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Evaluation of organic amendment in corn production in Villaflores, Chiapas, Mexico

Evaluación de abono orgánico en la producción de maíz en Villaflores, Chiapas, México

Avaliação de alteração orgânico na produção de milho em Villaflores, Chiapas, México

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Rev. Fac. Agron. (LUZ). 2023, 40(1): e234009
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v40.n1.09

Crop Production

Associate editor: Dra. Evelyn Peréz-Peréz
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Received: 28-09-2022
Accepted: 15-02-2022
Published: 27-02-2023

Keywords:

Degradation
Soil fertility
Nitrogen
Zea mays L.
Milky-doughy
Plant nutrition
Soil

Abstract

The use of organic fertilizers contributes to the improvement of the fertility of agricultural soils. The objective was to evaluate three doses of organic fertilizer incorporated into the soil (10, 20 and 30 $t.ha^{-1}$) and a control, in corn production. The management of the crop was conventional, after the preparation of the soil with agricultural machinery, the doses of compost were incorporated. Planting was manual with a density of 66,500 $plants.ha^{-1}$. A completely randomized design and three replicates per treatment were used. Data were analyzed with analysis of variance, tests of means, correlation analysis, and economic evaluation. The results indicated that the incorporation of organic fertilizer to the soil benefited the height of the plant and ear, leaf area, stem diameter, number and yield of $cobs.ha^{-1}$. A direct and positive relationship was found between the dose of amendment incorporated into the soil and the production of cobs in the milky-dough state. The application of 30 $t.ha^{-1}$ of organic fertilizer showed the best results for the indicated agronomic variables and presented the best economic benefits.

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Resumen

El uso de los abonos orgánicos contribuye con el mejoramiento de la fertilidad de los suelos agrícolas. El objetivo fue evaluar tres dosis de abono orgánico incorporado al suelo (10, 20 y 30 $t.ha^{-1}$) y un testigo, en la producción de maíz. El manejo del cultivo fue convencional, después de la preparación del suelo con maquinaria agrícola, se incorporaron las dosis de compost. La siembra fue manual con una densidad de 66.500 $plantas.ha^{-1}$. Se utilizó un diseño completamente al azar y tres replicas por tratamiento. Los datos se analizaron con análisis de varianza, pruebas de medias, análisis de correlación y evaluación económica. Los resultados indicaron que la incorporación de abono orgánico al suelo benefició la altura de planta y mazorca, área foliar, diámetro de tallo, número y rendimiento de mazorcas.ha^{-1}. Se encontró una relación directa y positiva entre la dosis de enmienda incorporada al suelo y la producción de mazorcas en estado lechoso-masoso. La aplicación de 30 $t.ha^{-1}$ de abono orgánico mostró los mejores resultados para las variables agronómicas señaladas y presentó los mejores beneficios económicos.

Palabras clave: degradación, fertilidad del suelo, nitrógeno, *Zea mays*, lechoso-masoso, nutrición vegetal, suelo

Resumo

A utilização de adubos orgânicos contribui para a melhoria da fertilidade dos solos agrícolas. Objetivou-se avaliar três doses de adubo orgânico incorporado ao solo (10, 20 e 30 $t.ha^{-1}$) e uma testemunha, na produção de milho. O manejo da lavoura foi convencional, após o preparo do solo com maquinário agrícola, foram incorporadas as doses de composto. O plantio foi manual com densidade de 66.500 $plantas.ha^{-1}$. Foi utilizado um delineamento inteiramente casualizado e três repetições por tratamento. Os dados foram analisados com análise de variância, testes de médias, análise de correlação e avaliação econômica. Os resultados indicaram que a incorporação de adubo orgânico ao solo beneficiou a altura da planta e espiga, área foliar, diâmetro do caule, número e produtividade de espigas.ha^{-1}. Encontrouse relação direta e positiva entre a dose de corretivo incorporado ao solo e a produção de espigas em estado pastoso. A aplicação de 30 $t.ha^{-1}$ de adubo orgânico apresentou os melhores resultados para as variáveis agronômicas indicadas e apresentou os melhores benefícios econômicos.

Palavras-chave: degradação, fertilidade do solo, nitrogênio, *Zea mays,* leitoso-pastoso, nutrição de plantas, solo

Introduction

Maize (*Zea mays* L.) is the main crop in Mexico, both in terms of cultivated area and *per capita* consumption (Cuevas, 2014). In 2021 in the country, 27,503,477 t were harvested in 7,139,620 ha, with a production value of 148,601,480 thousand pesos; for the state of Chiapas the numbers were 1,288,651 t, in 688,517 ha and 5,792,809 thousand pesos, respectively. In the socioeconomic region La Frailesca, Villaflores municipality, 214,481 t were harvested in 60,596 ha, with a production of 1,088,818 thousand pesos; for this territory, corn produced as a vegetable accumulated 784 ha (SIAP, 2021).

The consumption of corn in an immature state, with high moisture content and called elote, jojoto, choclo or baby corn, in other countries, is one of the most traditional and popular forms (boiled, roasted, in regional dishes or canned); this type of corn is categorized as a fresh vegetable or vegetable because they are sweeter and tender (Fernández-González *et al*., 2014). Corn production has several advantages over mature grain corn, since the crop cycle is shorter and favors the opportunity to plant new crops in less time (Espejel-García *et al*., 2020), reduces the risk of pests and diseases during post-harvest (Ortíz-Torres *et al*., 2013), and allows generating additional income by marketing the plant as fodder.

In the La Frailesca region, systematic management with technified agriculture led to negative consequences in the medium term, particularly on soils (López *et al*., 2018; López *et al*., 2019). This problem demand agroecological alternatives that allow the improvement and conservation of soils to improve their agroproductive capacity. Organic amendment is a relevant agrotechnology in the rehabilitation of the productive capacity of degraded soils (Fortis-Hernández *et al*., 2009), because they improve soil structure and provide nutrients to plants (Acevedo-Alcalá *et al*., 2020).

The implementation of production models with environmentally friendly technologies, such as the use of organic fertilizers, can improve crop yields, as well as plant health, since it implies the incorporation of new factors, such as: biological, nutritional and physical factors that improve soil properties (Morales and Hernández, 2021). The use of organic residues increases pH in acid soils, phosphorus in alkaline soils, as well as organic matter content in both soil conditions mentioned above, thus improving nitrogen concentration in the biomass and increasing grain yield in the crop (Arrieche & Mora, 2005).

The use of compost improves soil fertility, and therefore the yield of the corn crop, due to the improvement in the availability of nutrients for the plant (De Luna-Vega *et al*., 2016). Álvarez-Solís *et al*. (2010), reported increases of 17.7 % in maize grain yield by incorporating 6 $t.ha^{-1}$ of compost in combination with inorganic fertilization. Lagunes-Domínguez *et al*. (2018), concluded that the use of compost in doses of 18.5, 37 and 55.5 $t.ha^{-1}$, reflected results, statistically similar to inorganic fertilization for corn grain mass, quantifying higher volumes in the higher doses of use of the organic amendment.

Based on these premises and the availability of ruminant manure, including bovine manure and vegetable residues in La Frailesca of Chiapas, as well as literature that reviews the beneficial effect of organic amendments, the objective of the research was to evaluate the effect of incorporating organic fertilizer in the soil on the production of corn for vegetables.

Materials and Methods

Location of the study area

The trial was carried out in the municipality of Villaflores, Chiapas, Mexico, located at 16°32’ North Latitude, 93°45’ West Longitude, mean altitude of 610 masl; warm-sub-humid climate AW_1 (w”) (i) g, mean annual temperature of 22 ºC, accumulated rainfall of 1,200 mm (García, 1987) and alluvial soil, locally known as vega terrain.

Composting

The compost was made at the experimental site, using local materials. Dried and mechanically ground cattle manure and *Cynodon plectostachyus* (K. Schum.) Pilg. grass (Azteca®) were mixed in a 3:1 ratio, placed in piles, watered and stirred for 90 days, with a frequency of 5 days, to favor aeration. The physical and chemical characteristics of the compost were determined at the Soil Science laboratory of the Colegio de Postgraduados en Ciencias Agrícolas, Montecillos Campus. The determinations indicated pH 9.30, total N 1.47 %, M.O. 13.19 %, C 7.63 %, C/N 5.19, P 0.49 %, K 0.40 Cmol. kg^{-1}, Ca 0.38 $Cmol.kg^{-1}$, Fe 769.00 ppm, Mn 252.00 $Cmol.kg^{-1}$, Cu 15.50 $Cmol.kg^{-1}$ and B 29.70 ppm.

Agronomic management of the crop

The crop was managed similarly to regional sowing for vegetable production, including the use of the components of modern agriculture (FIRA, 2022). Soil preparation was carried out with two passes of mechanical harrowing. In the management of weeds, 15 days before planting, 10 $mL.L^{-1}$ of N-(phosphonomethyl) glycine-isopropylamine acid (1:1) were sprayed with a knapsack sprayer (20 L capacity). The organic fertilizer was applied and incorporated, manually, with tillage implements (hoe). For the 10 $t.ha^{-1}$ treatment, 25 kg of compost were used per experimental unit, for the 20 $t.ha^{-1}$ treatment, 50 kg, and for the 30 $t.ha^{-1}$ treatment, 75 kg were applied.

Planting was done manually, with a distance of 75 cm between rows and 20 cm between plants, depositing one hybrid corn seed (Sorento® NK800) per planting point (66,500 $seedlings.ha^{-1}$). Fertilizer 216-16-00 was applied to all treatments, at a rate of 3.50 $g.plant^{-1}$: 15 days after planting (dap) all the phosphorus and half of the nitrogen was applied, and 30 days after the first fertilization, the rest of the nitrogen was applied. The sources of N and P were ammonium sulfate and phosphonitrate. Additionally, four sprays of foliar fertilizer were made, at 18 days with Push® (25 $mL.L^{-1}$), at 21 days with foliar fertilizer 20-30-10 (5 $g.L^{-1}$) plus Boron 9% (5 $mL.L^{-1}$); at 35 and 43 days, Biozime® (5 $mL.L^{-1}$) was added to the foliar fertilization.

Post-emergence weeds were controlled manually and with the application of non-selective herbicides; at 27 dap with Paraquat (10 $mL.L^{-1}$), and at 50 dap, Glufosinate Ammonium (10 $mL.L^{-1}$). The predominant weeds were: *Cyperus rotundus*, L., *Melampodiem divaricatum* L. C. Rich. DC, *Echinochloa crus-galli* (L.) P. Beauv., *Cynodon dactilon* (L.) Pers.) and *Cynodon plectostachius* K. Schum. The crop was affected by *Spodoptera frugiperda* J.E. Smith and *Diabrotica balteata* Le Conte, for which insecticide applications were made, at 21 dap Lambdacyhalothrin + Chlorantraniliprole was applied at a rate of 1.25 $mL.L^{-1}$, and at 35 and 43 dds Chlorpyrifos Ethyl + Permethrin was applied at a rate of 3.37 $mL.L^{-1}$, finally at 73 dap Fenpyroximate was sprayed at a rate of 1.00 $mL.L^{-1}$. Twenty sprinkler irrigations were carried out with the help of a two-inch cannon, fed with a 6 hp electric pump (Hyundai®). At 88 dap, harvesting (manual) was carried out, for which the milky-massy grain stage, called corn, was considered.

Variables evaluated

The variables evaluated were: plant height and height of cob insertion, measured with the help of a stadial, leaf area (length x width x 0.75) measured with a tape measure, stem diameter at the base of the cob insertion, measured with the help of a vernier, number of cobs, yield of cobs with and without bracts (totomoxtle), ear length determined with a tape measure and cob diameter measured with the help of a vernier. For the economic analysis, the methodology of CIMMyT (1988) was used, including the partial budget and marginal analysis, for which the commercial yield ($kg.ha^{-1}$) and the costs of production of corn for vegetables ($) per unit area (ha) in the year 2021 were considered.

Experimental design and analysis

The design used was completely randomized, with three doses of compost (10, 20 and 30 $t.ha^{-1}$), and a control (0 $t.ha^{-1}$), with three replicates, for a total of 12 treatments or experimental plots. Plots measured 5 m wide × 5 m long and 1 m apart, between replicates and treatments.

An analysis of variance was performed using the Statistical Package for Social Sciences (SPSS) Version 19. The Tukey multiple range test ($p<0.05$) was applied for the comparison of means and Pearson's correlation analysis was performed.

Results and discussion

Agronomic variables

The variables plant and ear height, leaf area and stalk diameter of corn presented the highest values and were higher and different ($p<0.05$) when organic fertilizer was applied compared to the control (Table 1). This indicated a positive effect of organic manure on corn cob production and biomass for forage. Osuna-Ceja *et al*. (2015) reported increases of 50 % in corn forage production in the North Central zone of Mexico, by application of organic amendments.

The benefits of the use of organic fertilizers for corn production in the immature stage are based on the benefit to the solid phase of the soil, by improving the structure and regulating the temperature; from the liquid phase, these promote adequate water infiltration and moisture retention, favoring the growth and development of corn, especially in the grain filling stage, which is fundamental in the production of the vegetable (Giménez, 2017). Finally, although it was not measured in this study, compost improves air circulation, because it improves the total pore space, benefiting the gas phase and collaterally soil microbiology (García Mendívil *et al*., 2014).

Table 1. Effect of compost on plant height, cob height, leaf area and stalk diameter of corn.

Organic fertilizer ($t.ha^{-1}$)	Plant height (m)	Cob height (m)	Leaf area (cm^2)	Stem diameter (cm)
Control (0)	2.07 ± 0.18^b	1.04 ± 0.13^b	$6.548.80 \pm 827^b$	1.67 ± 0.06^b
10	2.27 ± 0.07^a	1.21 ± 0.04^a	$7.192.45 \pm 860^{ab}$	1.84 ± 0.07^a
20	2.29 ± 0.07^a	1.23 ± 0.04^a	$7.235.01 \pm 491^{ab}$	1.84 ± 0.06^a
30	2.30 ± 0.11^a	1.28 ± 0.09^a	$7.683.27 \pm 139^a$	1.85 ± 0.11^a
C.V. (%)	6.84	10.78	9.94	5.64

a, b Different letters in the same column indicate a significant statistical difference, according to Tukey's test ($p<0.05$).

The total number of $cobs.ha^{-1}$ was higher and different ($p<0.05$) in the 30 $t.ha^{-1}$ compost treatment compared to the control treatment which was lower (Table 2). This indicator is of great importance to affirm the positive effect of the use of compost, compared to the control treatment typically used by producers in the Frailesca region, Chiapas, Mexico. Similar results were reported by Daza-Torrez (2014), who experimented the use of compost in corn production and concluded that its use in combination with inorganic fertilizers, significantly improve soil characteristics, such as pH, exchangeable acidity, available phosphorus, organic matter and C/N and C/P ratios at the beginning of its application, as well as the concentration of nutrient elements in corn plants, ten weeks after planting. This behavior supports the present research with vegetable corn, where both sources were combined for plant nutrition.

Table 2. Effect of organic fertilizer on number of cobs, yield of corn cobs with and without bracts.

Organic fertilizer (t.ha^{-1})	Number of cobs. ha^{-1}	Yield of cobs with bracts (kg.ha^{-1})	Yield of cobs without bracts (kg.ha-^{1})
Control (0)	41,200 ±5,381^{b}	14,765 ± 1,775^{b}	9,785 ± 1,559^{b}
10	42,933 ± 4,277^{b}	16,528 ± 941^{b}	11,381 ± 661^{ab}
20	44,533 ±1,285^{ab}	16,533 ± 935^{b}	11,615 ± 488^{a}
30	49,067 ± 1,514^{a}	20,049 ± 1,786^{a}	13,098 ± 1,340^{a}
C.V. (%)	15.67	19.49	20.97

a, b Different letters in the same column indicate a significant statistical difference, according to Tukey's test ($p<0.05$).

The total yield of cobs.ha^{-1} with and without bracts was higher and different ($p<0.05$) with the treatment of greater volume of compost incorporation (30 t.ha^{-1}). The response of maize, to the treatments of greater amount of organic fertilizer applied, constitutes a fundamental indicator to infer that the agricultural soils of the Frailesca region, with high soil degradation, respond positively to the incorporation of organic amendments. Grageda-Cabrera *et al*. (2012), pointed out that one of the benefits of biofertilizers is the increase in plant yield, with a positive response of most crops to the application of organic fertilizers, due to their nutrient supply. Organic fertilizers improve soil structure, particularly in soils under intensive cultivation, compared to chemical fertilization.

Previous research conducted by Aguilar-Jiménez *et al*. (2019), on the use of compost in sorghum production in rainfed crops, reported results similar to those obtained in the present research, by determining that the best treatments were those with the highest volume of organic fertilizer incorporation into the soil. As in studies conducted by Fortis-Hernández *et al*. (2009), who reported higher green forage yields when using compost compared to conventional management.

These elements lead to affirm that the use of organic fertilizers constitutes a relevant agroecological practice for the Frailesca region, since the basic organic materials for their production are available to local farmers, being a useful practice for soil recovery, given the current state of degradation of soils in the territory (Martínez-Aguilar *et al*., 2020).

The analysis of the correlation matrix of the main maize growth variables, reflected that plant height, stalk diameter and cob length and diameter without bracts, were significantly correlated ($p<0.05$) with the response component, cob yield (Table 3).

Table 3. Correlation analysis between variables.

Variables	Plant height	Stem diameter	Length of cobs without bracts	Diameter of cobs without bracts
Stem diameter	0.691*			
Length of cobs without bracts	0.623*	0.613*		
Diameter of cobs without bracts	0.858**	0.770**	0.811**	
Cob yield	0.748**	0.513	0.488	0.688*

*: Significant ($p<0.05$), **Highly significant ($p<0.001$).

Cob yield was the most important indicator of maize productivity, when grown for sale as a vegetable (Ortíz-Torres *et al*., 2013). The correlation of plant height with corn cobs diameter also stood out, which indicated that the higher the plant height, the better the corn cobs will be obtained for marketing.

It should be noted that the highest productivity of the maize system for sale in its immature state is the number of cobs harvested, since its regional marketing is typically done by number of cobs, so it is desirable to have a high population density and a high number of cobs per plant. In this regard, Espinosa-Trujillo *et al*. (2004), pointed out that higher population densities result in a greater number of cobs, which has repercussions on the higher yield of cobs.ha^{-1}.

Economic analysis

Table 4 shows the partial budget, which was based on the temporary costs for the inputs used and the sale price of corn cobs per loaf (bag with approximately 120 immature corn cobs) in the Frailesca region of Chiapas.

Table 4. Partial budget for the use of organic fertilizer.

Concepts	Unit cost ($)	Organic fertilizer (t.ha^{-1})			
		Control	10	20	30
Yield (tarpaulins per ha)		343	358	371	409
Gross profit ($ ha^{-1})	130	44,633	46,540	48,230	53,170
Compost production ($ t^{-1})	100	0	1.000	2,000	3,000
Compost application ($ ha^{-1})	200	0	200	400	600
Total costs varying ($ ha^{-1})			1,200	2,400	3,600
Total production costs ($ ha^{-1})		13,392	14,592	15,792	16,992
Net Profit ($ ha^{-1})		31,241	31,948	32,438	36,178
Benefit/Cost Ratio		2.33	2.19	2.05	2.13

The cost for compost production was considered taking into account only labor, reusing local inputs, complying with one of the principles of agroecology (Iermanó *et al*., 2020). The net benefits were positive in all treatments and were correlated with the doses of organic fertilizer used, determining as the best treatment, the incorporation of 30 t.ha^{-1}. In addition, it should be noted that the effect of the incorporation of organic amendments in agricultural soils, under different forms and degrees of decomposition, constitutes an ecotechnology that subsequently benefits soil fertility and crop nutrition, since soil improvement remains for a prolonged time benefiting the system as a whole (Peralta-Antonio *et al*., 2019).

The durability of the benefits of organic amendments will be determined by their degree of degradation (Rodríguez *et al*., 2010). In this sense, Tlelo-Cuautle *et al*. (2020) stated that a fundamental aspect to be analyzed when incorporating organic fertilizers to degraded agricultural soils is that the agroecological benefits they provide on the system are very broad. In the first place, the restoration of soil fertility, through the improvement of its properties of agronomic interest. Secondly, they improve immediate nutrition, favoring crop production. Both aspects have a positive impact on the environmental conditions of the site, and in turn on the family economy. Although a slight decrease in the Benefit/Cost (B/C) ratio was observed in the three organic manure treatments (due to the higher cost compared to the control), there are great intangible benefits for the agroecosystem.

The marginal analysis is shown in Table 5. The organic manure treatments showed positive marginal rates of return, which indicated that the farmer will obtain benefits by investing financial resources with the incorporation of organic manure. Thus, going from the control treatment to incorporating 10, 20 or 30 t.ha^{-1}, the agroecosystem operator would recover the investment, and additionally would have $ 0.28, $ 0.40 and $ 3.11 additional pesos for each peso invested, respectively.

Table 5. Marginal analysis of the use of three doses of compost for corn production.

Treatment (t.ha^{-1})	Cost of production ($.ha)	Net profit ($.ha)	Marginal rate of return (%)
Control (0,0)	13,392	31,241	
10	14,592	31,948	28.91
20	15,792	32,438	40.83
30	16,992	36,178	311.66

Espejel-García *et al*. (2020), mentioned that corn production offers economic advantages with respect to dry grain, which accompanied by agroecological innovations improves the competitiveness of producers, as happened in the present research with the ecotechnology related to the application of organic fertilizer. In addition, it is appropriate to reaffirm that the application of organic amendments is a fundamental practice for the ecological management of agricultural soils, the benefits of which will be reflected in subsequent crop cycles.

Composting is not a regional limitation, since in the typical agricultural systems of Frailesca, Chiapas, Mexico, farmers combine the planting of basic crops and the raising of ruminants, which means that the basic materials for composting are available.

Conclusions

The agronomic variables of the maize crop harvested in its immature stage, plant height, cobs height, leaf area, stalk diameter, number of cobs and cobs yield, were favored by the effect of the incorporation of compost-type organic fertilizer, correlating positively with the highest doses of incorporation. From the economic perspective, the three doses of compost use achieved economic benefits. The use of compost at a dose of 30 t.ha^{-1} constitutes a viable alternative to improve the productivity of corn harvested as a vegetable crop in the Frailesca region, Chiapas, Mexico.

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