Scientific Paper

Effect of biological fertilization alternatives on agricultural yield traits of *Sorghum bicolor* (L.) Moench cv. UDG-110

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Abstract

Objective: To characterize the effect of biological fertilization alternatives on the agricultural yield performance of *Sorghum bicolor* (L.) Moench cv. UDG-110 under field conditions.

Materials and Methods: Six treatments were evaluated: I) control without fertilizer; II) Agromenas-G- 1,5 t/ha; III) earthworm humus – 4,0 t/ha; IV) Agromenas-G 1,5 t/ha + FitoMas-E® L/ha, V) earthworm humus 4,0 t/ha + FitoMas-E® L/ha and VI) absolute control with complete formula (9-13-17), 140 kg contributed at two moments: 50 % in the furrow at sowing and 50 % at 25 days. The indicators grain weight /panicle (number), grains/panicle and total biomass in 0,75 m^2 were evaluated. Data were processed by simple variance analysis for 5 % of significance.

Results: For the variables weight and number of grains per panicle, significant differences were found among the different treatments ($p \leq 0,05$). Treatment VI showed the best performance (51,8 and 1 468,2 g; respectively); while treatment I showed the lowest values (34,2 and 1 006,8 g; respectively). This performance was similar for panicle weight. Regarding grain yield, VI also stood out, with yields of 0,7 t/ha, which is a significant difference with regards to the other treatments ($p \leq 0,05$). III and V, with no differences between them, had yields of 0,6 and 0,5 t/ha, respectively. However, the control treatment had the lowest value, with yields of 0,3 t/ha, differing from the others.

Conclusions: Biological fertilization is a viable option for the production of *S. bicolor* cv. UDG-110, since with its use the evaluated yield traits showed acceptable results.

Keywords: biomass, grains, inflorescences

Introduction

Sorghum bicolor (L.) Moench (sorghum) is a C_4 metabolism plant that is well adapted to a hot and dry agroecological environment, in which it is difficult to grow other cereals (Martínez-Medina *et al*., 2016). It is a grass native to tropical and subtropical regions of Africa. This cereal constitutes an excellent foodstuff for human and animal nutrition; for the latter it is used in pig, cattle and poultry nutrition (Demanet-Filippi and Canales-Cartes, 2020).

The Republic of Cuba invests large amounts in the importation of grains and concentrate feeds for human and animal nutrition, in order to produce and supply the protein needs (increasingly greater and today unsatisfied) to a growing population. The costs of these foodstuffs are increasingly higher and, in turn, are difficult to acquire on the international market for various economic, political and social reasons. The country must solve serious problems for import substitution with the use of grains such as *S. bicolor* (Pérez *et al*., 2010).

A limiting factor in the use of *S. bicolor* for dual purpose is the nutritional quality of the stubble, because digestible energy, crude protein and minerals are low (Venkateswaran *et al*., 2019). Among the strategies developed to increase production volumes of this crop are the introduction of *S. bicolor* varieties from the Autonomous University of Nuevo Leon (UANL, for its initials in Spanish), Mexico. These varieties have been studied in Cuba by the Agricultural Research Center (CIAP, for its initials in Spanish) of the Central University Marta Abreu of Las Villas. Research has also been conducted on the application of organic fertilizers, an activity that according to Chisi and Peterson (2018) is of significant importance, since organic matter, especially humus, is the basic support for life in this environment; in addition to the fact that it can define its productive potential. In this regard, biological fertilizers (earthworm humus, filter cake, poultry manure, among others), as well as natural minerals and residues (zeolite, dolomite,

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Agromenas-G), contain useful elements for the improvement of the physical-chemical properties of the soil and, consequently, of crops as natural products that increase the availability of nutrients in the soil and generate substances that stimulate plant growth. This is translated into more organic and sustainable agriculture, besides having a positive impact on the balance of microbial populations living in the soil.

In addition, it is necessary to sustainably increase cereal production as an alternative to contribute to food security and meet the needs of the people. This has led farmers to seek to increase their production levels and achieve higher yields by using different species and varieties, as well as fertilization alternatives. In view of this, the objective of this work was to characterize the effect of biological fertilization alternatives on the agricultural yield of *S. bicolor* cv. UDG-110 under field conditions.

Materials and Methods

Location of the experimental area. The study was carried out at the Pastures and Forages Research Station Indio Hatuey, located in the central zone of Matanzas province, in the Perico municipality, at 22º 48' and 7'' North latitude and 79º 32'' and 2'' West longitude, at an altitude of 19.01 masl. (Hernández-Venereo, 2000).

Soil. The experiment was conducted on a flat topography soil, with a slope of 0,5 to 1,0 %, classified as leached Ferrallitic Red (Hernández-Jiménez *et al*., 2015).

Experimental design and treatments. A randomized block experimental design was applied, with six treatments and four replicas each. The indicator plant used was grain *S. bicolor*, cv. UDG-110. The following treatments were applied: I) control without fertilizer, II) Agromenas-G- 1,5 t/ha, III) earthworm humus – 4,0 t/ha, IV) Agromenas-G 1,5 t/ha + FitoMas-E® 1 L/ha, V) earthworm humus 4,0 t/ha + FitoMas-E® 1 L/ha, VI) absolute control: complete formula (9-13-17) 140 kg contributed 50 % in the furrow at sowing and 50 % after 25 days.

Experimental procedure. Once the soil preparation was completed and the area was furrowed, the plots were marked in the field with stakes and strings, according to the randomized block scheme. Each plot was identified with signs indicating the location of the treatments.

The following formula was used to calculate the amount of fertilizer to be applied in each plot:

$$y = a \times b/c \times 100$$

where:

y = amount of fertilizer to be applied on the plot area in kg
a = nutrient dose kg/ha
b = plot area m^2
c = nutrient content in percentage of the fertilizer carrier

For the application of Agromenas-G the same procedure was used. In the case of earthworm humus, it was calculated using the same formula. For the foliar application of FitoMas-E®, Jacto backpacks were used, with a capacity of 16 L of water for the dissolution of FitoMas-E® at a rate of one liter/ha. Fertilization work was organized by treatments and replications on different days, although in all cases the method was applied locally at the bottom of the furrow.

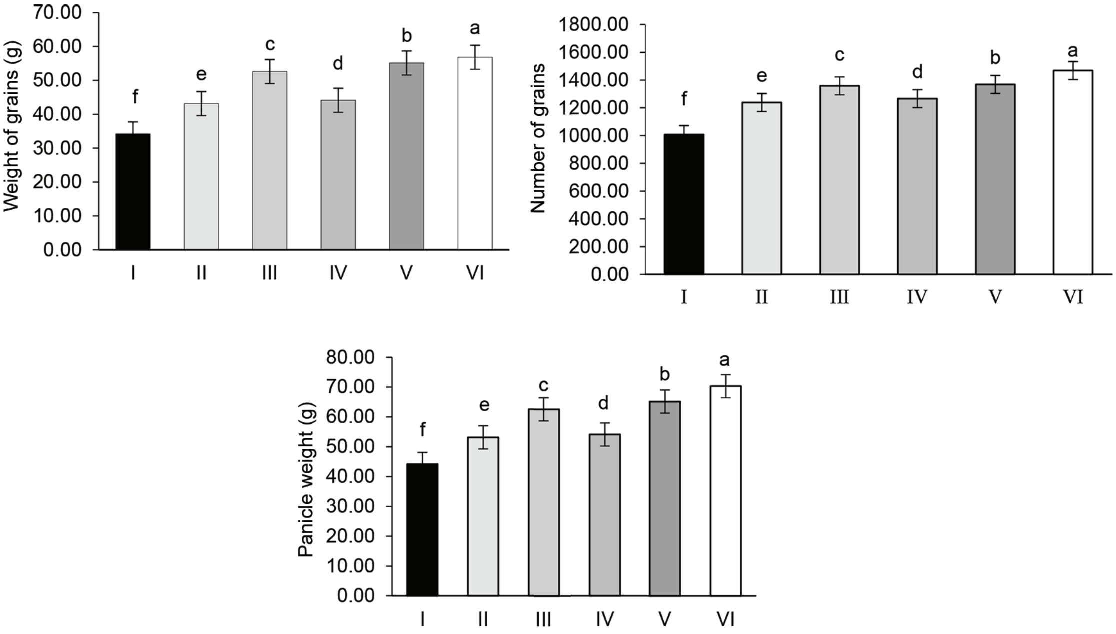
The experiment was planted in strips or plots of 10 furrows each, 7,50 m wide and 10 m long for an area of 75 m² for each treatment, represented in 24 plots in a net experimental area of 0,18 ha and a gross area of 0,307 ha. Measurements were made in 10 subplots or replicas, of 0,75 x 1,00 m, randomly distributed.

Evaluation of agricultural yield traits. To determine the performance of the studied cultivar, the following indicators were evaluated, according to Martínez-Medina *et al*. (2016): grain/panicle weight (g), number of grains/panicle (u), agricultural yield (t/ha) and total biomass in 0,75 m^2. Total plants (all 40 plants per treatments) were manually cut and weighed at the time of cutting. Forage weight was expressed in kg.

Statistical analysis. The results were subject to variance analysis, according to a simple linear classification model. Means were compared using Duncan's test, for 5 % significance, after verifying that they complied with the normal distribution and homogeneity of variance. They were also processed by principal component analysis; as analysis criteria those principal components that showed eigenvalues higher than 1 and sum factors or preponderance factors higher than 0,70, were taken. Correlation analysis (*Pearson*) was also used. The statistical program SPSS® version 22,0 for Microsoft® Windows® was used for this purpose.

Results and Discussion

Since the indicators showed uniformity in their performance, they were analyzed together (figure 1). Significant differences were found in the weight



a, b, c, d, e and f: Different letters mean that there are significant differences for $p \leq 0,05$.
I- no fertilizer control; II- 1,5 t/ha Agromenas-G; III- 4,0 t/ha earthwom humus; IV- 1,5 t/ha Agromenas-G + 1 L/ha FitoMas-E®; V- 4,0 t/ha earthworm humus + 1 L/ha FitoMas-E®; VI- absolute control: complete formula.

Figure 1. Performance of number and weight of grains per panicle and panicle weight.

and number of grains per panicle among the different treatments. Treatment VI showed the best performance, with a weight of 51,8 g and 1 468,2 grains per panicle. Treatment I showed the lowest values, with 34,2 g and 1 006,8 grains per panicle. In addition, a difference in panicle weight was observed ($p \leq 0,05$), with the best result in VI. This is due to the fact that the use of chemical fertilizer allows an adequate supply of nitrogen. This is an essential element for plant growth and metabolism. Its absence can be a limiting factor in plant development. In terms of importance, nitrogen metabolism is the second most important plant process, second only to photosynthesis.

N metabolism involves complex systems of absorption, assimilation and mobilization, which are always present in all species. According to reports by Pecina-Quintero *et al.* (2017), this nutrient is the most demanded in different crops, so it has been declared as the most important in the initial development of most of them. Demanet-Filippi and Canales-Cartes (2020) state that it is essential for the uptake and formation of carbon compounds required in the formation of new organs in the plant.

It is worth mentioning that the amount of N required by plants varies according to crop characteristics (species, variety, stage of development, production level, among others), climate factors (mainly humidity and temperature), soil properties (physical, chemical and biological) and plantation management. Madrigales-Reátiga (2019), who obtained similar results, refers that this is an element related to all metabolic pathways of plants, and that it directly and indirectly promotes greater photosynthetic activity and, consequently, higher biomass accumulation.

It is significant to note that studies on plant nutrition often focus on the effect of nitrogen fertilization, since N is the nutrient required in the greatest quantity and the one that probably limits carbon gain the most. The presence of N in any of the combinations, independent from the presence of potassium or phosphorus, favors total chlorophyll synthesis. This aspect has been reported by different authors. Cuitiño *et al.* (2021) point out that this occurs because N favors Mg absorption, which influences chlorophyll synthesis.

This also has an impact on the increase in soluble carbohydrate content and soluble protein content, which, in turn, is related to photosynthesis. In this process, soluble sugars are produced from CO_2 and H_2O, but this cannot be done without the production of proteins, enzymes and electron transfer molecules, such as chlorophyll, ADP and ATP, organic molecules that have N and phosphorus as fundamental constituents.

Grain weight also depends on the genetic factor, as well as on the plant's capacity to store dry matter, since the final grain weight depends on the produced dry matter. The descriptor grain weight has very little influence from the environment and is fundamentally linked to the characteristics of each variety. This variable demonstrates the capacity to transfer nutrients accumulated by the plant during its vegetative development and that are directed to the grain in the reproductive stage (Salas-López *et al*., 2018). It also refers to climate, soil fertility and available water.

In the case of the number of grains, this performance may be due to the fact that, in all treatments, leaf senescence was present, due to the fact that the panicles had to be bagged at harvest, because of attacks by birds, also called granivorous birds, which may have hindered photosynthetic activity due to the low absorption of solar radiation and, therefore, may have affected the final grain yield. These results agree with those reported by Pérez *et al*. (2010) and García-Centeno *et al*. (2010). The number of grains is frequently correlated with final grain yield and is influenced by the number of inflorescences, spikelets per inflorescence, florets per spikelet and the proportion of florets that produce grain. Panicle development from initiation to anthesis is important, as the highest limit of grain number is established during this period (Morell-Acosta *et al*., 2018).

Grain yield is also the result of several biological and environmental factors that are correlated and then expressed in yield. Approximately, 90 % of grain yield is due to photosynthesis in the panicle and the four upper leaves. Fariza *et al*. (2017) state that panicle length is one of the most important components in *S. bicolor* yield. A single panicle can produce 24 to 100 million pollen grains. Larger panicles have a higher number of spikelets and, therefore, a greater number of grains.

Panicle weight is of great importance when considering yield. The latter depends on the quality, quantity and size of grains, especially when strongly influenced by N supply (Cuitiño *et al*., 2021). Cardona-Fuentes (2018) indicated that yield is the product of the radiation intercepted by the foliage during its cycle, its conversion into biomass through photosynthesis and the distribution in dry matter towards the harvested fraction.

In terms of grain yield, the best performing treatment was VI (0,7 t/ha), which differed significantly from the others, followed by III and V (without differences between them 0,5 and 0,60 t/ha). The least valuable was the control, which differed from the others (0,3 t/ha). Dry matter content varied between the percentages recommended (table 1) by literature (20,7 and 24,8 %).

Similar results were described by Cortes-Ramírez (2018) and Parra (2022), who assert that this is due to the ability of plants to adapt to different environments. In the same way, they ascribe it to the organic matter content present in the soil, since this and a high content of nutrients are preferred by *S. bicolor*. However, this does not prevent

Table 1. Yield indicators and dry matter content.

Treatment	Grain yield, t/ha	Biomass yield, t/ha	Dry matter content, %
I	0,3^{d}	20,0^{d}	20,7^{c}
II	0,4^{c}	24,5^{c}	21,3^{b}
III	0,6^{b}	30,0^{b}	24,5^{a}
IV	0,5^{c}	24,0^{c}	21,5^{b}
V	0,6^{b}	29,0^{b}	24,7^{a}
VI	0,7^{a}	32,0^{a}	24,8^{a}
P - value	0,0001	0,0001	0,0003
SE ±	0,02	1,3	1,1

Unequal letters in the same column differ for $p \leq 0,05$ by Duncan.
I- control (no fertilizers); II- 1,5 t/ha Agromenas-G; III- 4,0 t/ha earthworm humus; IV- 1,5 t/ha Agromenas-G + 1 l/ha FitoMas-E®; V- 4,0 t/ha earthworm humus + 1 l/ha FitoMas-E®; VI- absolute control: complete formula.

the crop from adapting to different soil types in any environment. Alejandro-Allende *et al.* (2020) proposed that the type of root that this plant has allows it to explore a greater volume of soil, in addition to being more efficient in the absorption of nutrients and water. This shows that organic fertilizers, in addition to being a good source of nutrients, can provide them in a timely manner according to crop demand.

Likewise, these results could be due to the genotype-environment interaction, which causes plants to manifest themselves according to the environment in which they develop, regardless of the fact that climate factors (especially temperatures), which increase grain yield of *S. bicolor* and vary according to soil fertility, could also have had an influence. Cortes-Ramírez (2018) indicates that numerous processes involved in plant physiology, such as radiation intensity, amount of light, availability of water and nutrients, affect the final yield of the crop.

As for treatment VI, the performance is logical, because chemical fertilizers are assimilated by plants more rapidly than organic fertilizers, in addition to the amount of N and other macroelements they provide.

Regarding dry matter content, there were no significant differences between treatments VI, V and III, which reached 24,8; 24,7 and 24,5 %, respectively. These results differ from those reported by Martínez-Medina *et al.* (2016) and Ramos-Chic (2018), who with a group of *S. bicolor* varieties, under different soil and climate conditions, found that forage dry matter content did not exceed 18,0 %. However, in this study, cv. UDG-110 with the effect of the six treatments varied between 20,7 and 24,8 %, which validates its use as forage. In addition, Pérez *et al.* (2010) described the bromatological composition of *S. bicolor* (24 % DM; 68,6 % carbohydrates; 2,10 % protein; 3,41 % fat; 3,92 % fiber; 0,11 % condensed tannins; 1,72 % ash; and 1 440 caloric content, kj g^{-1}).

In general, and despite the fact that the best results were achieved in terms of yield indicators with treatment VI (complete formula fertilization), it can be affirmed that the use of biological fertilization alternatives is possible, since with treatment III (earthworm humus), good results were also achieved. This was followed by the combination of earthworm humus with FitoMas-E® (treatment V).

Table 2 shows the correlation among the evaluated indicators. Due to the importance ascribed to the interrelationships between yield and its components, the existence of strong and positive correlations can be highlighted. Reports by Parra (2022) show similar results in this regard.

Table 2. Matrix of phenotypical correlations.

Indicator	PW	NG	TBW	WG
PW, cm	-			
NG	**0,930**	-		
TBW, kg	**0,950**	**0,990**	-	
WG, g	**0,950**	**0,970**	**0,990**	-

** Correlation is significant at the 0.05 level.
TBW- total biomass weight, PW- panicle weight, NG- number of grains, WG- weight of grains.

The highest linear correlation was observed among the indicators grain weight, number of grains, panicle and grain weight and total biomass weight. This indicates that as one indicator increased, the other also increased. The above is ratified by the determinant coefficient found (0,006), which was close to zero, and is an indicator that there is a significant correlation structure among the descriptors, thus giving relevance to the factor analysis; in other words, it is an indicator that the descriptors are linearly related. This is corroborated by the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test. A KMO value of 0,855 and a significance of 0,000 were obtained, implying that the factor model was adequate to explain the data (table 3).

In Cuba, the development of high productions of *S. bicolor* constitutes a viable alternative to solve the problem of the feed basis, which is the great obstacle that slows down the growth of livestock, swine and poultry productions. For this reason, and in spite of the fact that the use of chemical fertilizers was the treatment with which the best performance in yield traits was obtained, the use of biological fertilizers is visualized as an option for the production of this crop. With its use, good results were achieved, and in the other treatments no significant differences were observed among them.

It is important to emphasize that by having a good content of organic matter and minerals, the plant will never stop receiving its daily dose of nutrients, so the soil remains fertile with minimal losses, which translates into higher quality plants and fruits.

One of the benefits of organically fertilized plants is that they are less prone to attack by

Table 3. KMO and Bartlett's test of sphericity.

Kaiser-Meyer-Olkin measure of sampling adequacy		0,855
Bartlett's test of sphericity	Approximate Chi-square	2675,10
	gl	28
	Sig.	0,000

potentially pest insects, as they have a more adequate balance of nutrients. It was the French scientist Francis Chaboussou in 1985, who proved the dependence between the nutritional quality of plants and the appearance of pests. This process generates the synthesis of proteins, and when there is a nutritional imbalance, the protein bonds break, splitting into amino acids, which constitute the food basis on which heterotrophic organisms feed to synthesize their own proteins. According to the theory of trophobiosis, the organic defenses of plants against attack by potentially pest insects lie in a balanced content of nutritional substances in the sap or cytoplasm.

Conclusions

Biological fertilization is a viable option for the production of *S. bicolor* cv. UDG-110, since with its use, yield traits showed acceptable results. Yield indicators were not affected with the implementation of biological fertilization alternatives.

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Authors' contributions

- Irma Cáceres Amores. Data collection and processing, manuscript writing and correction.
- Hilda Beatriz Wencomo-Cárdenas. Research advice, development of the experimental design and set-up, data processing and interpretation.
- Orlando Saucedo-Castillo. Genesis of the idea, data collection and interpretation, analysis of results, manuscript preparation and revision.
- Doris Torriente-Díaz. Data collection and processing.
- Yolanda Dora Cáceres-Amores. Data collection, processing and interpretation.

Conflict of interests

The authors declare that there is no conflict of interests among them.

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