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Article

Sustainable soil management for organic vegetable production in the State of Mexico

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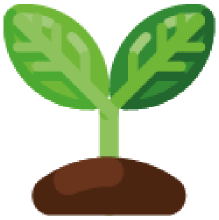
Abstract

A growing number of farmers in the east of the State of Mexico produce healthy, quality food that they sell in local organic markets. Their agricultural practices have been poorly evaluated, and there is a risk that long-term intensive food production will result in decreased soil fertility and productivity. The effect of the application of organic fertilizers on *Brassica rapa* L. var. *chinensis* (pak choi) and *Brassica oleracea* L. var. *acephala* (kale) in two growth cycles (spring-summer and autumn-winter) and on the chemical quality of the soil was studied. The field experiments were carried out in the municipalities of Teotihuacán and Texcoco, State of Mexico. The experimental design was randomized blocks. The treatments tested were compost 10 t ha^{-1}, compost 10 t ha^{-1} + 4% supermagro, 4% supermagro, and a control without application. Variables of morphological response, crop yield, and soil chemical quality indicators (pH, electrical conductivity, organic matter, $N_{Kjeldahl}$, P_{Olsen}, and K, Ca, Mg, and Na exchange bases) were evaluated. The results were analyzed using the SAS 9.0 statistical package. In both sites, applying these organic fertilizers increased the commercial yield of both vegetables and some morphological variables. The treatments experimented improved, or at least maintained, the initial fertility of the soils in the short term.

Keywords:

Brassica oleracea L. var. *acephala*, *Brassica rapa* L. var. *chinensis*, organic fertilizers, soil quality indicators.



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Introduction

Rapid population growth entails an increase in the demand for food. Intensification of agriculture can contribute to soil degradation (Kopittke *et al*., 2019) and infertility (Imadi *et al*., 2016). Intensive food production, particularly commercial production, imposes an agricultural system that demands the use of agrochemicals that can cause environmental and health problems (Kopittke *et al*., 2019).

To address this problem, sustainable agriculture strategies have been adopted, including organic or ecological farming (Reeve *et al*., 2016). The incorporation of organic fertilizers or composts into the soil is a practice that is becoming important due to the benefits they provide to fertility and other properties of the soil (Muñoz-Villalobos *et al*., 2014; Hernández-Rodríguez *et al*., 2020; Bhunia *et al*., 2021).

A growing number of smallholder farmers in Texcoco and Teotihuacan, State of Mexico, produce healthy, quality food that they sell at local organic markets. The effect of organic fertilizers on the fertility of cultivated soils has been little studied. The status of the soil's fertility is determined by evaluating its physical, chemical, and biological characteristics and properties.

In the present study, we worked with two Chinese vegetables recently introduced in the sector of interest: pak choi (*Brassica rapa* L. var. *chinensis*) and kale (*Brassica oleracea* var. *acephala*). Pak choi is characterized by rapid growth and development (50-60 days after sowing). The growth of kale is slower, but it has the advantage of starting to be harvested 70 days after sowing and continuing to form leaves continuously, its productive cycle is longer than pak choi. Pak choi and kale leaves quickly cover the surface of the soil and protect it from water and wind erosion.

Kale has gained great popularity as a 'superfood' due to its high content of bioavailable Ca, riboflavin, vitamins K, C, and A, fibers, minerals such as K, Mg, Fe, Cu, etc. (Šamec *et al*., 2018). Pak choi provides vitamins B9, A, E and minerals such as K, Mg, Ca, Mn, Fe, Ni, etc. (Khan *et al*., 2022).

The studies published around the world that evaluate both vegetables report little or no information about the properties and characteristics of the soils in which they are grown because most of the production is carried out under protected agriculture systems. The objectives of this study were: 1) to evaluate the effect of organic fertilizers on the growth and yield of pak choi and kale under field conditions; and 2) to determine the effect of the application of these organic fertilizers on the characteristics and chemical properties of the soil after two crop cycles at two sites in the State of Mexico.

Materials and methods

Establishment of the crop

The experiments were established in two localities in the State of Mexico, 1) Purificación, Teotihuacán and 2) San Luis Huexotla, Texcoco. The climate in Teotihuacán is subhumid temperate, with rainfall in summer and temperature between 14 to 16 °C; in Texcoco, it is semi-dry with rainfall in summer, temperature from 6 to 16 °C.

At both sites, the duration of the experiments was 7 months (June-December 2021) and comprised two growth cycles: spring-summer (SS), from June 30 to August 5 in Teotihuacán and from July 30 to September 7 in Texcoco, and autumn-winter (AW), from August 26 to October 13 in Teotihuacán and from September 24 to November 3 in Texcoco. The transplantation to the field was performed when seedlings reached a height of 6-10 cm, 2-3 true leaves, and 21-28 days after sowing (DAS). Given the longer growth period of kale, plants established in SS were kept for AW.

In Teotihuacán, sowing beds 25 m long by 1.2 m wide were used, and five rows of crops 25 cm apart in each bed. The sowing distance of kale and pak choi was 30 and 20 cm between plants, with densities of 13.8 and 20.8 plants m^{-2}, respectively. In Texcoco, 110 m long furrows 80 cm apart were used; crops were established in double rows in a hexagonal system, and a sowing density of 8.3 plants m-2 in kale and 12.5 plants m-2 in pak choi. Teotihuacán received drip irrigation and Texcoco gravity irrigation.

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Experimental design and treatments

The experimental design was randomized complete blocks, with four replicates per treatment. In both cases, three central plants were taken as the sampling unit. Four treatments were evaluated: control (T1), compost 10 t ha^{-1} (T2), compost 10 t ha^{-1} + 4% supermagro (T3), and 4% supermagro (T4). The control treatment (T1) is the condition of the soil of the producer or reference; the producer of Teotihuacán incorporated remains of their crops, some composted material, but no chemical fertilizer because they are organic producers, they also rotate their vegetables; the producer of Texcoco does not apply any type of fertilization.

Compost was incorporated into the soil before the SS cycle at both locations. Supermagro (liquid biofertilizer) was applied at 4% (40 ml L^{-1}) to the crop leaves and soil 1 day after transplantation (DAT) and every 14 days. Pak choi received three applications per cycle, and kale received eight applications in total.

Evaluation of agronomic variables in the field

The morphological and yield response variables were evaluated at the end of each production cycle: 56 DAS in pak choi and 70 and 160 DAS in kale. For pak choi: 1) plant height (HE) to the apex of the largest leaf; 2) number of leaves with commercial value (NLC); 3) rosette diameter (RD), measured at half the height of the plant; 4 and 5) length and width of the larger leaf petiole (PL and PWI, respectively); 6 and 7) fresh and dry rosette weight (FRW and DRW, respectively), DRW in an oven at 70 °C to constant weight; and 8) commercial yield per hectare (YIE).

For kale: 1) plant height (HE); 2) total number of leaves with commercial value per plant (NLC); 3 and 4) leaf length and width (LL and LWI, respectively) (average number of leaves harvested at each cut); 5 and 6) fresh and dry weight of the aerial part of the plant (AFW and ADW, respectively); and 7) commercial yield per hectare.

Soil sampling and analysis

Two soil samplings were carried out in each locality, one before the establishment of the crop (initial soil) and one at harvest. In both cases, the sample was taken at a depth of 0-20 cm. Composite samples were formed: 15-20 subsamples of the initial soil and 5-10 subsamples of each treatment evaluated (at harvest).

In the soil, the following were evaluated: 1) pH in water (1:2); 2) electrical conductivity (EC); 3) organic matter (OM); 4) $N_{Kjeldahl}$ (N); 5) P_{Olsen}; and 6) exchangeable cations (K, Ca, Mg, and Na), (SEMARNAT, 2002).

Statistical analysis

An analysis of variance (Anova) was performed on all the evaluated variables with the randomized complete block experimental design. Variables with significant effects were subjected to multiple comparisons of means using LSD ($p \leq 0.05$). In all cases, the SAS v. 9.0 statistical package was used (SASInstitute, 2002).

Results and discussion

Morphological and yield parameters of pak choi and kale. The production of pak choi in Teotihuacán during the SS cycle (Table 1) showed that the treatment with 4% supermagro (T4) presented the highest values of plant height (29 ±2.5 cm), rosette diameter (56.5 ±4.3 cm), petiole width (2 ±0.2 cm), fresh rosette weight (202.7 ±39.9 g), dry rosette weight (13.7 ±2.1 g) and a commercial yield of 42 ±7.9 t ha^{-1}.

Table 1. Morphological and yield parameters of 'Pak Choi White' in Teotihuacán.

Treatment	NLC	RD (mm)	HE (cm)	PL (cm)	PWI (cm)	FRW (g plant^{-1})	DRW (g plant^{-1})	YIE (t ha^{-1})
				Spring-Summer				
T1) control	7.2	52.5	28.5	14	1.8	183.5	13.2	38.2
T2) compost	7	50.7	26.2	13.5	1.9	165.7	11.5	34.5
T3) com +super	7	53	27	12.5	1.8	161.2	11	33.7
T4) supermagro	7.2	56.5	29	14	2	202.7	13.7	42
[1]LSD	1.99	8.36	2.93	2.57	0.36	49.97	3.26	10.34
				Autumn-Winter				
T1) control	7.5	34.5	22.2	9	1.7	66.5	6.2	13.7
T2) compost	7.5	30.5	20.7	8.5	1.5	47.5	5	10
T3) com +super	7.7	34.2	23	10	1.8	71.7	6.5	15
T4) supermagro	7.5	31.2	21	8.7	1.7	55.5	5.5	11.5
[1]LSD	1.22	6.54	2.93	2.03	0.42	26.84	2.19	5.6

com+super= compost + supermagro; HE= plant height; NLC= number of leaves with commercial value; RD= rosette diameter; PL= petiole length; PWI= petiole width; FRW= fresh rosette weight; DRW= dry rosette weight; YIE= commercial yield per hectare; [1]LSD= least significant difference, LSD test ($p \leq 0.05$).

In AW, it was the combination of compost + supermagro (T3) that showed the highest plant height (23 ±2.6 cm), petiole length (10 ±1.7 cm), petiole width (1.8 ±0.2 cm), fresh rosette weight (71.7 ±19 g), dry rosette weight (6.5 ±1.5 g) and commercial yield (15 ±4 t ha^{-1}). In both cycles, the variables evaluated in the control were similar or slightly lower than those of the best treatments (T4 SS cycle and T3 AW cycle), attributable to the organic management applied by the producer.

At the Texcoco site, the effect of T3 in SS stands out, favoring the height (29.6 ±2.8 cm), rosette diameter (24.2 ±3.6 cm), fresh rosette weight (260.3 ±49.9 g) and commercial yield (32.5 ±6.2 t ha^{-1}) of pak choi (Table 2). In AW, it was the supermagro (T4) that presented the highest values in most of the measured variables, which is attributable to the residual effect of this product.

Table 2. Morphological and yield parameters of 'Pak Choi White' in Texcoco.

Treatment	HE	NLC	RD	PL	PWI	FRW	DRW	YIE
	(cm)		(mm)	(cm)		(g plant^{-1})		(t ha^{-1})
				Spring-Summer				
T1) control	25.9	11.6	17.5	11.6	3	167.1	13.1	21
T2) compost	28.5	13.2	21.8	13	3.6	251	18.3	31.2
T3) com +super	29.6	12.6	24.2	12.8	3.4	260.3	16.8	32.5
T4) supermagro	27.5	12.5	22	12	3	246.2	17.9	30.7
LSD	5.26	1.85	6.4	2	1.07	138.14	5.64	16.81
				Autumn-Winter				
T1) control	18.2	8.8	10.2	6.2	1.4	43.7	3.8	5.5
T2) compost	18.7	9.6	11.2	6.6	1.5	53.7	4.6	6.7

Treatment	HE	NLC	RD	PL	PWI	FRW	DRW	YIE
	(cm)		(mm)	(cm)		(g plant^{-1})		(t ha^{-1})
T3) com +super	19.5	8.6	10.7	6.4	1.5	50	4.2	6.5
T4) supermagro	19.9	9.5	11	6.6	1.6	80.1	6.2	10.2
LSD	4.08	2.37	3.21	1.7	0.49	60.54	4.67	7.51

com+super= compost + supermagro; HE= plant height; NLC= number of leaves with commercial value; RD= rosette diameter; PL= petiole length; PWI= petiole width; FRW= fresh rosette weight; DRW= dry rosette weight; YIE= commercial yield per hectare; LSD= least significant difference, LSD test ($p \leq 0.05$).

The positive effect of supermagro (T4) and its combination with compost (T3) is associated with the foliar application of the former, which improves nutrient absorption (Bindraban *et al*., 2015). The performance of kale in Teotihuacán (Table 3) indicated that T2 led to higher aerial fresh weight (351 ±35.4 g), aerial dry weight (56.5 ±7.4 g), and commercial yield (48.7 ±4.8 t ha^{-1}). The application of supermagro (T4) alone or combined with compost (T3) did not increase morphological and yield variables, which is explained by the organic management carried out by the producer on this site.

For this vegetable at the Texcoco site, the effect of T3 stood out, which led to the highest values of aerial fresh weight (388.3 ±155 g), aerial dry weight (57 ±10.1 g), and commercial yield (32.34 ±12.9 t ha^{-1}).

Table 3. Morphological and yield parameters of 'Kale Verde' in two locations in the State of Mexico.

Treatment	NLC	HE (cm)	LL (cm)	LWI (cm)	AFW (g plant^{-1})	ADW (g plant^{-1})	YIE (t ha^{-1})
				Teotihuacán			
T1) control	24.7	31.2	24.7	10.2	289	49.7	40.2
T2) compost	28.5	33.2	27.2	11	351	56.5	48.7
T3) com +super	24.2	31.5	25.5	10.7	306.5	46	42.2
T4) supermagro	28.5	31.2	23.7	10.2	307.5	49.2	42.7
LSD	4.64	7.72	3.8	0.99	96.26	14.77	13.32
				Texcoco			
T1) control	22.4	27.5	21.4	10.2	323.9	53.7	26.98
T2) compost	24.2	28.8	21.8	9.7	315.7	50.5	26.3
T3) com +super	25.2	31.5	24.9	10.8	388.3	57	32.34
T4) supermagro	23.2	28.5	22.8	9.8	314.2	54	26.18
LSD	2.87	7.8	5.37	1.43	134.99	11.74	11.24

com+super= compost + supermagro; HE= height; NLC= number of commercial leaves; LL= leaf length; LWI= leaf width; AFW= aerial fresh weight; ADW= aerial dry weight; YIE= commercial yield; LSD= least significant difference, LSD test ($p \leq 0.05$).

Although no significant differences ($p \leq$ 0.05) were obtained in the morphological variables and yield of pak choi and kale because of the addition of organic fertilizers (compost and supermagro alone or combined) in both sites, a beneficial effect was observed in some of these variables.

Since the metabolism of both vegetables is fast growing, 56 days for pak choi and 160 days for kale, both require a greater amount of mineral nutrients for their development in the short term than other slower-growing crops; so, the application of supermagro (every 15 days) and possibly its dose

(4%) were insufficient to cause significant differences in morphological and yield variables in the short term of the experiment's evaluation.

The SS and AW production cycles and the Teotihuacán and Texcoco locations significantly affected ($p \leq 0.05$) the growth and development of pak choi. The comparison of means (LSD, $p \leq 0.05$) showed that the highest productivity of pak choi was obtained in the SS cycle and that it was higher in Teotihuacán than in Texcoco. This reflected the influence of climatic conditions on pak choi production, as reported by Kalisz *et al*. (2012); Acikgoz (2016).

Chemical properties of the soil. The soil of Teotihuacán presented a moderately alkaline pH (H_2O, 1:2) throughout the experiment, indicating the buffering power of the soil caused by the addition of organic amendments. The EC increased from 0.1 dS m^{-1} to 0.7 dS m^{-1} in both periods (Table 4).

Table 4. Chemical properties of the soil in Teotihuacán at the beginning and end of the experiment.

Treatment	pH	EC (dS m^{-1})	OM	N	P_{Olsen}	K	Ca	Mg	Na
			(%)		(ppm)	(cmol kg^{-1})			
				Pak choi					
Initial soil	8.1 b	0.1 c	3.2 a	0.19 a	94 a	3 a	19 b	14 b	0.8 a
T1) control	8.4 a	0.65 b	2.8 b	0.15 b	78 ab	4 a	24 a	16 a	0.7 ab
T2) compost	8.4 a	0.65 b	2.6 b	0.17 ab	73 ab	4 a	23 a	16 a	0.7 ab
T3) com +super	8.4 a	0.7 a	2.8 b	0.17 ab	77 ab	4 a	23 a	15 a	0.6 b
T4) supermagro	8.4 a	0.62 b	2.6 b	0.15 b	68 b	4 a	23 a	16 a	0.7 ab
LSD	0.1	0.02	0.42	0.04	24.11	1.52	3.39	1.31	0.14
CV (%)	0.9	4	10.1	16.6	20.7	26.6	10.8	6.1	14.2
				Kale					
Initial soil	8.1 a	0.1 b	3.2 a	0.19 a	94 a	3 a	19 b	14 b	0.8 a
T1) control	8.2 a	0.37 a	2.8 b	0.15 a	72 ab	3 a	23 a	17 a	0.6 b
T2) compost	8.3 a	0.42 a	2.8 b	0.12 a	78 ab	3 a	24 a	18 a	0.7 ab
T3) com +super	8.2 a	0.4 a	2.5 b	0.12 a	59 b	3 a	21 ab	17 a	0.6 ab
T4) supermagro	8.2 a	0.4 a	2.6 b	0.15 a	65 b	3 a	23 a	17 a	0.6 ab
LSD	0.12	0.08	0.44	0.06	25.89	1.53	3.69	1.65	0.12
CV (%)	1.1	19.9	10.6	30.5	23.3	33.2	11.9	7.2	12.3

com+super= compost + supermagro; LSD= least significant difference; CV= coefficient of variation. Means with the same letter within columns do not differ statistically according to the LSD test ($p \leq 0.05$).

N, considered high (0.19%), showed a slight decrease (0.12%) as did OM content (from 3.2 to 2.5%). The application of organic fertilizers allowed the concentration of these elements in the soil to be maintained close to initial values, before the establishment of the plants, except for P_{Olsen} (94 ppm), which decreased to 59 ppm. The initial high concentrations of N and P_{Olsen} respond to the organic management practiced by the producer on the site.

The initially high exchangeable Ca and Mg in the soil (SEMARNAT, 2002) generally increased even after the experiment (14 to 18 cmol Mg kg^{-1} and 19 to 24 cmol Ca kg^{-1}); the differences are statistically significant in both. Soil exchangeable K ranged from about 3 to 4 cmol kg^{-1}, and exchangeable sodium decreased from (0.8 to 0.6 cmol kg-1). In the Texcoco soil, the pH (H2O, 1:2) varied around 8 (Table 5). Electrical conductivity was maintained throughout the experiment <0.2 dS m^{-1}.

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Table 5. Chemical properties of the soil in Texcoco at the beginning and end of the experiment.

Treatment	pH	EC (dS m^{-1})	OM	N	P_{Olsen}	K	Ca	Mg	Na
			(%)		(ppm)	(cmol kg^{-1})			
				Pak choi					
Initial soil	8.2 a	0.2 a	2.8 a	0.11 b	38 a	2 a	38 ab	13 b	1.4 a
T1) control	8.2 a	0.19 a	2.7 a	0.16 ab	42 a	2 a	40 ab	15 a	1.2 a
T2) compost	8.2 a	0.2 a	3 a	0.16 ab	55 a	2 a	39 ab	14 ab	1.2 a
T3) com +super	8.2 a	0.23 a	3 a	0.17 ab	53 a	2 a	35 b	15 a	1.3 a
T4) supermagro	8.3 a	0.2 a	2.6 a	0.2 a	57 a	2 a	41 a	15 a	1.4 a
LSD	0.12	0.11	0.4	0.06	36.11	0.63	4.94	1.73	0.37
CV (%)	1	39	10	31.1	53	25.2	8.9	8.5	19.1
				Kale					
Initial soil	8.2 a	0.2 a	2.8 a	0.11 b	38 a	2 ab	38 a	13 b	1.4 a
T1) control	8.4 a	0.16 a	2.7 a	0.14 ab	27 a	1 b	36 a	14 ab	1.4 a
T2) compost	8.4 a	0.13 a	3 a	0.19 a	37 a	2 a	35 a	15 a	1.4 a
T3) com +super	8.3 a	0.16 a	2.8 a	0.15 ab	38 a	2 a	34 a	15 a	1.4 a
T4) supermagro	8.4 a	0.15 a	2.8 a	0.15 ab	35 a	2 ab	37 a	15 a	1.4 a
LSD	0.18	0.12	0.37	0.05	15.57	0.46	4.3	1.67	0.36
CV (%)	1.5	51	9.2	28.4	30.4	19.9	8.2	8.1	17.9

com+super= compost + supermagro; LSD= least significant difference; CV= coefficient of variation. Means with the same letter within columns do not differ statistically according to the LSD test ($p \leq 0.05$).

These values indicate a moderately alkaline reaction with no salinity problems (SEMARNAT, 2002). The OM, considered intermediate, remained around 3% throughout the experiment. N remained unchanged or increased slightly (0.11 to 0.2%) due to organic material inputs. Soil P_{Olsen} increased from 38 ppm to 57 ppm or remained close to the initial soil concentration. It reaffirms that organic fertilizers preserve or improve soil fertility.

The higher concentration of P_{Olsen} in the soil with pak choi (42-57 ppm) compared to that obtained with kale (27-38 ppm) suggests that the latter has a greater extraction capacity, which would be associated with a greater number and length of lateral roots (Hammond *et al*., 2009). Concentrations of P_{Olsen} in the soil with kale are considered low for short-lived horticultural crops (Yan *et al*., 2013).

The concentrations of the exchangeable bases: Ca (35-40 cmol kg^{-1}), Mg (13-15 cmol kg^{-1}), K (1-2 cmol kg^{-1}), and Na (1.2-1.4 cmol kg^{-1}) are considered adequate for the production of this type of crop (Kopittke and Menzies, 2007) and are in line with the requirements reported for Brassicas (Pennington and Fisher, 2010). K, Ca, Mg, and P are mineral elements that have been reported to be the most important in various kale cultivars (Waterland *et al*., 2017). A trend of positive association between soil N and P with fresh and dry pak choi yield and weight was observed, similar to that reported by Liao *et al*. (2019).

Conclusions

The application of organic fertilizers favored the height, petiole width, rosette weight, and commercial yield of pak choi and increased the commercial yield, leaf length and width, and aerial weight of kale in both study sites.

This effect was more evident at the Texcoco site, where the producer applies nothing, than at Teotihuacán, where the producer has organic management. The production of pak choi was higher in the spring-summer cycle than in the autumn-winter cycle, which shows the effect of the climatic factor on the development of this vegetable.

The concentration of nitrogen, organic matter, and P_{Olsen} in the soil decreased at the Teotihuacán site, but the application of organic fertilizers allowed the levels of these elements to be kept close to the initial levels. At the Texcoco site, the chemical condition of the soil was improved by increasing nitrogen, and initial fertility was preserved by maintaining the concentration of organic matter and P_{Olsen}. In general, the concentrations of Ca and Mg in the soil, elements highly demanded by these vegetables, increased in both sites.

These results are conclusive in terms of the beneficial effect of the application of organic fertilizers on the production of pak choi and kale, but not in terms of the increase in the percentages of N and OM in the soil, effects that are unlikely to be conclusive due to the short time of the experiment.

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