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Effect of organic and inorganic fertilization on the growth and yield of *Gossypium hirsutum* L. in Ecuador

Efecto de la fertilización orgánica e inorgánica sobre el crecimiento y rendimiento de *Gossypium hirsutum* L. en Ecuador

Efeito da adubação orgânica e inorgânica no crescimento e rendimento de *Gossypium hirsutum* L. no Equador

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Crop production

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Abstract

The cultivation of cotton (*Gossypium hirsutum* L.) has a significant impact on the global economic and agricultural sectors, with its productivity being closely linked to nutrient management and the sustainability of the production system. The objective of this study was to evaluate the effect of organic and inorganic fertilization on the growth and yield of *G. hirsutum* in Ecuador. A completely randomized block design was used with a 2×4×2 factorial arrangement, which included two nitrogen sources (organic matter and urea), four nitrogen fertilization rates (50, 100, 150, and 200 kg $N.ha^{-1}$), and the presence or absence of efficient microorganisms (EM). Phenological, morphometric, and yield-related variables were measured, along with foliar concentrations of N, P, and K. The results indicated that urea fertilization promoted greater vegetative growth and yield, while organic matter enhanced foliar potassium uptake. The application of efficient microorganisms (EM) did not produce statistically significant differences compared to the control treatment across all evaluated variables, as it significantly increased yield. Moreover, the interaction between nitrogen sources and fertilization rates showed that the combination of 150 kg $N.ha^{-1}$ with EM optimized production. Inorganic fertilization with urea maximized cotton productivity, while organic matter contributed to a more sustainable production system, promoting sustainable agriculture.

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Resumen

El cultivo del algodón (*Gossypium hirsutum* L.) tiene una alta repercusión en la actividad económica y agrícola a nivel mundial, su productividad está estrechamente relacionada con el manejo nutricional y la sostenibilidad del sistema productivo. El objetivo de la investigación fue evaluar el efecto de la fertilización orgánica e inorgánica sobre el crecimiento y rendimiento de *G. hirsutum* en Ecuador. Se empleó un diseño de bloques completamente al azar con un arreglo factorial 2×4×2, que incluyó dos fuentes de nitrógeno (materia orgánica y urea), cuatro dosis de fertilización nitrogenada (50, 100, 150 y 200 kg $N.ha^{-1}$) y la presencia o ausencia de microorganismos eficientes (ME). Se midieron variables fenológicas, morfométricas y productivas, así como la concentración foliar de N, P y K. Los resultados indicaron que la fertilización con urea promovió un mayor crecimiento vegetativo y rendimiento, mientras que la materia orgánica favoreció la absorción de potasio foliar. La aplicación de ME no generó diferencias estadísticamente significativas con respecto al tratamiento testigo en todas las variables evaluadas, ya que incrementó significativamente el rendimiento. Asimismo, la interacción entre fuentes nitrogenadas y dosis mostró que la combinación de 150 kg $N.ha^{-1}$ con ME optimizó la producción. La fertilización inorgánica con urea maximizó la productividad del algodón, mientras que la materia orgánica contribuyó a un sistema productivo, promoviendo una agricultura sostenible.

Palabras clave: nutrición vegetal, fertilización sostenible, algodón, microorganismos eficientes, productividad agrícola.

Resumo

O cultivo do algodão (*Gossypium hirsutum* L.) desempenha um papel crucial na economia e na agricultura global, sendo sua produtividade diretamente influenciada pelo manejo nutricional e pela sustentabilidade dos sistemas de produção. O objetivo deste estudo foi avaliar o efeito da adubação orgânica e inorgânica no crescimento e rendimento de *G. hirsutum* no Equador. O experimento foi conduzido em um delineamento em blocos completamente casualizados, seguindo um arranjo fatorial 2×4×2, que considerou duas fontes de nitrogênio (matéria orgânica e ureia), quatro doses de adubação nitrogenada (50, 100, 150 e 200 kg $N.ha^{-1}$) e a presença ou ausência de EM. Foram avaliadas variáveis fenológicas, morfométricas e produtivas, além das concentrações foliares de N, P e K. Os resultados indicaram que a fertilização com ureia favoreceu o crescimento vegetativo e o rendimento da cultura, enquanto a matéria orgânica potencializou a absorção foliar de potássio. A aplicação de microrganismos eficientes (ME) não resultou em diferenças estatisticamente significativas em relação ao tratamento controle para todas as variáveis avaliadas, porém aumentou significativamente o rendimento. Além disso, a interação entre fontes e doses de nitrogênio revelou que a combinação de 150 kg $N.ha^{-1}$ com EM otimizou o rendimento do algodão. Conclui-se que a adubação inorgânica com ureia maximizou a produtividade, enquanto a matéria orgânica contribuiu para uma nutrição mineral equilibrada. A integração de EM pode aprimorar a eficiência do sistema produtivo, promovendo uma agricultura mais sustentável.

Palavras-chave: nutrição vegetal, fertilização sustentável, algodão, microrganismos eficientes, produtividade agrícola.

Introduction

Cotton, known as 'white gold' (*Gossypium hirsutum* L.), is a natural fibre widely used in the textile industry and a key resource for the global economy (Bozorov *et al*., 2018). In addition to its fibre, its seeds have a high oil (18-24 %) and protein (20-40 %) content, extending its importance in the food and livestock industry (Li *et al*., 2019). Its cultivation is concentrated in Pakistan, Brazil, the United States, China and India, accounting for 78.5 % of the world's production (Vitale *et al*., 2024). In Ecuador, production is limited, with 1,800 ha cultivated mainly in Guayas and Manabí and 1,200 tonnes per year of production (Chinga *et al*., 2020).

Nitrogen fertilization is crucial for cotton yields, but its intensive use has generated problems such as soil acidification, loss of microbial biodiversity and high production costs (Cañarte *et al*., 2020). In response, the use of organic fertilizers and efficient microorganisms (EM) has emerged as a sustainable alternative, improving soil fertility, optimising nutrient uptake and crop resilience (Wu *et al*., 2023).

Shi *et al*. (2023) suggested that combined fertilization (inorganic + organic fertilization) optimised cotton productivity without compromising fibre quality, when they found statistically significant effects of such combinations on the number of acorns (cotton fruit) per plant and cotton yield by outperforming the control and chemical fertilization. The 75 % chemical and 25 % organic treatment achieved a yield of 479.43 $kg.ha^{-1}$; 12.10 % higher than conventional. There was also a greater stem diameter in the combined treatments, while variables such as plant height, boll biomass and fibre percentage did not show statistical differences.

On the other hand, Hussain *et al*. (2024) reported significant improvements in soil fertility in cotton, with increased levels of nitrogen (7.30 ppm), phosphorus (8.27 ppm) and potassium (178 ppm) when fermented manure was used. A yield of 356.53 $kg.ha^{-1}$ of seed cotton was obtained, 18.7 % higher than the conventional treatment. In addition, improvements in fibre quality were observed, including a higher percentage of fibre obtained after ginning and greater fibre length.

The results found by Wang *et al*. (2024) on the impact of combined fertilization on cotton yield sustainability, where the treatment with 75 % inorganic fertiliser and 25 % organic fertiliser was the most efficient in terms of yield sustainability and soil quality. A significant increase in organic matter, total nitrogen and available phosphorus content was indicated, which improved soil enzyme activity and nutrient uptake efficiency.

In this context, this research evaluated the effect of organic and inorganic fertilization on the growth and yield of *G. hirsutum* in Ecuador, integrating efficient microorganisms as a strategy to improve the sustainability of the production system.

Materials and methods

Experiment location and edaphoclimatic characteristics

The study was conducted from April to September 2019 (rainy season from December to May and dry season from June to November), at La Teodomira Experimental Farm, Faculty of Agronomic Engineering, Technical University of Manabi, Ecuador (01°10'14.834' S, 80°23'27' W; 60 masl) located on the Ecuadorian coast, in a life zone according to the Holdridge system of tropical dry forest (bs-T) (Holdridge, 1978). The mean annual temperature was 27.5 °C, with the presence of deciduous trees, shrubs and herbaceous plants adapted to drought, such as *Ceiba trichistandra*, *Prosopis juliflora* and *Bursera graveolens*, among others. During the experiment, rainfall and temperature data were recorded (Figure 1).

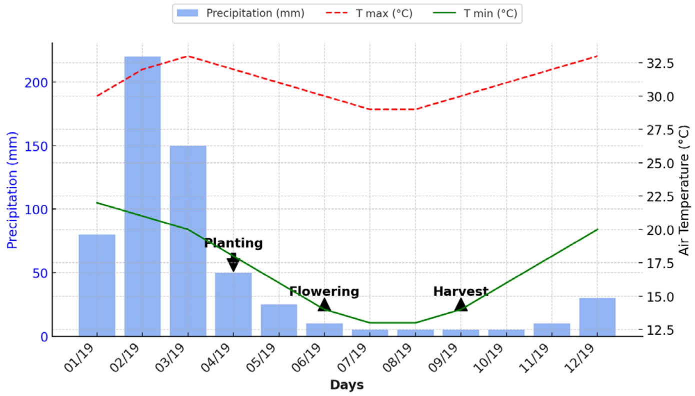

Figure 1. Precipitation and maximum and minimum temperatures recorded at the La Teodomira Experimental Farm, Faculty of Agronomic Engineering, Technical University of Manabí, during the research.

The soil where the sowing was performed has a clay loam texture with a pH of 7.5. It has 0.90 % organic matter and 0.04 % total nitrogen. The available phosphorus content is 17.4 mg.kg^{-1}, while exchangeable potassium is 1.06 mg.kg^{-1}. Calcium and magnesium concentration is 15.25 cmol.kg^{-1} and 5.27 cmol.kg^{-1}, respectively. Hydrogen reaches 26.7 cmol.kg^{-1}. Among the micronutrients, manganese is 5.55 mg.kg^{-1}, cobalt 2.19 mg.kg^{-1} and zinc is <2.60 mg.kg^{-1}.

Plant material and agronomic management

The *G. hirsutum* variety used in this research was DP-Alcalá 90, known for its adaptability, fibre quality and low pest incidence (Cañarte *et al*., 2020). It flowers 51 days after emergence (DDE), reaching an average height of 90 cm and a yield of 1,637.71 kg.ha^{-1} of seed cotton (Rodríguez and Ruiz, 1996). The seeds for this study were provided by the +Cotton Ecuador project, implemented by FAO. Sowing was carried out on 10 April 2019, directly into the soil at a distance of 0.40 m between plants and 1.00 m between rows. Seedling emergence occurred after six days. Harvesting was carried out 140 days after emergence.

The organic matter used in the experiment consisted of bovine manure compost, whose analytical composition was 4 % nitrogen (N), 0.58 % phosphorus (P), 1.58 % potassium (K), 1.42 % calcium (Ca) and 0.50 % magnesium (Mg). This compost was generated by a controlled aerobic decomposition process over a period of 60 days and then applied according to the organic source treatments in each planting furrow prior to planting. Efficient microorganisms (EM) prepared in a 200 L biodigester according to Higa and Parr (1995), consisting of lactic acid bacteria (*Lactobacillus* spp.), photosynthetic bacteria (*Rhodopseudomonas* spp.), fermenting fungi (*Aspergillus* spp., *Saccharomyces* spp.), actinobacteria (*Streptomyces* spp.), nitrogen-fixing bacteria (*Azotobacter* spp.) and yeasts (*Saccharomyces* spp.), with an average concentration of 1×10^6 to 1×10^8 CFU.mL^{-1}, grown under controlled anaerobic conditions for activation.

Experimental design and treatments

A completely randomised block design with a 2×4×2 factorial arrangement was used, in which three factors were evaluated: nitrogen source (organic matter and urea), level of nitrogen fertilization (50, 100, 150 and 200 kg N.ha^{-1}) and presence or absence of efficient microorganisms. As base fertilization in treatments carrying urea, 120 kg.ha^{-1} of P_2O_5 and 60 kg.ha^{-1} of K_2O were applied at sowing (Shareef *et al*., 2019) and nitrogen in the form of urea was applied in two fractions: 50 % at 20 days after emergence (DAE) and the rest at the beginning of flowering (50 DAE). Efficient microorganisms were supplied at three times: 0.5 L.ha^{-1} at sowing, 1 L.ha^{-1} at 20 DAE and 1 L.ha^{-1} at the beginning of flowering (Higa and Parr, 1995). Mepiquat chloride 5 % (1 L.ha^{-1}) was applied at anthesis as a growth controller.

Variables assessed

Growth and yield variables were measured. Flowering was recorded when 50 % of the plants entered anthesis. Plant height and stem diameter were measured at 77 DAE with metric ruler and digital caliper, respectively. The number of acorns-plant^{-1} was quantified at 129 DAE, considering the fully developed acorns. Diameter, length and biomass of acorns, fibre and seeds were measured. Yield was obtained by harvesting the central rows of the useful plots (140 days after sowing) and fibre biomass was determined on an analytical balance. For foliar uptake of N, P and K, five fully developed leaves were collected from 10 plants per treatment at 77 DAE. Samples were dried at 60 °C for 72 hours, pulverised and analysed (Henriquez *et al*., 1998). N was quantified by the Kjeldahl method, while P and K were quantified by wet digestion.

Statistical analysis

Data were analysed by analysis of variance (ANOVA), and means were compared with Tukey's test ($P\leq0.05$). To ensure the validity of the results, the assumptions of normality and homogeneity of variances were checked using the Shapiro-Wilk and Hartley tests. All statistical analyses were performed with INFOSTAT software (Di Rienzo *et al*., 2019).

Results and discussion

Significant effects ($P<0.05$) were identified in several variables as a function of N sources and doses, and the application of efficient microorganisms; as well as in their interactions, except in the triple interaction. The most relevant combinations were observed in the number of acorns per plant (NAPP), diameter and biomass per acorn, yield and foliar K concentration.

Agro-productive performance of cotton under the influence of two sources of N, organic matter (OM) and urea (U) showed significant statistical differences ($P<0.05$) in the variables evaluated, evidencing the differential impact of the sources on crop development and yield (Figure 2).

Urea fertilization accelerated flowering compared to organic matter, in agreement with previous studies in intensive nitrogen management systems (Shareef, 2019). Also, U-fertilized plants attained greater height and stem diameter, which was consistent with research associating mineral nitrogen with vigorous vegetative growth (Geng *et al*., 2020; da Silva *et al*., 2023).

One of the reasons why urea accelerates flowering in cotton is because it provides readily available nitrogen, which stimulates vigorous growth and early differentiation of reproductive structures, whereas organic fertilization releases nitrogen more gradually, leading to sustained development but slightly later flowering, which was corroborated by Li *et al*. (2017) and Yang *et al*. (2021).

The easy availability of the nitrogen source urea is crucial for protein and growth hormone synthesis. This translates into a greater effect on variables associated with plant growth (height and stem diameter). Also, as nitrogen is a component of the chlorophyll

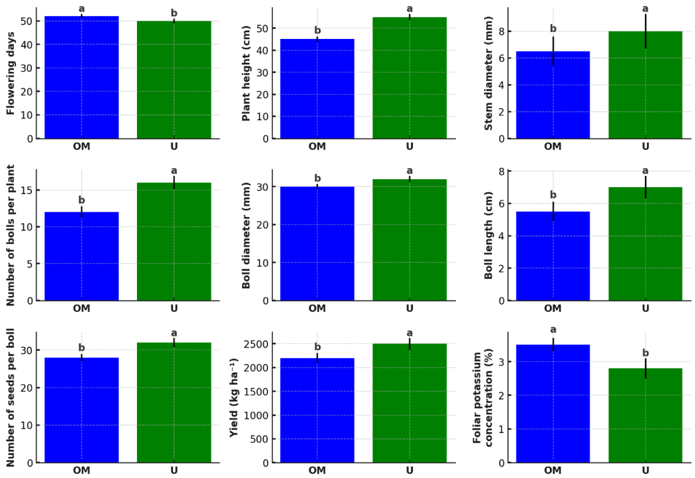

Figure 2. Agro-productive response of cotton to two nitrogen sources. Abbreviations: OM= organic matter; U= urea; means with the same letter did not differ significantly from each other, according to Tukey's test (*P*≤0.05).

molecule, this type of fertilization increases chlorophyll and therefore photosynthetic activity, thereby increasing biomass accumulation and growth-related variables by improving nitrogen uptake and utilization (Duan *et al*., 2020).

In terms of productivity, urea application increased the number of acorns per plant, as well as their diameter and length. In addition, this treatment favoured a higher number of seeds in the acorns and a higher yield when compared to OM. However, leaf potassium concentration was significantly higher in plants fertilized with organic matter, reflecting its sustained nutrient supply and its positive effect on mineral nutrition, as reported by Higa and Parr (1995) and Cañarte *et al*. (2020).

The higher foliar potassium content in plants fertilized with organic matter is due to several reasons, among others, to the progressive and constant release of potassium, to its lower leaching due to a higher retention of this element in the soil, to the presence of a higher microbial activity, this contributes to a greater availability and accessibility of potassium in soils with organic fertilization, which in turn explains its higher concentration in the leaf tissue, compared to plants fertilized with urea.

Vesco *et al*. (2022) evaluated three levels of nitrogen fertilization (60, 120 and 180 kg.ha^{-1}) on NIAB-111, CIM-496 and FH-901 varieties, finding that 120 kg.ha^{-1} promoted higher seed and fibre biomass. However, in the present investigation, the lower dose (50 kg.ha^{-1}) resulted in higher seed and fibre biomass, suggesting atypical crop behaviour under the experimental conditions.

This could be associated with an optimal nutrient balance, which improved nitrogen use efficiency and favoured the partitioning of photoassimilates to reproductive structures, avoiding excessive vegetative growth. In addition, mild nutrient stress may have induced an adaptive response, prioritising reproduction. In turn, a better carbon:nitrogen (C:N) ratio favoured the quality and quantity of fibre produced. These results highlight the importance of adjusting fertilization to agroecological conditions to optimise crop productivity and are in line with findings by Gospodinova & Panayotova (2019) and Baird *et al*. (2024).

Zonta *et al*. (2016) indicated similar results by identifying that the optimal dose in semi-arid conditions ranged between 70 and 140 kg.ha^{-1}, although with variations depending on the environment, agronomic management and the variables evaluated. In this study, boll length, fibre biomass and seed biomass responded significantly to N doses, which partially coincided with Palomo *et al*. (2004), who determined an optimum yield with 80 kg.ha^{-1} in the variety Laguna 89.

Table 1 shows the results of the variables evaluated according to the doses of nitrogen fertilization. The highest acorn length was recorded at 150 kg.ha^{-1} (6.18 mm), while fibre biomass (2.67 g) and seed biomass (4.60 g) peaked at 50 kg.ha^{-1}. These results highlighted the need to consider not only total yield, but also nitrogen use efficiency, optimising inputs and maximising productivity in sustainable farming systems.

Table 1. Cotton yield response to four fertilization rates.

Dose (kg de N.ha^{-1})	Acorn length	Biomass fibre	Seed biomass
	(mm)	(g)	
50	5.93 ± 0.12^{b}	2.67 ± 0.22^{a}	4.60 ± 0.52^{a}
100	5.84 ± 0.11^{c}	2.37 ± 0.09^{ab}	4.10 ± 0.15^{b}
150	6.18 ± 0.25^{a}	2.27 ± 0.11^{b}	4.20 ± 0.20^{ab}
200	6.09 ± 0.33^{ab}	2.51 ± 0.30^{ab}	4.30 ± 0.53^{ab}

Means with the same letter did not differ significantly from each other, according to Tukey's test (P≤0.05).

The analysis of the agro-productive variables in response to the application of efficient microorganisms (EM) showed different effects. There were no statistical differences in acorn length, acorn biomass and seed biomass. However, yield was significantly higher with EM application, reaching 3,270.80 kg.ha^{-1}, compared to 2,879.60 kg.ha^{-1} without EM application (Table 2). These results highlighted the potential of EM in combination with organic or inorganic fertilizers to optimize crop productive performance, probably due to their ability to improve nutrient availability and uptake, stimulate soil microbial activity and promote root growth, which favours greater efficiency in the use of soil resources and increases crop productivity.

Table 2. Productive responses of cotton due to the presence of efficient microorganisms.

ME	Acorn length	Acorn bio-mass	Seed biomass	Yield
	(cm)	(g)		(kg.ha^{-1})
WEM	5.89 ± 0.11^{b}	2.03 ± 0.05^{b}	4.10 ± 0.29^{b}	3,270.80 ± 547.11^{a}
WOEM	6.13 ± 0.30^{a}	2.27 ± 0.13^{a}	4.50 ± 0.30^{a}	2,879.60 ± 731.85^{b}

EM= efficient microorganisms; WEM= with efficient microorganisms; WOEM= without efficient microorganisms. Means with the same letter did not differ significantly from each other, according to Tukey's test (*P*≤0.05).

Previous findings support this trend. Wang *et al*. (2020) reported that the use of organic fertilizers in Hexi region, Gansu province, China, increased the number of acorns per plant, dry biomass accumulation and cotton growth. An increase in fibre and seed yield was also observed, confirming the benefit of integrating organic fertilizers with complementary strategies to improve crop productivity.

Analysis of the interaction between nitrogen sources and nitrogen doses revealed significant differences in cotton yield variables (Table 3). The highest number of acorns per plant (NBP) was obtained with the combination of urea (U) and 200 kg N.ha^{-1} (18.00), being significantly higher than organic matter (OM) with 100 and 200 kg $N.ha^{-1}$, as well as U with 50 kg $N.ha^{-1}$.

For acorn diameter, the highest responses were observed with U at doses of 200, 150 and 50 kg $N.ha^{-1}$, significantly outperforming MO at 200 kg $N.ha^{-1}$. As for leaf potassium concentration (% K), the highest values were recorded with MO at 50 and 100 kg $N.ha^{-1}$, differing from U at 50, 100 and 150 kg $N.ha^{-1}$.

Table 3. Cotton production response to the interaction between nitrogen source and dose.

Sources	Dose (kg de $N.ha^{-1}$)	NAP	Acorn diameter	K
		(number)	(mm)	(%)
OM	50	13.25 ± 3.37^{ab}	33.00 ± 1.33^{ab}	1.93 ± 0.24^{a}
OM	100	12.45 ± 2.41^{b}	34.07 ± 2.32^{ab}	1.94 ± 0.09^{a}
OM	150	13.50 ± 2.02^{ab}	34.29 ± 2.13^{ab}	1.81 ± 0.17^{b}
OM	200	12.23 ± 5.08^{b}	32.12 ± 1.27^{b}	1.67 ± 0.23^{bc}
U	50	12.15 ± 3.04^{b}	34.15 ± 2.31^{a}	1.45 ± 0.16^{c}
U	100	14.08 ± 2.26^{ab}	33.09 ± 3.11^{ab}	1.44 ± 0.28^{c}
U	150	17.53 ± 3.23^{ab}	34.24 ± 0.64^{a}	1.55 ± 0.19^{c}
U	200	18.00 ± 4.31^{a}	34.77 ± 1.72^{a}	1.79 ± 0.20^{bc}

NAP= number of acorns per plant; K= foliar potassium concentration; OM= organic matter; U= urea; means with the same letter did not show significant differences between them, according to Tukey's test ($P \leq 0.05$).

Wang *et al*. (2020) reported that the combination of organic fertilizers with efficient microorganisms (EM) in cotton significantly increased yield compared to single application of organic fertilizers or EM. This effect was attributed to the synergy between the two components, which supports the results of the present study regarding the impact of organic matter (OM) on potassium balance. Similarly, Blaise *et al*. (2005) found that the use of manure in rainfed cotton not only improved fibre yield, but also maintained a positive potassium balance, highlighting the role of organic sources in agricultural sustainability.

Liu *et al*. (2023) found that application of 150 kg $N.ha^{-1}$ optimised seed cotton yield (fibre and seed) and fibre quality compared to doses of 75, 150 and 300 kg $N.ha^{-1}$. In contrast, the 75 kg $N.ha^{-1}$ dose showed inconsistent results, while the effects of applications below this threshold were unclear. Taken together, these findings confirm that integrated management of nitrogen sources and adjusted doses maximises yields and optimises the nutritional balance of the crop, promoting effective strategies for sustainable agriculture.

Table 4 presents the results of the interaction between nitrogen sources and the application of efficient microorganisms (EM) on the acorn diameter and biomass variables. The largest acorn diameter (34.43 mm) was obtained with the interaction of urea (U) and the presence of EM (WEM), being significantly higher than organic matter (OM) with WEM. In contrast, in the treatments with OM, the largest diameter was recorded without the application of EM (WOEM), suggesting that OM could contain microorganisms such as plant growth-promoting bacteria and growth promoters, as well as arbuscular mycorrhizal fungi and saprophytes that contribute to these results. In terms of acorn biomass, the OM×WOEM interaction showed the highest value (2.38 ± 0.42 g), differing significantly from OM×WEM.

Table 4. Productive response of cotton to the interaction between sources and presence of efficient microorganisms.

Sources	EM	Acorn diameter	Acorn biomass
		mm	g
OM	WEM	32.64 ± 1.70^{b}	1.89 ± 0.22^{b}
OM	WOEM	34.10 ± 2.25^{a}	2.38 ± 0.42^{a}
U	WEM	34.43 ± 2.26^{a}	2.17 ± 0.56^{ab}
U	WOEM	33.69 ± 1.99^{ab}	2.15 ± 0.29^{ab}

EM= efficient microorganisms; OM= organic matter; U= urea; WEM= with efficient microorganisms; WOEM= without efficient microorganisms. Means with the same letter did not show significant differences between them, according to Tukey's test ($P \leq 0.05$).

Khaliq *et al*. (2006) demonstrated that the combination of organic fertilizers with efficient microorganisms in cotton crop resulted in higher yields (1,552 $kg.ha^{-1}$), in contrast to the results obtained with pure organic fertilizers (1,263 $kg.ha^{-1}$) or EM alone (1,278 $kg.ha^{-1}$). These results reflected the synergy between organic components and microorganisms in improving the productive performance of cotton.

In this study, favourable responses were observed with both OM and U in combination with EM, particularly in acorn diameter. However, the use of OM without EM was shown to be an efficient strategy for the variables evaluated, possibly due to the presence of native microorganisms in its composition. These results highlighted the importance of considering both the quality of the organic source and the integration of OM in sustainable management strategies to optimise crop performance.

Table 5 shows the results of acorn yield and diameter as a function of the interaction between N dose and presence or absence of efficient microorganisms (EM). The highest yields were obtained with the application of 150 $kg.ha^{-1}$ of N and EM (WME), reaching 3,805.56 $kg.ha^{-1}$, while the lowest yield was recorded with 100 $kg.ha^{-1}$ of N without EM (WOEM), with 2,500.00 $kg.ha^{-1}$. Regarding acorn diameter, the highest values were observed with 150 $kg.ha^{-1}$ of N and SME (34.74 mm), followed by similar values among the other treatments.

Table 5. Cotton productive response to the interaction between doses and presence of efficient microorganisms.

Doses (kg de $N.ha^{-1}$)	EM	Acorn diameter	Yield
		(mm)	($kg.ha^{-1}$)
50	WEM	33.84 ± 2.29^{ab}	$3{,}037.04 \pm 376.25^{bc}$
100	WEM	33.79 ± 2.78^{ab}	$3{,}055.56 \pm 304.29^{bc}$
150	WEM	33.79 ± 1.20^{ab}	$3{,}805.56 \pm 553.05^{a}$
200	WEM	32.73 ± 1.65^{b}	$3{,}185.19 \pm 603.15^{bc}$
50	WOEM	33.32 ± 1.57^{ab}	$2{,}851.85 \pm 615.31^{c}$
100	WOEM	33.37 ± 2.79^{ab}	$2{,}500.00 \pm 363.45^{d}$
150	WOEM	34.74 ± 1.85^{a}	$2{,}574.07 \pm 674.03^{d}$
200	WOEM	34.16 ± 2.17^{ab}	$3{,}592.59 \pm 762.28^{b}$

WEM= with efficient microorganisms; WOEM= without efficient microorganisms. Means with the same letter did not show significant differences between them, according to Tukey's test ($P \leq 0.05$).

The findings of this study are in agreement with previous research such as Chen *et al*. (2019) who reported that 240 kg $N.ha^{-1}$ improved acorn quality, an effect similar to that observed with 200 kg $N.ha^{-1}$ in this work. Tao *et al*. (2017) demonstrated that organic fertilizers (3.0-6.0 $Mg.ha^{-1}$) improved productivity in extensive systems. Similarly, Chen *et al*. (2019) highlighted that the optimal nitrogen dose depends on agroecological factors, which coincides with the higher productivity obtained in this study when combining EM and an intermediate dose of N. These results highlight the importance of integrated fertilization management and efficient microorganisms to optimize cotton yield in a sustainable manner.

Conclusions

Nitrogen fertilization management significantly influences cotton growth and yield in Ecuador. The combination of organic, inorganic and efficient microorganisms (EM) fertilization shows potential to optimize productivity without relying exclusively on synthetic fertilizers. The application of EM showed a positive effect on productivity, especially with an intermediate dose of nitrogen (150 $kg.ha^{-1}$), although its impact varies according to management conditions. This study provides a scientific basis for optimizing cotton fertilization and improving decision making in agricultural systems. It is recommended to continue with studies that evaluate its application in different agroclimatic contexts and its long-term effect on input use efficiency.

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Literature cited

Baird, J., Schwenke, G., Macdonald, B., Nachimuthu, G., McPherson, A. & Mercer, C. (2024). Efficiency over excess: Maximising cotton lint yields with optimum irrigation and nitrogen fertiliser application. *Field Crops Research*, *315*, 109484, https://doi.org/10.1016/j.fcr.2024.109484

Blaise, D., Singh, J. V., Bonde, A. N., Tekale, C. & Mayee, C. (2005). Effects of farmyard manure and fertilizers on yield, fibre quality and nutrient balance of rainfed cotton (*Gossypium hirsutum*). *Bioresource Technology*, *96*(3), 345-349. https://www.sciencedirect.com/science/article/abs/pii/S096085 2404001439

Bozorov, T., Usmanov, R., Yang, H., Hamdullaev, A., Musayev, S., Shavkiev, J., Nabiev, S., Zhang, D. & Abdullaev, A. (2018). Effect of water deficiency on relationships between metabolism, physiology, biomass, and yield of upland cotton (*Gossypium hirsutum* L.). *Journal of Arid Land.*, *10*(3), 441-456. https://doi.org/10.1007/s40333-018-0009-y

Cañarte, E., Sotelo, R. & Navarrete, B. (2020). Generación de tecnologías para incrementar la productividad del algodón *Gossypium hirsutum* L. en Manabí, Ecuador. *Revista Ciencia UNEMI*, *13*(33), 1-17. http://ojs.unemi.edu.ec/index. php/cienciaunemi/article/view/1085/1096

Chen, J., Liu, L., Wang, Z., Sun, H., Zhang, Y., Bai, Z. & Li, C. (2019). Nitrogen fertilization effects on physiology of the cotton boll–leaf system. *Agronomy*, *9*(6), 2-16. https://doi.org/10.3390/agronomy9060271

Chinga, W., Torrez, A., Mármol, L. & Chirinos, D. (2020). Efecto de un lixiviado de vermicompost sobre el crecimiento y producción del algodón. *Revista Científica Ecuatoriana*, *7*(2), 1-9. https://doi.org/10.36331/revista.v7i2.130130

da Silva, C. M., de Albuquerque Ribeiro, A., da Silva, E. F., Garcias da Silva, M., Vieira Alencar, S. & Vicente Paulo, S. A. (2023). Cotton nitrogen doses in the edaphoclimatical conditions of northeastern Brazil. *Brazilian Journal of Biosystems Engineering*, *17*, 1194. https://doi.org/10.18011/bioeng.2023. v17.1194

Di Rienzo, J., Casanoves, F., Balzarine, M., Gonzales, L., Tablada, M. & Robledo, C. (2019). *InfoStat versión 2019*. Grupo InoStat. FCA. Universidad Nacional de Córdoba, Argentina. http://www.infostat.com.ar

Duan, W.-J., Ma, T.-T., Zhang, Y.-J., Chen, L., Jiang, D., Liu, L.-T., Sun, H.-C., Zhang, K., Bai, Z.-Y. & Li, C.-D. (2020). Effects of different nitrification inhibitor DCD addition ratios in nitrogen fertilizer on cotton growth and yield. *Journal of Plant Nutrition and Fertilizers*, *26*(11), 2095-2106. doi: 10.11674/zwyf.20092

Geng, J., Yang, X., Huo, X., Chen, J., Lei, S., Lang, Y. & Liu, Q. (2020). Effects of controlled-release urea combined with fulvic acid on soil inorganic nitrogen, leaf senescence and yield of cotton. *Scientific Reports*, *10*, 17135. https://doi.org/10.1038/s41598-020-74218-2

Gospodinova, G., Panayotova, G. (2019). Strategies for nitrogen fertilization of cotton (*Gossypium hirsutum* L.). A review. *Bulgarian Journal of Agricultural Science*, *25*(Suppl. 3), 59-67. https://www.agrojournal.org/25/03s-10.pdf

Henríquez, C., Bertsch, F. & Salaas, R. (1998). *La fertilidad de suelos: Manual de laboratorio.* Asociación Costarricense de la Ciencia del Suelo.

Higa, T. & Parr, J. F. (1995). Beneficial and effective microorganisms for a sustainable agriculture and environment. *International Nature Farming Research Center*, *1*, 16. https://www.em-pars.com/wp-content/uploads/2018/05/7-beneficial-and-effective-microorganisms-for-a-sustainab-.pdf

Holdridge, L. R. (1978). Ecología basada en zonas de vida. Centro Científico Tropical. Instituto Interamericano de Ciencias Agrícolas. San José, Costa Rica. https://hdl.handle.net/11324/7936

Hussain, I., Saleem, S., Ullah, H., Nasir, M., Iqbal, M. U., Saleem, M., Khaliq, A., Masood, S. A., Farooq, M. S., Hanif, M., Nisa, Z. U., Jabbar, A., Ullah Ghazali, H. M. Z. & Khan, A. A. (2024). The role of fermented farmyard manure in promoting soil health and economic sustainability in cotton farming under changing climate. *Journal of Economic Impact*, *6*(3), 273-277. https://doi.org/10.52223/econimpact.2024.6312

Khaliq, A., Abbasi, K. & Hussain, T. (2006). Effects of integrated use of organic and inorganic nutrient sources with effective microorganisms (EM) on seed cotton yield in Pakistan. *Bioresource Technology*, *96*(8). 967-972. https://doi.org/10.1016/j.biortech.2005.05.002

Li, P. C., Liu, A. Z., Liu, J. R., Zheng, C. S., Sun, M., Wang, G. P., Li, Y, B., Zhao, X. H. & Dong, H. L. (2017). Effect of timing and ratio of urea fertilization on 15n ecovery and yield of cotton. *The Journal of Animal & Plant Sciences*, *27*(3), 929-939. https://thejaps.org.pk/docs/v-27-03/30.pdf

Li, P., Rashid, H., Chen, T., Lu, Q., Ge., O., Gong, W., Liu, A. Gong, J. Shang, H., Deng, X., Li, J., Li, S., Xiao, X., Lui., R., Zhang, Q., Duan, L., Zou, X., Zhang, Z., Jiang, X., Zhang, Y., Peng, R., Shi, Y. & Yuan, Y. (2019). Transcriptomic and biochemical analysis of upland cotton (*Gossypium hirsutum*) and a chromosome segment substitution line from *G. hirsutum* × *G. barbadense* in response to *Verticillium dahliae* infection. *BMC Plant Biology*, *19*(19), 21-24. https://doi.org/10.1186/s12870-018-1619-4

Liu, Z., Jin, W., Guo, J., Yuan, J., Wang, S., Yang, H., Meng, Y. & Zhou, Z. (2023). Efficient cotton population photosynthetic production synergistically increases seedcotton yield and fiber quality through straw incorporation with appropriate nitrogen fertilization in wheat-cotton rotation system, *Field Crops Research*, *304*, 109147. https://doi.org/10.1016/j.fcr.2023.109147.

Wang, N., Nan, H. Y., & Feng, K. Y. (2020). Effects of reduced chemical fertilizer with organic fertilizer application on soil microbial biomass, enzyme activity and cotton yield. *The Journal of Applied Ecology, 31*(1), 173-181. doi:10.13287/j.1001-9332.202001.022

Palomo, A., Gaytán, M., Contreras, A., Sánchez, R. & Gutiérrez, D. (2004). Rendimiento y calidad de fibra de algodón en respuesta al número de riegos y dosis de nitrógeno. *Terra LatinoAmericana*, *22*(3), 299-305. http://www.redalyc.org/articulo.oa?id=57322306

Rodríguez, A. & Ruiz, P. (1996). *El sistema agroindustrial del algodón en España*. Ministerio de Agricultura, Pesca y Alimentación. https://www.mapa.gob.es/ministerio/pags/Biblioteca/fondo/pdf/18252_all.pdf

Shareef, M., Gui, D., Zeng, F., Waqas, M., Ahmed, Z., Zhang, B., Iqbal, H. & Xue, J. (2019). Nitrogen leaching, recovery efficiency, and cotton productivity assessments on desert-sandy soil under various application methods. *Agricultural Water Management*, *223*, 105716. https://doi.org/10.1016/j.agwat. 2019.105716

Shi, Y., Niu, X., Chen, B., Pu, S., Ma, H., Li, P., Feng, G. & Ma, X. (2023). Chemical fertilizer reduction combined with organic fertilizer affects the soil microbial community and diversity and yield of cotton. *Frontiers in Microbiology*, *14*, 1295722. https://doi.org/10.3389/fmicb.2023.1295722

Tao, R., Wakelin, S. A., Lian, Y. & Chu, G. (2017). Organic fertilization enhances cotton productivity, nitrogen use efficiency, and soil nitrogen fertility under drip irrigated field. *Agronomy Journal*, *109*, 2889-2897. DOI: 10.2134/agronj2017. 01.0054

Vesco Galdi, L., dos Santos Cordeiro, C. F., de Senna e Silva, B., Rodríguez de La Torre, E. J. & Echer, F. R. (2022). Interactive effects of increased plant density, cultivars and N rates in environments with different cotton yield recovery potential. *Industrial Crops and Products*, *176*, 114394. https://doi.org/10.1016/j.indcrop.2021.114394.

Vitale, G. S., Scavo, A., Zingale, S., Tuttolomondo, T., Santonoceto, C., Pandino, G., Lombardo, S., Anastasi, U. & Guarnaccia, P. (2024). Agronomic strategies for sustainable cotton production: A sistematic literatura review. *Agriculture*, *14*(9), 1597. https://doi.org/10.3390/agriculture14091597

Wang, N., Nan, H. & Feng, K. (2020). Effects of reduced chemical fertilizer with organic fertilizer application on soil microbial biomass, enzyme activity and cotton yield. *Journal of Applied Ecology*, *31*(1), 173-181. https://doi.org/10.13287/ J.1001-9332.202001.022

Wang, N., Zhan, J., Feng, K., Qi, J. & Nan, H. (2024) Higher yield sustainability and soil quality by reducing chemical fertilizer with organic fertilizer application under a singlecotton cropping system. *Front. Plant Sci.*, *15*,1494667. doi: 10.3389/fpls.2024.1494667

Wu, D., Wang, W., Yao, Y., Li, H., Wang, Q. & Niu, B. (2023). Microbial interactions within beneficial consortia promote soil health. *Science of the Total Environment*, *900*, 165801. https://10.1016/j.scitotenv.2023.165801

Yang, X., Geng, J., Huo, X., Lei, S., Lang, Y., Li, H. & Liu, Q. (2021). Effects of different nitrogen fertilizer types and rates on cotton leaf senescence, yield and soil inorganic nitrogen. *Archives of Agronomy and Soil Science*, *67*(11), 1507-1520 doi:10.1080/03650340.2020.1799983

Zonta, J. H., Brandao, Z. N., Rodrigues, J. I. D. S. & Sofiatti, V. (2017). Cotton response to water deficits at different growth stages. *Revista Caatinga*, *30*, 980-990. https://doi.org/10.1590/1983-21252017v30n419rc