100 % NPK.

Palabras clave: análogo de brasinoesteroide, *Azotobacter chroococcum*, inoculante micorrízico, quitosano.

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INTRODUCTION

Maize is part of the Cuban diet and, at the same time, a decisive component of animal feed. National production does not meet the needs for this food, and imports are necessary (1), although these prove insufficient. Among the reasons for low production are low yields (1), associated, among other causes, with a limited supply of nutrients. In general, nutrient supply has been based on the application of mineral fertilizers, but the country's difficult economic situation strongly restricts imports and even national production of these inputs, resulting in their low availability in Cuba.

Since the end of the last century, the development of different bioproducts has been promoted, based both on beneficial soil microorganisms namely arbuscular mycorrhizal fungi, rhizobia, and other plant growth-promoting bacteria, as well as on biostimulants derived from compounds with bioactive properties, including brassinosteroid analogues, chitosans, and oligosaccharides (2). The proven benefits of these bioproducts include greater absorption of nutrients from the soil and fertilizers (3), increased fixation of atmospheric nitrogen (4), promotion of germination and plant growth, greater tolerance to stresses, and yield increases (5, 6). All of this leads to greater efficiency in fertilizer use, better exploitation of the productive capacity of cultivars, and generally, a reduction in the necessary doses of fertilizers (3).

The difficult economic situation, the lack of fertilizers, and the growing evidence of positive results from bioproduct applications led to the approval of a Bioproduct Policy (7). This policy calls for increasing the production of bioproducts and their use in agricultural technologies. The aforementioned bioproducts present complementary mechanisms of action (8), which supports their combined application.

The working approach, based on the near-universality of arbuscular mycorrhizal symbiosis in economic crops (9) and its various benefits, such as increased absorption of nutrients from soil and fertilizers (3), reduced damage from certain pests (10), and the establishment of cooperative relationships with other rhizospheric microorganisms (11), among others, always includes the application of mycorrhizal inoculants. Given the diverse functions of nitrogen (12) and its high requirements for plants (13), the approach also includes the application of a nitrogen fixer, either symbiotic or associative depending on the crop. In addition, different stimulants can be used, such as those based on brassinosteroid analogues, chitosans, and oligosaccharides.

Different bioproducts, with the exception of nitrogen fixers, do not provide nutrients to the system. Nitrogen fixers only provide nitrogen, and even symbiotic ones do not always guarantee the full requirement of the crop (14). Therefore, the use of bioproducts to meet crop needs must be combined with applications of synthetic and organic fertilizers, as well as green manures and amendments, within the framework of integrated nutrient management (15).

In Cuba, numerous studies integrating mycorrhizal inoculants with fertilization systems (3) have shown positive results, ensuring high yields with lower doses of mineral or organic fertilizers. Likewise, benefits have been reported from integrating mycorrhizal inoculants with rhizobia and brassinosteroid analogues in soybean (16), with endophytic (17) or associative (18) nitrogen fixers in forage crops, and with an oligosaccharide-based stimulant in maize (19), among others. However, no studies have yet been reported in maize that optimize the combined management of more than two bioproducts and fertilizer doses to fully exploit the complementary benefits of the different bioproducts.

Bioproducts, together with nutrient sources and nutrients available in the soil, can form an integrated system to meet the nutritional requirements of the crop. These requirements depend on the yield potential of the cultivar (20), or more specifically, on the maximum experimental yield. On the other hand, although bioproducts increase the agronomic efficiency of fertilizers, when maximum yields are high, crops treated with bioproducts may require greater amounts of fertilizers than under conditions of lower maximum yields, although always in smaller amounts than if bioproducts were not present. Moreover, their effectiveness will depend both on the maximum experimental yield and on the fertilizer doses supplied, since the latter may limit or inhibit their effectiveness (21).

For all these reasons, the present study aims to evaluate the effectiveness of the joint application of several bioproducts in relation to fertilizer doses and maximum experimental yields of maize grown on Eutric Nitisols. This evaluation seeks to optimize the use of these inputs and serve as a basis for the development of crop production technologies.

MATERIALS AND METHODS

Three experiments were conducted during the period 2009-2015 on Eutric Nitisols according to the soil classification system (22), equivalent to Eutric Nitisols under the World Reference Base (23). The first experiment was carried out in the experimental areas of the Genetic livestock company 'Niña Bonita', located in Bauta municipality, Artemisa province, at coordinates 22º55′ N, 82º22′ W, at an altitude of 50 m. The other two experiments were conducted in the experimental areas of the National Institute of Agricultural Sciences (INCA), located in San José de las Lajas municipality, Mayabeque province, at coordinates 22º59′ N, 82º08′ W, at an altitude of 138 m a.s.l. The main chemical characteristics of the soils are presented in Table 1.

The interpretation of the results of the chemical analysis was carried out based on the established criteria (26), and revealed the following: the soils presented neutral pH-H_2O, with calcium and magnesium contents typical of this soil type. The values of organic matter, although medium, indicated a good state of conservation under conditions of continuous cultivation and low altitude. Potassium contents were low (0.2 $cmol_c\ kg^{-1}$).

Table 1. Main chemical characteristics of Eutric Nitisols at the beginning of the experiments (0-20 cm depth)

Experiments	pH H_2O	OM (g kg^{-1})	P (mg kg^{-1})	Ca^{2+}	Mg^{2+}	K^+	Na^+	Spores in 50 g
				(cmol$_c$ kg^{-1})				
Niña Bonita 2009-10	6,5	32,5	14	9,7	2,2	0,21	0,15	109
INCA 2013	6,8	30,0	175	10,2	2,4	0,65	0,1	55
INCA 2015	6,7	32,0	144	11,5	2,4	0,24	0,10	65

Average values from the different experiments. In each experiment, 8 composite soil samples were taken. Chemical determinations were carried out according to the Manual of Analytical Techniques (24): pH-H_2O by potentiometer; OM (organic matter) by Walkley-Black; P by extraction with 0.05 M H_2SO_4; exchangeable cations by extraction with 1 M NH_4Ac solution at pH 7 (24); mycorrhizal spores by the wet sieving and decanting method (25)

Climatic conditions

In both localities, the rainy season extends from May to October, concentrating between 75 and 80 % of the annual precipitation. The remaining 20-25 % occurs during the dry season, from November to April. During the rainy season, the average daily temperature ranged between 25.8 and 27.2 °C, being 4 to 5.5 °C higher than that recorded in the dry season.

The locality of Niña Bonita is characterized by an average annual precipitation of 1258 mm (15-year average) and an average daily temperature of 24.2 °C. In the experimental period, which coincided with the dry season, precipitation was 230 mm and the average daily temperature was 21.1 °C.

At INCA, the average annual precipitation was 1579 mm (historical series 1968-2018), although 2013 was a rainy year with accumulated precipitation of 1710 mm, while 2015 had slightly lower precipitation than the average (86 %). The annual average daily temperatures were similar in both years, at 24.4 °C. During the experimental period, which coincided with the rainy season, precipitation was higher in 2013 (1035 mm) than in 2015 (677 mm), while temperatures were slightly higher in 2015 (26.2 °C) than in 2013 (25.7 °C).

Experiment 1 at Genetic livestock company 'Niña Bonita'

The experiment was conducted during the dry season, with sowing on 18/11/2009 and harvest on 17/03/2010. Thirteen treatments were studied, consisting of a response curve to NPK fertilization with five treatments: 0, 25, 50, 75, and 100 % of NPK fertilization, which corresponds to 120, 90, and 117 kg ha^{-1} of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), respectively. In the presence of 50 and 75 % NPK doses, the following bioproducts were applied: EcoMic®, EcoMic® + Biobras-16®, EcoMic® + Fitomas-E®, and EcoMic® + Biobras-16® + Fitomas-E®, which constituted the remaining 8 treatments. A randomized block design with four replicates was used.

The transgenic variety FR-BT1, obtained by the Cuban Center for Genetic Engineering and Biotechnology, resistant to fall armyworm (*Spodoptera frugiperda*) and tolerant to glyphosate, was used. The planting frame was 0.7 m between rows and 0.25 m between plants. The experimental plots consisted of 8 rows of 5.25 m in length, with a surface area of 29.4 m² and a calculation area of 17.85 m² (96 plants). The 100 % NPK dose was ensured by applying the equivalent of 450 kg ha^{-1} of the 14-20-26 formula and 150 kg ha^{-1} of urea.

Experiment 2 at INCA, San José de las Lajas

The experiment was conducted during the rainy season, with sowing on 15/06/2013 and harvest on 01/10/2013. Thirteen treatments were studied. The first five consisted of a response curve to NPK fertilization with the following treatments: 0, 50, 75, 100, and 125 %. In the presence of 50 and 75 % NPK doses, the effects of different combinations of bioproducts were evaluated: EcoMic®; EcoMic® + Fitomas-E®; EcoMic® + Fitomas-E® + Biobras-16®; and EcoMic® + Fitomas-E® + Biobras-16® + Quitomax®. A randomized block design with four replicates was used. The 100 % NPK dose consisted of 128 kg ha^{-1} of nitrogen, 52 kg ha^{-1} of P_2O_5, and 68 kg ha^{-1} of K_2O.

The hybrid Pioneer 30P49 was used. The planting frame was 0.9 m between rows and 0.3 m between plants. The experimental plots consisted of 6 rows of 6.3 m in length, with a surface area of 34.02 m² and a calculation area of 18.36 m² (68 plants). The 100 % NPK dose was ensured by applying the equivalent of 400 kg ha^{-1} of the 9-13-17 formula and 200 kg ha^{-1} of urea.

Experiment 3 at INCA, San José de las Lajas

The experiment was conducted during the rainy season, with sowing on 10/06/2013 and harvest on 27/09/2013. Fourteen treatments were studied. Four consisted of a response curve to NPK fertilization: 0, 50, 75, and 100 %. In this experiment, Fitomas-E® was replaced by Dimargon® (formulation based on *Azotobacter chroococcum*). In the presence of the 50 % NPK dose, the effects of different combinations of bioproducts were evaluated, namely: EcoMic®; EcoMic® + Quitomax®; EcoMic® + Biobras-16®; EcoMic® + Dimargon®; EcoMic® + Quitomax® + Biobras-16®; EcoMic® + Quitomax® + Dimargon®; EcoMic® + Biobras-16® + Dimargon®; and the four bioproducts together. Applications of the four bioproducts were also evaluated in the presence of 75 % NPK and 75 % NK-50 % P doses (75% N and K, 50% P). A randomized block design with four replicates was used.

The variety 'Raúl' was used. The planting frame and plot size were similar to those used in Experiment 2. The 100 % NPK dose was ensured by applying the equivalent of 400 kg ha^{-1} of the 9-13-17 formula and 200 kg ha^{-1} of urea, equivalent to 128 kg ha^{-1} of N, 52 kg ha^{-1} of P_2O_5, and 68 kg ha^{-1} of K_2O. The 75 % NK; 50 % P dose was prepared by applying 200 kg ha^{-1} of 9-13-17, 34 kg ha^{-1} of 0-0-50, and 170 kg ha^{-1} of 46-0-0. The remaining fertilization doses were percentages of the amounts applied with the 100 % NPK dose.

Bioproducts, doses, and application methods

Mycorrhizal inoculant. The commercial inoculant EcoMic®, based on *Glomus cubense* (Y. Rodr. & Dalpé) / INCAM-4, DAOM241198/, with a minimum of 20 spores g^{-1} and undetermined amounts of root fragments and mycelium, was used. It was applied by seed coating, previously moistened with water, at a rate of 2 kg of EcoMic® per 25 kg of seed (27).

Biostimulant Fitomas-E ® . The commercial product, based on oligosaccharides and nitrogenous bases in liquid formulation, was used. It was applied via foliar spraying at two times, each at a dose of 1 L ha^{-1}, sprayed at 25 and 45 days after sowing (DAS), in high-volume applications equivalent to 200 L ha^{-1} (8).

Biostimulant Biobras-16 ® . Based on brassinosteroid analogues in liquid formulation. It was prepared at the Center for Natural Products of the University of Havana. It was applied via foliar spraying at two times, 25 and 45 DAS. At each time, the equivalent of 20 mg ha^{-1} (8) was applied, dissolved in water for high-volume applications.

Biostimulant Quitomax ® . Based on chitosans in liquid formulation. It was prepared at the National Institute of Agricultural Sciences. It was applied via foliar spraying at two times, 25 and 45 DAS. At each time, the equivalent of 200 mg ha^{-1} was dissolved in 200 L of water, sprayed over one hectare in high-volume applications (8).

Depending on the treatments, the bioproducts applied via foliar spraying were applied together in the same spray.

Bioproduct Dimargon ® . Based on *Azotobacter chroococcum* with a titer of 10^{10} CFU. It was prepared at the Institute of Fundamental Research in Tropical Agriculture (INIFAT). It was applied by soil spraying at sowing at a dose equivalent to 2 L ha^{-1}, diluted in water 1/10 (v/v) (8).

Fertilization and irrigation

The amounts corresponding to the NPK formulas were applied at the beginning in the furrow bottom. Supplementary nitrogen was applied as urea in bands 30 days after sowing and incorporated into the top 10 cm of soil with a hoe. In the dry season for maize cultivation, irrigation was applied at a rate of 350 m^3 ha^{-1} every seven days until ear formation, then increased to 400 m^3 ha^{-1}, and between 80 and 100 days irrigation was suspended for grain maturation. In the rainy season, irrigation was applied under similar criteria when rainfall did not meet the application norms.

Evaluations

Soil analysis. At the beginning of each experiment and in each replicate, two composite samples were taken, each consisting of 10 subsamples randomly collected at a depth of 0-20 cm. In each sample, the determinations presented in Table 1 were carried out. The methods used were those established in the Manual of Analytical Techniques (24), for the following determinations: pH in water, organic matter by the Walkley-Black method, available phosphorus by extraction with 0.05 M H_2SO_4, and exchangeable cations extracted with 1 M NH_4Ac at pH 7.

Arbuscular mycorrhizal fungal spores. These were evaluated at the beginning, using the initial soil sampling. For spore extraction, a modification of the wet sieving method was performed according to the protocol used (25). Spores were counted under a stereoscopic microscope and expressed as spores per 50 g of soil.

Harvest. In all experiments, harvest was carried out in the calculation area of each plot: at 120 DAS in the dry season, and between 110 and 115 DAS in the rainy season. The harvested cobs were processed, and yield was expressed in tons per hectare (t ha^{-1}) of grain at 14 % moisture.

Statistical analyses

In each case, the assumptions of normality and homogeneity of variance were verified using Levene's and Kolmogorov-Smirnov tests. Subsequently, the corresponding ANOVA were performed, and whenever yield differences were significant, they were tested according to Duncan's test at $p \le 0.05$.

RESULTS

Experiment 1

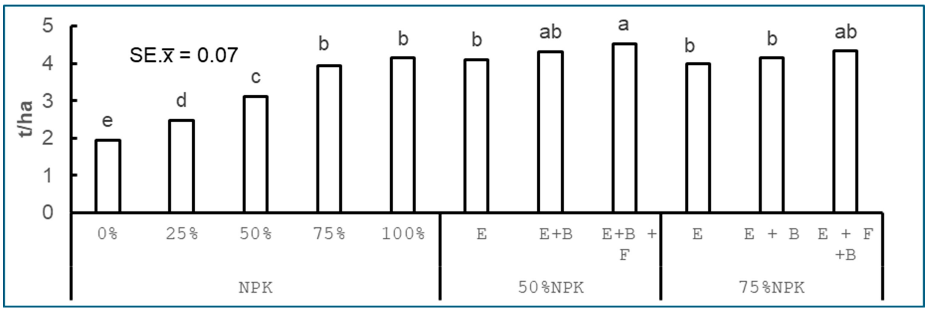
Maize responded positively ($p \le 0.05$) to NPK fertilization (Figure 1), and with 75 % NPK a yield close to 4 t ha^{-1} was achieved, similar to that obtained with the 100 % NPK dose. In the presence of the 50 % NPK dose, maize responded significantly to the application of the mycorrhizal inoculant, with yield increases of 32 % compared to the non-inoculated counterpart and yields similar to the highest obtained with mineral fertilization (100 % NPK).

The combined application with brassinosteroids did not differ significantly from the yield obtained with EcoMic®, but the additional application of FitoMas-E® thus involving three bioproducts achieved the highest experimental yields, around 4.5 t ha^{-1}, which were superior ($p \le 0.05$) to those obtained with EcoMic® alone and to the highest yields obtained with mineral fertilization.

In the presence of 75 % NPK application, no significant response was found to the application of the mycorrhizal inoculant. No response was found either to the combinations of bioproducts, and the different treatments showed similar yields ($p \le 0.05$) to those obtained with the non-inoculated counterpart. Although the application of the three bioproducts in the presence of 75 % NPK fertilization resulted in a similar yield ($p \le 0.05$) to that obtained when applying these bioproducts with 50 % NPK, it was less efficient as it required greater amounts of fertilizers.

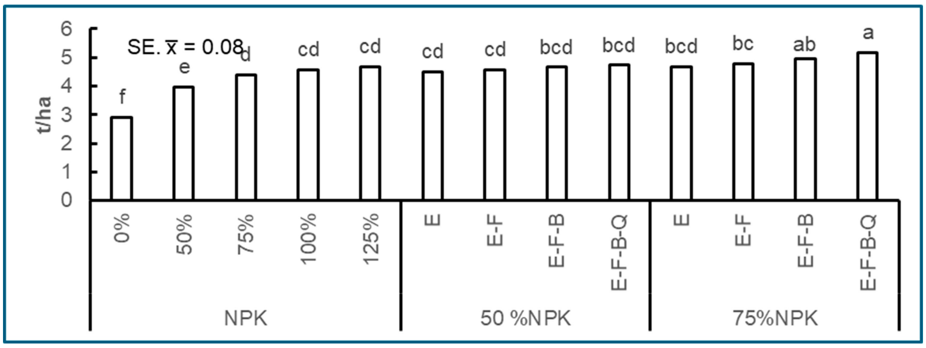
Experiment 2

A positive response ($p \le 0.05$) was also found to mineral NPK fertilization, and with the 75 % NPK dose yields of 4.4 t ha^{-1} (Figure 2) were achieved, higher than those obtained with lower doses and not differing from those obtained with higher fertilizer doses. The application of the mycorrhizal inoculant showed a positive response ($p \le 0.05$) in the presence of the 50 % NPK dose, with yield increases of 13 %



Different letters indicate significant differences at $p \leq 0.05$. E (EcoMic® - *G. cubense*/INCAM-4); B (Biobras-16®); F (Fitomas-E®). 100 % NPK (120, 90, and 117 kg ha^{-1} of N, P_2O_5, and K_2O, respectively)

Figure 1. Effect of bioproduct combinations in the presence of two NPK fertilizer doses and response curve to NPK fertilization in FR-BT1 maize, an Eutric Nitisols, Genetic livestock company 'Niña Bonita', Nov. 2009 - Mar. 2010



Different letters indicate significant differences at $p \leq 0.05$. E (EcoMic® - *G. cubense*/INCAM-4); F (Fitomas-E®); B (Biobras-16®); Q (Quitomax®). 100 % NPK (128 kg ha^{-1} of N, 52 kg ha^{-1} of P_2O_5, and 68 kg ha^{-1} of K_2O)

Figure 2. Effects of applications of different bioproducts and fertilizer doses on the cultivation of Pioneer 30P49 hybrid maize on an Eutric Nitisols, San José de las Lajas, June-October 2013

compared to the un-inoculated counterpart and values similar to the maximum yields achieved with mineral fertilization. The different combinations of bioproducts in the presence of the 50 % NPK dose did not significantly increase yields compared to the application of EcoMic®.

In the presence of the 75 % NPK dose, the application of EcoMic® did not show a significant response ($p \leq 0.05$) compared to the non-inoculated counterpart, nor did it differ from the yield obtained with EcoMic® applied in the presence of the 50 % NPK dose. Nevertheless, the different combinations of bioproducts did show higher yields compared to those obtained with the non-inoculated treatment (75 % NPK). The highest experimental yields were achieved with the application of the four bioproducts, reaching 5.17 t ha^{-1}, which were greater ($p \leq 0.05$) than those obtained with mycorrhizal inoculation, 18 % higher than those obtained with the 75 % NPK dose, and greater than those obtained with higher fertilizer doses. Likewise, with this treatment, yields were higher ($p \leq 0.05$) than those obtained with bioproduct applications in the presence of the 50 % NPK dose. Interestingly, the highest yields in this experiment were 14 % higher than the maximum yields obtained in Experiment 1.

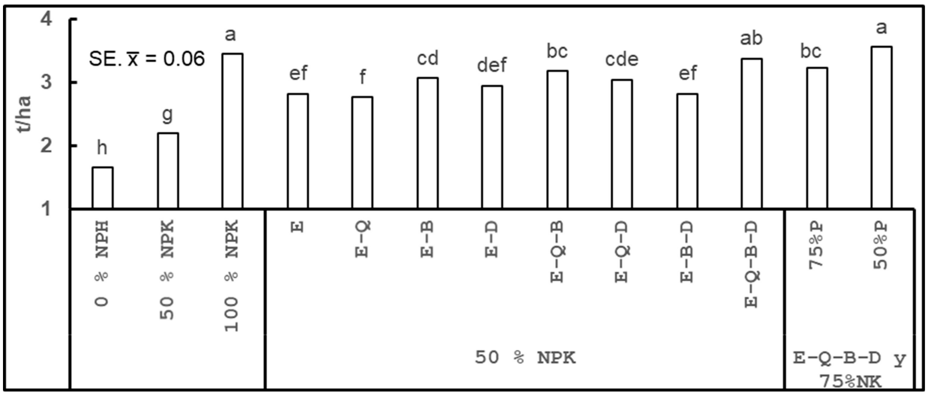
Experiment 3

A significant and increasing response ($p \leq 0.05$) to mineral fertilization was also obtained (Figure 3), although with yields lower than those obtained in the previous experiments, in this case around 3.45 t ha^{-1}. In the presence of the 50 % NPK fertilization, maize responded significantly to inoculation with EcoMic®, with yield increases of 28 % compared to the non-inoculated counterpart. The additional application of Biobras-16® increased yield by 40 % relative to the 50 % NPK dose, although with a yield lower than that obtained with 100 % NPK. The remaining combinations of bioproducts did not show a beneficial effect compared to the EcoMic® + Biobras-16® combination, except for the combined application of the four bioproducts, which achieved the highest yields, similar to those obtained with the 100 % NPK dose.

When using the 75 % NPK dose, the application of the four bioproducts did not produce yields higher than those obtained in the presence of the 50 % NPK dose; however, when P was reduced to 50 %, yields increased significantly. Nevertheless, the yield of this latter treatment was not superior to that obtained with the application of the four bioproducts in the presence of the 50 % NPK dose.

DISCUSSION

The positive response to inoculation with EcoMic®/INCAM-4 has been found in different crops on soils with a pH-H_2O range between 5.8 and 7.2, ensuring high yields with lower doses of mineral fertilizers (3). This is explained by the increased nutrient absorption capacity of efficiently mycorrhized plants from both soil and fertilizers.



Different letters indicate significant differences at $p \leq 0.05$. Sowing date: 10/06/2015. 100 % NPK: 128 kg ha^{-1} N, 52 kg ha^{-1} P_2O_5, and 68 kg ha^{-1} K_2O. E (EcoMic® - *G. cubense*/INCAM-4); Q (Quitomax®); B (Biobras-16®); D (Dimargon)

Figure 3. Effects of applications of different bioproducts and fertilizer doses on the cultivation of 'Raul' maize on an Eutric Nitisols, San José de las Lajas, June -September 2015

The beneficial or positive effects of the different combinations of EcoMic® + Biobras-16® with Fitomas-E®, Quitomax®, and Dimargon®, which resulted in high yields with lower fertilizer doses and at the same time surpassed previously reported results with single applications of EcoMic® (3), or combinations of EcoMic® + Biobras-16® (16), EcoMic® + Fitomas-E® (19), and EcoMic® + Quitomax® (28), corroborate that these bioproducts present complementary mechanisms and therefore their combined application, including up to four bioproducts, is effective.

Since not all experiments studied the same bioproducts, it is not possible to establish whether any particular combination of four bioproducts is more effective than another. However, the positive effect of the different combinations studied was established, which always included the application of EcoMic® and Biobras-16®, and in two of the three experiments also included Fitomas-E® and Quitomax®. Likewise, although the application of bioproducts led to increases in fertilization efficiency achieving higher yields with lower fertilizer doses it was established that fertilizer requirements increase as maximum experimental yields become higher.

This behavior is similar to that observed in the relationships between fertilizer doses and maximum experimental yields in the presence of mycorrhizal inoculants in different crops (3), as well as in applications of several of these bioproducts in beans (21). It indicates that, with the participation of bioproducts in crop nutrition, a certain amount of nutrients is guaranteed, depending on the products included in the applied combination. When conditions favor higher yields and, consequently, increase the crop's nutritional requirements, nutrient supply must be increased, which also allows greater effectiveness in the application of bioproducts. Nevertheless, such supply will always be lower than that required in the absence of bioproducts.

In the presence of combined bioproduct applications, the yield increase observed when reducing P from 75 % NPK to 75 % NK-50 % P in soils with high available P content seems explainable by the well-recognized decrease in the effectiveness of mycorrhizal symbiosis under high phosphorus supply, which has been widely documented (29, 30) and also found in the country with this same inoculant (31). This situation may also have been present in Experiment 2, where under conditions of high maximum experimental yield no response to mycorrhizal inoculation was found with the 75 % NPK dose, but yield increased when combined with other bioproducts.

Although under conditions of high maximum experimental yield a positive response was observed to the application of the four bioproducts in the presence of 75 % NPK, the results suggest that in soils with high available P content the supply of this nutrient should be maintained at 50 % P. This strategy allows high yields to be achieved without the need to increase the dose of phosphate fertilizer.

It is of high practical importance that even when maximum experimental yields range between 3 and 5 t ha^{-1}, the combined application of four bioproducts in the presence of 50 % NPK fertilization allowed yields similar to those obtained with traditional nutrient management based on high doses of 100 % NPK. That is, although for yields around 5 t ha^{-1} it is preferable to apply 75 % NK-50 % P together with bioproducts, this does not invalidate the agronomic usefulness of 50 % NPK.

This alternative is especially relevant in the national context, where fertilizer availability is limited and the absence of other inputs may compromise expected yields. Under such conditions, yields tend to fall within ranges where it is more appropriate to recommend the application of 50 % NPK together with bioproducts.

CONCLUSIONS

Maize responded positively to the combined applications of the bioproducts studied, requiring lower fertilizer doses to achieve yields equal to or higher than those obtained when only mineral fertilizers were applied. When maximum experimental yields ranged between 3.5 and 4 t ha^{-1}, bioproduct applications allowed fertilization to be reduced to 50 % of the recommended dose (100% NPK). Under conditions of higher yield (up to 5 t ha^{-1}), fertilizer requirements increased to 75 % NPK. Regarding phosphorus, in soils with high available phosphorus values, the application of 75 % P reduced the yield of combined bioproduct applications; therefore, it should be maintained at 50 % P. The application of bioproducts in the presence of 50 % NPK fertilization consistently achieved yields similar to those obtained with 100 % NPK.

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