Cultivos Tropicales, 2015, vol. 36, no. 4, pp. 43-54 October-December

ISSN impreso: 0258-5936
ISSN digital: 1819-4087

Ministerio de Educación Superior. Cuba
Instituto Nacional de Ciencias Agrícolas
http://ediciones.inca.edu.cu

MANAGEMENT OF ARBUSCULAR MYCORRHIZAL SYMBIOSIS AND NUTRIENT SUPPLY IN BANANA PLANTATIONS 'FHIA-18' (*Musa* AAAB) CULTIVAR ON PHAEOZEMS HAPLIC CALCARIC SOILS

Manejo de la simbiosis micorrízica arbuscular y el suministro de nutrientes en plantaciones de banano cv. 'FHIA-18' (*Musa* AAAB) en suelo Pardo mullido carbonatado

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ABSTRACT. From the benefits of arbuscular mycorrhizal symbiosis for most plants and regularities in the efficient strain management of arbuscular mycorrhizal fungi (AMF), positive results are increased because of their application in different crops. By considering these aspects, this work was performed in order to assess the feasibility of integrated management proposals of mycorrhizal inoculants and supplemental doses of organ-mineral fertilization for banana plantations cv. 'FHIA -18' on Phaeozems haplic calcaric soils. Two schemes to supply nutrients to plants were studied, one based on mineral fertilizers and other from organ-mineral sources, both in the presence or absence of an efficient AMF strain inoculation and during mother plant cycles and shoot -1 and 2. A randomized block design with four replications was used. A high response to fertilization was found. The recommended doses of both mineral and organ-mineral fertilization were fully equivalent to yield and nutritional status in banana. The supplemented AMF application with 75 % of both fertilizations studied, ensured equivalent yields and similar nutritional states and with treatments receiving only 100 % of the dose, but high percentages of mycorrhizal colonization and spore production. The AMF inoculation at transplanting time, maintained its effectiveness and permanence in the three production cycles evaluated. Foliar potassium content was directly associated with the performance and response of banana to AMF inoculation

Key words: AMF inoculation, fertilization, banana plantation

RESUMEN. A partir de los beneficios de la simbiosis micorrízica arbuscular para la mayoría de las plantas y de regularidades en el manejo de cepas eficientes de hongos micorrízicos arbusculares (HMA), se incrementan los resultados positivos sobre su aplicación en diferentes cultivos. Teniendo en cuenta estos aspectos se realizó este trabajo, con el objetivo de evaluar la factibilidad de propuestas integradas de manejo de inoculantes micorrízicos y dosis complementarias de fertilización orgánico-mineral, para plantaciones del cultivar 'FHIA-18' en suelo Pardo mullido carbonatado. Se estudiaron dos esquemas para suministrar los nutrientes a las plantas, uno a base de fertilizantes minerales y otro a partir de fuentes orgánico-minerales, ambos en presencia o no de la inoculación de una cepa eficiente de HMA y durante los ciclos de planta madre y vástago-1 y 2, utilizando un diseño de bloques al azar con cuatro repeticiones. Se encontró una alta respuesta a la fertilización, siendo completamente equivalentes para el rendimiento y estado nutricional del banano, las dosis recomendadas tanto de fertilización mineral como órgano-mineral. La aplicación de HMA complementada con el 75 % de ambas fertilizaciones estudiadas, garantizaron rendimientos equivalentes y estados nutricionales similares entre sí y con los tratamientos que recibieron solo el 100 % de las dosis, pero con altos porcentajes de colonización micorrízica y producción de esporas. La inoculación de HMA realizada en el trasplante, mantuvo su efectividad y permanencia en los tres ciclos productivos evaluados. Las concentraciones foliares de potasio se asociaron directamente con el rendimiento y con la respuesta del banano a la inoculación con HMA.

Palabras clave: inoculación con HMA, fertilización, plantación de banano

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NTRODUCTION

The cultivation of bananas (Musa acuminata) and bananas (Musa balbisiana) are an important source of food for a large part of the world population, located mainly in underdeveloped countries of Asia, Africa, Central and South America, with an estimated annual production in 102 million tons[A]. Cuba is no exception and there is even an increase in the area devoted to cultivation over the next few years (1).

Intensive and excessive exploitation of resources has been the main trend in productive agroecosystems in the last decades in the world. Soils exhausted and saturated by excess fertilizers and biocides, as well as salinity conditions are good examples of the current situation (2, 3, 4, 5).

Results from studies in various regions of the world report that at least 30 to 50 % of crop yields are attributable to the application of mineral fertilizers (6); However, chemical reduction is a major issue, both for environmental and economic reasons.

Among the practices used to reduce or substitute chemical inputs are the use of organic fertilizers and other mineral sources (7) with high effectiveness in different agro-systems and even in banana production[B] (8, 9).

Likewise, the literature on the benefits of arbuscular mycorrhizal fungi (HMA) in different crops (10, 11, 12) is mainly related to a better use of nutrients and a decrease in fertilizer requirements to maintain high yields, Especially from the feasibility of inoculating efficient strains of HMA by soil type and the low specificity of the efficient strain HMA-culture[C] (13). The aforementioned is the existence of mycorrhizal inoculants that are applied in low quantities and are integrated with cultural practices (14, 15, 16, 17), all of which has allowed them to become a promising practice of biological basis for agricultural production (18).

Specifically in bananas and plantains, from the last decade of the last century, good experimental results were obtained with the inoculation of HMA, making clear the mycorrhizal dependence of the same (19, 20, 21), mainly with the application Of efficient strains of HMA, by soil type, in the phase of acclimatization of plants

In vitro, guaranteeing vigorous postures and decrease of the requirements of organic fertilizers in the substrates used.

In relation to the evaluation of the mineral fertilizer requirements of banana plantations inoculated with efficient strains of HMA, only one previous work has been reported (13), in which it was also found that the doses of fertilizers that guaranteed an optimal functioning Mycorrhizal and high yields were significantly lower than the doses commonly used in uninoculated plantations, and no other published experimental results were found.

Because of the importance of this issue in current agriculture and in the development of more sustainable, even organic, technologies for production, it is important to evaluate the feasibility of integrated management proposals for mycorrhizal inoculants and complementary doses of organic-mineral fertilizers in plantations Cv. 'FHIA-18' in Brown soil; Even starting from plants obtained

In vitro and inoculated in the acclimatization phase, with the objective of ensuring efficient mycorrhizal performance of bananas at all stages of the crop, high yields, reduction of organic-mineral fertilizer quantities and total substitution of mineral fertilization for this culture.

MATERIALS AND METHODS

The experimental work was carried out in the agricultural areas of the Research Institute of Tropical Viands (INIVIT), in the municipality of Santo Domingo, province of Villa Clara, Cuba, during the period from April 2006 to October 2008 in a soft carbonated Pardo (22) whose main fertility characteristics and initial contents of resident HMA spores are presented in Table I.

In general, fertility characteristics were typical of these soils with slightly basic pH and high Ca and Mg contents (23); However, organic matter contents were low. As for the initial number of HMA spores, although they were low, they correspond to the values previously obtained in this type of soils and in this same locality (16, 24), possibly associated to the history of management and cultivation of these.

The treatments studied are presented in Table II.

[A] FAO. *Anuario Estadístico de la FAO* [en línea], *FAOSTAT*, 2012, [Consultado: 27 de junio de 2015], Disponible en: <http://faostat.fao.org/site/339/defalt.aspx>.

[B] Instituto de Investigaciones de Viandas Tropicales (INIVIT). *Instructivo Técnico para el cultivo del plátano*, Ministerio de la Agricultura (MINAG), La Habana, Cuba, 2011, 12 p.

[C] Ruiz, M.L. *Efectividad de las asociaciones micorrízicas en raíces y tubérculos en dos tipos de suelos* [Tesis de Doctorado], Universidad Agraria de La Habana. Instituto Nacional de Ciencias Agrícolas, La Habana, Cuba, 2001, 101 p.

Table I. Characterization and content of initial HMA spores of the soil Carbonated soft duck.Depth 0-20 cm

Año	pH		MO	P_2O_5	K_2O	Ca	Mg	K	No. esporas
	KCl	H_2O	(%)	(mg 100 g^{-1})		(cmol$_c$ kg^{-1})			(esporas 50 g^{-1})
2006	6,81	7,85	2,10	3,19	23,26	44,94	3,24	0,40	47,50
$Z_{1-\alpha}$ * Es $\bar{x}$	0,14	0,11	0,12	0,13	1,88	1,20	0,11	0,09	14,60

$Z_{1-\alpha}$ * Es $\bar{x}$: Confidence interval (1-α=0,05), being Z_1 = 1,96. Each value is an average of eight composite samples

pH en H_2O y KCL (KCl solution1 M) in relation to soil: solution(1:2,5) By the potentiometric method. Determination of organic matter by the Walkley-Black method (oxidation of C with $K_2Cr_2O_7$ 0,5 M in H_2SO_4 18 M al 98 %) And titration with 0.25 M solution of ferrous ammonium sulfate. Extraction of available P and K with extractive solution of $(NH_4)_2CO_3$, 10 g L^{-1}, pH 9,0 and valuation with HCl 0,05 M And orange methyl gauge. Extraction of interchangeable cations with NH_4Ac 1 M y pH 7 In relation soil: solution of 1: 5 and stirring for 5 minutes as described in Manual of analytical techniques for analysis of soil, foliar, organic fertilizers and chemical fertilizers (23). Quantification of spores according to the modification of Herrera *et al.*[D] To the initial protocol of Gerdemann and Nicholson (25)

Table II. Treatments studied in each of the growth cycles

Absolute control
HMA
75 % NPK
75 % NPK + HMA
100 % NPK
75 % FOM
75 % FOM + HMA
100 % FOM
100 % FOM + HMA

100 % NPK= 300 y 720 g plantón^{-1} ciclo^{-1} de N y de K_2O, Absolute control respectively and 38 g seedlings^{-1} de P_2O_5 only applied in the cycle of PM[B]; 100 % FOM= 20 y 10 kg plant^{-1} cycle^{-1} of compost and ash respectively[B]; 75 % FOM = 15 y 7,5 kg plant^{-1} cycle^{-1} compost and ash respectively; 75 % NPK= 225 y 540 g seedling^{-1} cycle^{-1} N and K_2O, respectively and 29 g seedling^{-1} Only applied in the cycle of PM; HMA = Plants inoculated with an efficient strain for this type of soil in the nursery phase and in field transplant[C].

The experiment was developed from the planting of banana plants of cv. 'FHIA-18' obtained *in vitro*. In the treatments inoculated with HMA the plants that were used were inoculated in two moments, first in the acclimatization phase and later at the time of transplant to the field, the acclimatized postures were obtained according to the Technical Instruction (26). The design used was random blocks with four replicates and was executed during the cycles of mother plant and two shoots.

Banana plantation was done manually and the plantation frame used was 4 x 2 x 2.4 m, equivalent to 1 388 plants ha^{-1}. Each experimental plot had an area of 144 m^2, with a total of 20 plants. The calculation area per plot was 43.2 m^2 with six evaluable plants. In the experiment three productive cycles were evaluated: Mother plant (PM) and the follower sons Vástago-1 (V-1) and Vástago-2 (V-2). The selection of the shoots was performed by the method of a carrier and the best child, according to methodology described in the Technical Instructions for the cultivation of bananas[B].

For the inoculation with arbuscular mycorrhizal fungi, the *R. intraradices* strain was used, because it behaved efficiently in this type of soil (13). The inoculation consisted in the application of 10 g of inoculant at the beginning of the acclimatization phase. The adaptation of the plants obtained in vitro was done in semicontrolled conditions in a house of cultivation covered by a plastic mesh (zarán), that allowed the passage of 60 % of the natural illumination or a flow of photosynthetic photons (FFF) of 600 mmol m^{-2} s^{-1}, placing a plant in each bag of black polyethylene containing 0.5 kg of the substrate and subsequently in the transplant of these in the field, at a rate of another 20 g plant^{-1} in the bottom of the Hole, always located under the roots and in direct contact with them.

Two schemes were used to supply the nutrients to the plants under field conditions. One from mineral fertilizers (N, P and K) and with the carriers: urea (46 % N), triple superphosphate (46 % P_2O_5) and potassium chloride (60 % K_2O) and another using organic fertilizer- (FOM), from compost (19.5, 3.1 and 9.9 g kg^{-1} of N, P_2O_5 and K_2O, respectively) and of cane straw ash with average contents of 9.9; 6.6 and 42.8 g kg^{-1} of N, P_2O_5 and K_2O, respectively.

The doses of mineral fertilizers (NPK) and organic-minerals (compost and ash) were applied in each cycle.

In the PM cycle the mineral fertilizers were divided as follows: urea in four equal applications, at 45, 90, 135 and 180 days after planting (ddp) and potassium fertilizer in two applications at 45 and 135 ddp. All applications were made by forming a circle around the plant. In the case of phosphoric fertilizer, it was not fractionated and fully applied before establishing the plantation at the bottom of the groove[B].

In each of the cycles corresponding to the two stems, the doses of N and K_2O were split in two applications in equal parts and were applied as crescent to the corresponding stem, one half when 80-90 % of the plants Of the previous cycle were in the harvest stage and the second 60 days after the first application.

In the case of compost and ash (FOM) applications, in the PM cycle they were divided equally in two moments and were applied in the plantation at the bottom of the groove and the other half at 90 days of the First, of circular form around the plant; In the V-1 and V-2 cycles, ash and compost applications were split into two applications and applied as a crescent to the corresponding stem, one-half when 80-90 % of the plants in the previous cycle Were in the harvest phase and the second 60 days after the first harvest.

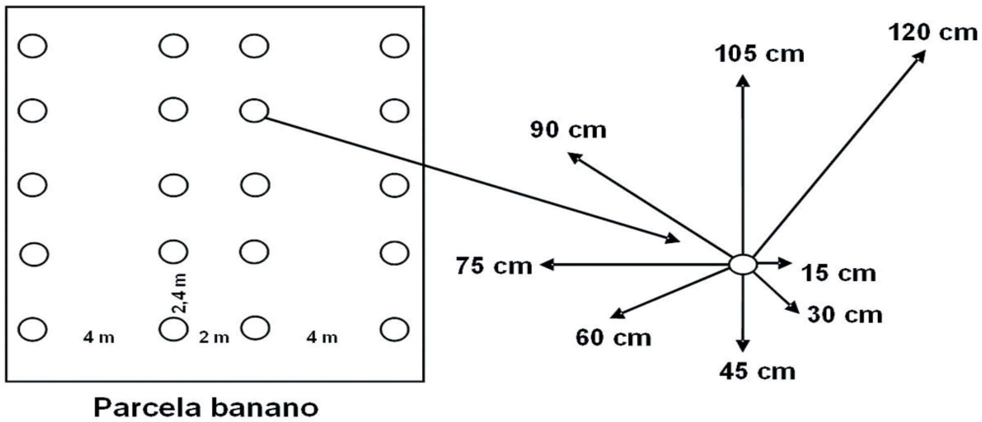
All agrotechnical attentions in the banana plantations were carried out as recommended in Technical Instruction[B].

Among the evaluations and determinations made, the spore counts of HMA, expressed in spores 50 g^{-1} of soil, were performed at the beginning of the experiment and in the flowering stage of each of the banana cycles, expressed in number of Spores 50 g^{-1} of soil. The initial counts of resident HMA spores were performed in each of the eight soil composite samples at depth 0-20 cm, prior to the assembly of the experiment. At the time of flowering of banana 'FHIA-18' the soil samples were also taken in the depth of 0-20 cm. In each plot four plants were sampled and in each plant eight points (15-30-45-60-75-90-105-120 cm) as a spiral, as shown in Figure 1, using soil sampling methodology for agrochemical analysis in banana plantations, so that each sample per plot was composed of 32 subsamples.

For the extraction of the spores the procedure of Herrera *et al.*[E] was carried out according to the initial protocol of Gerdemann and Nicholson (25), later they were washed with distilled water and they were poured in Petri dish, for their count with the use of the stereo microscope 70x (Stemi 2000-C).

The percentage of total mycorrhizal colonization was determined in all cycles in the flowering phase of banana. For the evaluations the roots of four plants per plot were spotted from approximately 200 mg of roots in each sample, which were dried in an oven at 70 ^oC to constant mass, to be stained, according to methodology described by Phillips and Hayman (27). The evaluation was performed under a stereo microscope 70x (Stemi 2000-C) and then the intercepts method, developed by Giovanetti and Mosse (28) for its determination.

Leaf analyzes, expressed as g kg^{-1} of the dry mass, were performed at each cycle of the banana crop. For leaf sampling (N, P and K), leaf III of the plant was selected for each flowchart and flowering stage of each crop cycle and a 10 cm band of each semilimbo was taken in The center of the limbo[E]. Leaf samples from each plot were homogenized, oven dried at 65 °C and then ground. The N by the colorimetric method of Nessler and the P and K by wet digestion (H_2SO_4 + Se), as described in the Manual of Analytical Techniques for analysis of soil, foliar, organic fertilizers and chemical fertilizers (23).



Banana plantation plan: 4 x 2 x 2,4 m.

Figure 1. Graphical representation of the sampling method composed of soil (0-20 cm depth) for banana[E] plants and adapted for sampling HMA spores in this crop

[D] Guijarro, R. *Investigaciones con relación al régimen nutrimental y fertilización del plátano en las condiciones de los suelos Ferralíticos Rojos* [Tesis de Doctorado], ISCAH, La Habana, Cuba, 1980, 107 p.

[E] Herrera, R.A.; Ferrer, R.L.; Furrazola, E. y Orozco, M.O. *Estrategia de funcionamiento de las micorrizas VA en un bosque tropical. Biodiversidad en Iberoamérica. Ecosistemas, Evolución y Procesos sociales*, (ed. ser. Monasterio, M.), [Programa Iberoamericano de Ciencia y Tecnología para el desarrollo, Diversidad Biológica, Subprograma XII], Mérida, México, 1995.

The agricultural yield was determined by weighing the clusters in each of the six calculation plants of each plot and in the different cycles studied. The yield (t ha^{-1}) of each treatment was expressed as yield of each cycle and the total accumulated.

For the statistical analysis, after verification of the normality and homogeneity of variance assumptions by Kolmogorov-Smirnov and Levene, double-variance analyzes were performed for each of the variables evaluated and in each of the cycles studied, as well as with The cumulative performance using the statistical package of the SPSS Program (29). In the case of significant differences, the means of the treatments were docimaron according to the test of multiple comparison of Tukey (p≤0,05).

RESULTS AND DISCUSSION

For a better understanding and interpretation of the effects of inoculation with efficient HMA strains on the mineral and organic-mineral fertilizer requirements of banana and from the statistical analysis of the performance of the nine treatments (Table II), the results will be shown subdivided into two topics: 1) effects on the requirements of mineral fertilizers and 2) on the requirements of organic-mineral sources.

Effect of inoculation with an efficient HMA strain on the mineral fertilizer (NPK) requirements of cv. 'FHIA-18'

A high response to mineral fertilization was found (Figure 2), with significant differences in the three cycles evaluated and the higher yields with the recommended dose for high crop yields (100 % NPK).

These effects were found in any of the productive cycles and accumulated yield.

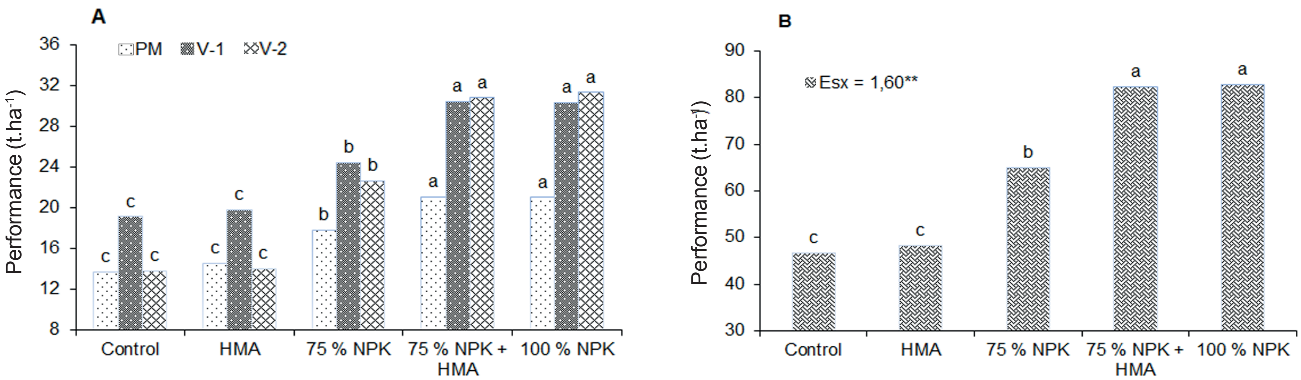
In relation to the combined application of HMA and mineral fertilizer, a positive and significant effect of the inoculation with *R. intraradices* and the 75 % fertilizer dose was found in any of the cycles and accumulated, with significantly higher yields (P≤0.05) to those obtained with the application of 75 % of the NPK dose, in the absence of HMA inoculation and similar to those obtained with the application of the maximum dose of mineral fertilizer (100 % NPK).

The treatment that was inoculated, but did not receive any application of fertilizer, showed no difference in yield in any of the cycles compared to the control treatment without fertilization.

Effect of inoculation with an efficient HMA strain on the requirements of organic-mineral sources of cv. 'FHIA-18'

Similarly, a significant and increasing response was found to the application of different doses of organic-mineral fertilization (FOM), expressed in yield in each of the three cycles evaluated and accumulated. With the application of 100 % FOM, yield levels similar to those obtained when 100 % NPK were applied (Figure 3).

The effect of the inoculation with R. intraradices combined with the 75 % FOM dose in the different cycles showed a positive and significant effect (p≤0.05) on this variable, reaching higher yields than the treatment that only received the 75 % FOM and without significant differences with the treatments that received the highest doses of mineral fertilization and FOM.



P̄M Esx= 0,50** V̄-1 Esx= 1,05** V̄-2 Esx= 1,19**

Different letters imply significant differences (p≤0.05) according to the Tukey Test.

100 % NPK = 300 and 720 g seedlings^{-1} cycle^{-1} of N and K_2O respectively and 38 g seedl^{-1} of P_2O_5 only applied in the PMB cycle; 75 % NPK=225 and 540 g seedlings^{-1} cycle^{-1} of N and K_2O, respectively and 29 g seedlings^{-1} only applied in the PMC cycle; HMA=plants inoculated with efficient strain for this type of soil in the nursery phase and in field transplant. PM = Mother plant, V-1 = Stem-1, V-2=Stem-2

Figure 2. Effect of the application of R. intraradices and mineral fertilization (NPK) on the yield of cv. 'FHIA-18' grown in soil Carbonated softwood in cycles PM, V-1 and V-2 (A) and accumulated total

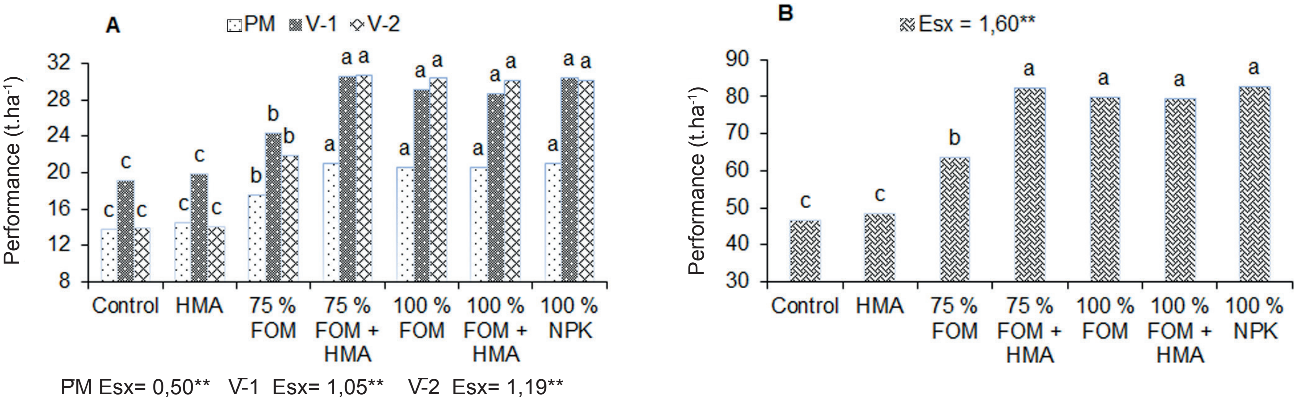
The application of HMA in the presence of the higher dose of FOM did not increase the yields compared to those obtained with the higher doses of mineral fertilization and FOM.

Effect of inoculation with an efficient HMA strain and doses of mineral and organic-mineral fertilizers on fungal variables in plantation cv. 'FHIA-18'

In all cases, the percentage of mycorrhizal colonization and number of spores (Table III) in the rhizosphere of cv. 'FHIA-18', significantly higher (p≤0.05) than those achieved in uninoculated variants.

In the inoculated treatments that received doses of mineral or organic-mineral fertilizer, the highest percentages of mycorrhizal colonization were always reached, which were of the order of 60-63 % during the PM and V-1 cycle, decreasing slightly to 56-57 % In the V-2. The inoculated treatment that did not receive additions of fertilizer always presented values significantly smaller than the previous ones and of the order of 50 %, although superior to the uninoculated treatments.

A differentiated response of treatments on spore production was similarly found. The highest values of this variable were associated with the inoculated treatments that received doses of 75 % of the mineral or organic-mineral fertilizer.



Different letters imply significant differences (p≤0.05) according to the Tukey Test.

100 % FOM= 20 y 10 kg plant^{-1} cycle^{-1} compost and ash[B], respectively; 75 % FOM = 15 y 7,5 kg plant^{-1} cycle^{-1} compost and ash, respectively; 100 % NPK= 300 y 720 g seedling^{-1} cycle^{-1} N and K_2O, respectively y 38 g seedling^{-1} P_2O_5 only applied in the cycle of PM[B]; HMA= Plants inoculated with efficient strain for this type of soil[C] in the nursery phase and in field transplant. PM= Mother plant, V-1= Stem-1, V-2= Stem-2.

Figure 3. Effect of the application of *R. intraradices* and organ-mineral fertilization on the yield of cv. 'FHIA-18' in soil Carbonated softwood in cycles PM, V-1 and V-2 (A) and accumulated total

Table III. Effect of the application of HMA and mineral and organ-mineral fertilizer on cv. 'FHIA-18' on the percentage of mycorrhizal colonization and the number of HMA spores in 0-20 cm depth

Treatment	Colonization (%) PM	Colonization (%) V-1	Colonization (%) V-2	No. of spores (spores 50 g^{-1} soil) PM	No. of spores V-1	No. of spores V-2
Absolute control	13,50 c	16,50 c	9,50 c	47,50 c	38,25 c	31,25 b
HMA	51,75 b	54,50 b	49,25 b	191,75 b	259,00 b	98,75 b
75 % NPK	13,75 c	15,75 c	10,00 c	53,75 c	32,50 c	35,00 b
75 % NPK + HMA	61,00 a	63,25 a	56,00 a	353,75 a	458,50 a	292,75 a
100 % NPK	14,25 c	16,25 c	10,50 c	61,75 c	45,25 c	40,50 b
75 % FOM	12,75 c	15,25 c	10,50 c	54,25 c	50,75 c	47,25 b
75 % FOM + HMA	61,25 a	63,25 a	57,50 a	365,50 a	424,25 a	332,50 a
100 % FOM	13,75 c	15,75 c	11,50 c	65,75 c	60,00 c	58,25 b
100 % FOM + HMA	60,00 a	61,75 a	56,75 a	220,25 b	137,75 bc	111,00 b
Es $\bar{x}$ =	0,93**	1,10**	0,80**	36,21**	42,82**	27,89**

Different letters imply significant differences (p≤0.05) according to the Tukey Test

100 % NPK= 300 y 720 g seedling^{-1} cycle^{-1} N and K_2O, respectively and 38 g seedling^{-1} de P_2O_5 only applied in the cycle of PM[B]; 75 % NPK= 225, 29 y 540 g seedling^{-1} cycle^{-1} de N, P_2O_5 y K_2O, respectively; 100 % FOM= 20 y 10 kg plant^{-1} cycle^{-1} compost and ash[B], respectively; 75 % FOM= 15 y 7,5 kg plant^{-1} cycle^{-1} de compost and ash, respectively; HMA= Plants inoculated with an efficient strain for this soil type[C] in the nursery stage and in field transplant. PM = Mother Plant; V-1 = Stem-1; V-2 = Rod-2

Inoculated treatments that did not receive fertilizers or that received 100 % of the organic-mineral fertilization had significantly lower values than those previously mentioned, although all were superior to the non-inoculated treatments.

In general, the highest values of spore numbers were found in V-1, which were slightly higher than those found in PM and higher than those found in V-2, and these variations did not influence the general behavior of The treatments described above.

Effect of HMA and dose inoculation of mineral and organic-mineral fertilizers on foliar concentrations (N, P, K, g kg^{-1}) in plantations of the cv. 'FHIA-18'

Significant differences were found between treatments in any of the three cycles evaluated (Table IV), so that the highest concentrations of leaf nitrogen were found in the treatments that did not receive fertilizer application, while the lowest concentrations were found in the Treatments that received the highest doses of mineral or organic-mineral fertilizers or inoculated treatments that received fertilization. Uninoculated treatments receiving doses of 75 % of the fertilizer requirements presented mean values of N concentration.

Likewise, a tendency was observed for the decrease of the concentrations of foliar nitrogen according to the cycles of the plantation.

In the case of the foliar concentration of P (Table IV) no differences between treatments were found, presenting similar concentrations ranging from 0.20 to 0.22 %. This behavior manifested itself in an analogous way in each cycle evaluated.

There was a marked positive and significant effect of fertilization, both mineral and organic-mineral, on leaf potassium concentrations (Table IV), an effect that occurred in any of the cycles.

A positive effect of inoculation with *R. intraradices* in the presence of doses of mineral or organic-mineral fertilizers on foliar potassium concentrations was found, so that these treatments had higher concentrations of potassium than the non-inoculated homologous treatments and Similar to the concentrations obtained with the treatments that received the highest amounts of fertilizers.

In general, no effect of the cycles on foliar potassium concentrations was found and the differences between treatments were manifested in a similar way in each cycle.

On the other hand, similar foliar concentrations (N, P and K) were found, both in the inoculated treatment that did not receive fertilizers and in the control treatment that did not receive any application.

The results of this study made clear the important nitrogen and potassium fertilizer requirements of banana[E], as well as the equivalence between the recommended doses of both mineral and organic-mineral fertilization for this crop in the country[B]. The organic-mineral fertilization with 20 and 10 kg plant^{-1} cycle^{-1} of compost and ash, respectively, was able to guarantee throughout the three crop cycles studied the nutritional requirements and the high yields of the banana grown in soils Carbonated soft ducks.

Inoculation with *R. intraradices*, together with the application of 75 % of the mineral or organic-mineral fertilizer doses recommended to guarantee the nutritional requirements of bananas, was highly effective.

Table IV. Effect of the application of HMA and mineral and organ mineral fertilizer on the foliar concentration of N, P and K (%) evaluated in the middle leaf of the III leaf in flowering cv. 'FHIA-18' on a soft Carbonated Brown Soil

Treatment	Cycle Mother plant			Cycle Stem-1			Cycle Stem-2		
	N	P	K	N	P	K	N	P	K
				(g kg^{-1} of the dry mass)					
Control	32,3 ab	2,1	22,9 c	30,5 a	2,2	24,1 c	29,3 a	2,1	22,6 c
HMA	32,9 a	2,0	22,1 c	30,0 a	2,2	24,6 c	28,9 a	2,0	22,0 c
75 % NPK	30,0 abc	2,0	29,3 b	27,8 ab	2,2	30,8 b	25,6 bc	2,2	29,4 b
75 % NPK + HMA	29,1 bcd	2,1	33,3 a	26,3 b	2,2	35,5 a	24,6 bcd	2,2	36,9 a
100 % NPK	28,7 cd	2,1	34,4 a	25,9 b	2,2	36,0 a	23,1 d	2,2	37,0 a
75 % FOM	29,4 bcd	2,0	27,9 b	27,5 ab	2,1	30,6 b	26,4 b	2,0	29,0 b
75 % FOM + HMA	26,3 d	2,0	33,5 a	25,3 b	2,2	34,8 a	23,9 cd	2,1	35,3 a
100 % FOM	27,0 cd	2,0	33,6 a	25,3 b	2,1	35,1 a	24,3 bcd	2,1	34,8 a
100 % FOM + HMA	28,1 cd	2,1	34,1 a	26,1 b	2,1	35,4 a	24,9 bcd	2,1	35,1 a
Es $\bar{x}$ =	0,10**	0,01 ns	0,10**	0,09**	0,01 ns	0,05**	0,07**	0,02 ns	0,12**

Different letters imply significant differences (p≤0.05) according to the Tukey Test

100 % NPK= 300 y 720 g seedling^{-1} cycle^{-1} N and K_2O, respectively and 38 g seedling^{-1} de P_2O_5 only applied in the cycle of PM[B]; 75 % NPK= 225, 29 y 540 g seedling^{-1} cycle^{-1} de N, P_2O_5 y K_2O, respectively; 100 % FOM= 20 y 10 kg plant^{-1} cycle^{-1} compost and ash[B], respectively; 75 % FOM= 15 y 7,5 kg plant^{-1} cycle^{-1} de compost and ash, respectively; HMA= Plants inoculated with an efficient strain for this soil type[C] in the nursery stage and in field transplant. PM = Mother Plant; V-1 = Stem-1; V-2 = Rod-2

This combination ensured high yields and nutritional requirements[E], and made clear the effectiveness of *R. intraradices* for bananas in softwoods[C]. On the other hand, it corroborated the criteria that an effective mycorrhizal function increases the absorption of the nutrients of the soil and the fertilizers (30, 31).

Thus, if plants inoculated with efficient strains of HMA require an adequate supply of nutrients for optimum mycorrhizal functioning and thus obtain the benefits of mycorrhization, this supply will be lower than the requirements of fertilizers of the same Non-inoculated culture[C, F] (13).

The percentage decrease in fertilizer requirements for 'FHIA-18' inoculated plantations, coincides with the percentages previously obtained in 'Burro CEMSA' banana in this same soil and inoculated with the same HMA strain (16).

The results related to the use of organic-mineral fertilization agree with what has been reported in the literature[B] (17, 32). The application of mycorrhizal inoculants led to decreases in the requirements of these fertilizers, as found in coffee and pastures[F, G] (17).

Also the application of compost and ash, by influencing soil structure, pH, nutrient content, moisture retention and favoring the proliferation of microbial communities in the soil, could have led to more favorable conditions to guarantee the effectiveness Of the inoculation and to obtain beneficial effects on the mycorrhizal functioning (33, 34).

The inferior behavior of the plants in the inoculated treatment that did not receive complementary doses of fertilizers in the different mycorrhizal variables, yield and nutritional status, corroborated the need for an adequate supply of nutrients to the inoculated plants to guarantee an optimal mycorrhizal functioning, nutritional status And, therefore, higher yields. This had already been obtained both in roots and tubers, tobacco, Brachiaria pastures, and in production of coffee and fruit stands[C, F, G] (35, 36), among other crops.

That is, inoculation with an efficient strain of AMF will not be effective if the nutrient supply is not adequate to ensure an efficient mycorrhizal function (13) and may reach the point where there is practically no inoculation effect in the absence of fertilizers, as in this case.

The different treatments not inoculated in the presence or absence of mineral and organic-mineral fertilizers had lower values in the percentages of mycorrhizal colonization and spore production, in relation to the treatments inoculated and that received fertilizers. This behavior makes it clear that the level of performance obtained with resident HMA strains was low and should be related to the low amounts of initial HMA spores and indicating the need to inoculate under these conditions to obtain the benefits of arbuscular mycorrhizal symbiosis.

Positive response to inoculation with *R. intraradices* has been found in this type of soil, not only in the presence of low initial amounts of spores[C] (24), but even in the presence of 400 spores 50 g^{-1} of soil of resident strains H, indicating that the positive response to Inoculation is not only in soils with low amounts of resident spores.

Although the percentage of colonization and the production of spores presented the highest values in the inoculated treatments that received 75 % of the fertilization and in correspondence with the higher yields and concentration of foliar potassium, indicative of an optimal mycorrhizal function , Inoculation in the presence of higher doses of organic-mineral fertilizers caused a differentiated behavior between colonization rates and the number of spores in the soil.

In this treatment the amounts of spores appeared more sensitive to reflect variations in mycorrhizal functioning than the percentage of colonization, since high nutrient supplies are generally not favorable for optimal performance (18, 37). Although the percentages of mycorrhizal colonization obtained in this treatment were high, the spore contents decreased significantly in relation to the inoculated treatment that received 75 % of the FOM, being even similar to the inoculated treatment that did not receive any fertilizer and whose General behavior was lower.

This type of behavior of the spores, reflecting a greater sensitivity than the colonization rates as indicative of the mycorrhizal functioning, has been found previously when evaluating the influence of different soil characteristics on the effectiveness of *G. cubense*[I].

[F] Fernández, M.F. *Efecto del manejo de las asociaciones micorrízicas arbusculares sobre la producción de posturas del cafeto* (*C. arabica* L.) [Tesis de Doctorado], Universidad Agraria de La Habana. Instituto Nacional de Ciencias Agrícolas, La Habana, Cuba, 1999, 102 p.

[G] Sánchez, C. *Uso y manejo de los hongos micorrizógenos arbusculares y los abonos verdes en la producción de posturas de cafeto* (*C. arabica* L.) *en algunos suelos del macizo Guamuaya* [Tesis Doctorado], Universidad Agraria de La Habana. Instituto Nacional de Ciencias Agrícolas, La Habana, Cuba, 2001, 103 p.

[H] González, P. *Comunicación personal*, 2014.

[I] Rivera, R. *Informe anual del proyecto P131LH0010003*, Instituto Nacional de Ciencias Agrícolas, 2013, 20 p.

In that study it was found that *G. cubense*, a strain that shows a good performance above pH 6, at pH close to 5, practically did not produce spores; However, colonization rates did remain high (65 %) at these pH levels. As the pH continued to decrease to 4.5, both spores and percentages of mycorrhizal colonization were minimal.

According to the above, the spores could be taken into account as indicators of the functioning and efficiency of an HMA strain and, especially, from the existence of the permanence effect of the initial inoculation[C, H] (38), which is related to the Own reproduction of propagules that performs the inoculated crop and for which the edaphic environment is required. That is, the effect of an efficient HMA strain is not only established through the initial inoculation obtained with the inoculated culture, but also the ability to guarantee the permanence effect, at least with the first subsequent culture (18).

The foliar concentrations of N, P and K found indicated the importance and necessity of the supply of these nutrients to the plantation.

In relation to the foliar concentration of phosphorus, the results corroborate the low need of phosphoric fertilizer for the crop obtained, both internationally (39) and in Cuba[E], therefore the doses used in the crop are generally low, being very frequent Long-term applications, once for several years[B].

Leaf nitrogen concentration showed a very different behavior, higher concentrations were associated with treatments with lower yields and vice versa, indicating the existence of a dilution effect and the fact that it was not a limiting element in these conditions. Likewise, a decrease in the concentration of nutrients in leaf III flowering in banana cultivation has been observed in the plants with the greatest growth and development[E].

A very different behavior reflected the concentrations of leaf potassium in the three cycles evaluated, with a direct response to fertilization, either mineral or organic-mineral, being the values obtained with the highest amounts of fertilizers, indicative of adequate potassium nutrition in any of the cycles[E].

This behavior indicated that potassium was the determinant element in banana nutrition in this experiment, directly relating its concentrations to the yield of the plantation.

Inoculation with *R. intraradices* in the presence of mean doses of fertilizers guaranteed adequate foliar potassium levels and similar to those obtained with the highest doses of fertilizers in the absence of inoculation.

Although the international literature does not commonly reflect a direct effect of arbuscular mycorrhizal symbiosis on potassium uptake, relatively recent works with ^{86}Rb[J] as K tracer and *M. truncatula* plants inoculated with *G. clarum* and *G. intraradices* spores strict conditions of *in vitro* culture demonstrated the functionality of the symbiosis in an autotrophic system of culture totally *in vitro*, through the transport of ^{86}Rb by the extrarradical hyphae of these strains of HMA, to the aerial system of plants of *M. truncatula*, which indicates their participation in the acquisition and translocation of K to plants.

When integrating the results reported in this type of soil with the inoculation with *R. intraradices* in different crops such as cassava, sweet potato, malanga, pasture, coffee, characteristics and nutritional balances varied[C, G] (13), with those found in a crop Potashophile as banana and with few requirements of phosphorus[E], is in agreement with approaches made by other authors (13).

In them it is emphasized that HMAs when associated with their hosts behave more like extensors of the radical system, contributing to increase the absorption of nutrients and it is the plant based on their needs, which selects which elements they enter or not.

A very interesting aspect is that the positive effects of the inoculation in the presence of the 75 % fertilization doses, on the yield as well as on the variables of mycorrhizal functioning and the concentrations of foliar potassium, were obtained in each one of the three cycles studied.

If we start from the inoculation that was performed at the time of transplantation, it is clear that this culture maintains a permanence effect of the initial inoculation that is transmitted from one cycle to another, possibly associated with the fact that the successive growth of the children with the active development and mycorrhizal functioning of the preceding cycle.

This behavior should not be unrelated to the fact that, due to the high water requirements of banana, it was always guaranteed adequate irrigation.

These conditions, together with the fact that it is a tropical crop adapted to high temperatures, as well as the complementary applications of fertilizers, caused me to maintain the mycorrhizal functioning throughout the plantation, which does not seem to be a general behavior for others Perennial crops such as fruit trees or coffee.

[J] Fernández, K. *Establecimiento de un sistema eficiente de micorrización in vitro de plántulas de Solanum tuberosum* L. *y Medicago truncatula* Gaertn [Tesis de Doctorado], Universidad de La Habana, Instituto Nacional de Ciencias Agrícolas, La Habana, Cuba, 2013, 117 p.

In permanent forage areas, in this same type of soil inoculated with *R. intraradices*, as the *Brachiaria* grasses under intensive cutting systems, it has been found that the effect of the initial inoculation is maintained from one to two years, depending on The species of grass. However, the spore numbers that indicated the need to reinoculate were 600 spores 50 g^{-1} of soil, higher than those found in inoculated treatments that received 75 % of the fertilization and indicated that in bananas, The spore contents of about 350 spores 50 g^{-1} of soil maintain mycorrhizal functioning from one cycle to another.

Also, in sequences of cultures inoculated with this same strain of HMA and in this soil has been verified that the effect of permanence of the inoculation was only adequately expressed on the first culture after inoculation[C, K]. Therefore, it seems that the very way of vegetatively reproducing bananas, guaranteed conditions to maintain optimal mycorrhizal functioning in the plantation.

CONCLUSIONS

- A positive response to inoculation with *R. intraradices* was found in banana cv. 'FHIA-18' cultivated in soft carbonated Pardo soil, guaranteeing high yields, percentages of mycorrhizal colonization and production of HMA spores, as well as adequate nutritional contents with a decrease in the requirements of mineral or organic-mineral fertilizers.
- The inoculation with HMA performed in the transplant, maintained its effectiveness and permanence in the three productive cycles evaluated. It was found that the amounts of recommended organic-mineral fertilizers completely replaced the mineral fertilization.
- Foliar concentrations of potassium were directly associated with yield and with banana response to mycorrhizal inoculation.

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Recibido: 14 de abril de 2014
Aceptado: 8 de diciembre de 2014