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Greenhouse Cucumber Production with Organic and Inorganic Fertilizers

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ABSTRACT

Cucumber production (*Cucumis sativus* L.) utilizes great number of chemical fertilizers leading to environmental pollution. Therefore, organic fertilizers represent a tool to meet crop nutrient demand. The objective of this work consisted of evaluating different organic and inorganic fertilizers for cucumber production. The experiment consisted of three treatments and a control (TES), T1 (100% organic fertilizer), T2 (65% organic fertilizer + 35% inorganic fertilizer), T3 (50% organic fertilizer + 50% inorganic fertilizer) and TES (100% inorganic fertilizer). The physiological variables were plant height, number of leaves, stem diameter, dry and fresh biomass. Production variables were number, weight, length and diameter of fruits. Quality variables were total soluble solids (TSS), firmness, pH, electrical conductivity, titratable acidity, color and shelf-life. It was found that T2 had the highest plant height (355 cm and 50 leaves) and higher fresh fruit weight (326.37 g), fruit length 25.1 cm and diameter of 4.7 cm, T3 had greater number of flowers and root biomass; while TEST had the highest total soluble solids content, pH, color and shelf-life. it is advisable the implementation of T2 due to reduction of production costs without affecting yield and fruit quality.

KEYWORDS: *Cucumis sativus*, Plant nutrition, Crop, Productivity, Food quality.

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Producción de pepino con fertilización orgánica e inorgánica en invernadero

RESUMEN

La producción de pepino (*Cucumis sativus*) utiliza gran cantidad de fertilizantes químicos provocando contaminación al medio ambiente. Por lo tanto, los fertilizantes orgánicos representan una herramienta para cubrir la necesidad nutrimental de un cultivo. El objetivo del trabajo fue evaluar diferentes fertilizantes orgánicos e inorgánicos para la producción de pepino. El experimento consistió en tres tratamientos y un testigo (TEST), T1 (100% fertilizante orgánico), T2 (65% orgánico + 35% inorgánico), T3 (50% orgánico + 50% inorgánico) y TES (100% inorgánico). Las variables fisiológicas fueron altura de planta, número de hojas, diámetro de tallo, biomasa fresca y seca; de producción fueron número, peso, longitud y diámetro de frutos, y de calidad fueron sólidos solubles totales, firmeza, pH, CE, acidez titulable, color y vida postcosecha. El T2 tuvo la mayor altura de planta (355 cm y 50 hojas), mayor peso fresco (326.37 g), 25.1 cm de longitud y 4.7 cm de diámetro de fruto, el T3 tuvo mayor número de flores y biomasa radicular; mientras que el TES tuvo mayor contenido de SST, pH, color y vida postcosecha. Se recomienda la implementación del T2 debido a la reducción de costos de producción sin afectar la calidad y rendimiento de frutos.

PALABRAS CLAVE: *Cucumis sativus*, Nutrición de las plantas, Cultivo, Productividad, Control de alimentos.

Introduction

Cucumber crop (*Cucumis sativus*) is one of the vegetables that is produced in several countries and can be grown directly on the field or greenhouse, depending upon weather conditions (Calero-Hurtado et al., 2019). This crop is of great economic importance for its nutritional value and high consumption index. Additionally, the attraction of this crop to growers is due to higher yields and income in a short time. The main producing countries are China, Unites States, Turkey, Iran, Japan and Mexico (Rodríguez-Fernández & Girón-Acosta, 2020). Optimal crop development demands high fertilizer and pesticide applications to increase yield and fruit quality (Ramos-Agüero & Alfonso, 2014). However, the indiscrete use of these chemical products implies not only elevation costs but also underground water and soil pollution (Luna-Murillo et al., 2016). Organic agriculture is a sustainable production practice that decreases the use of pesticides and fertilizers. According to Reyes-Pérez et al. (2017) is important to enhance organic fertilizer efficiency to avoid environmental degradation. They also mention that organic amendments supply organic matter, nutrient and microorganisms which enhance soil fertility and nutrient uptake. The liquid extracted from organic residue decomposition is termed "worm leachate"; this product supplies many nutrients that plants need for growth and development. Another property of vermiculture is the supply of organic compounds that influence nutrient availability in soils and those nutrients needed in stages of maximum demand (Martínez-Scott & Ruiz-Hernández, 2018).

SEMARNAT, (2016) encourages the public to transform the organic waste to a product with high economic value that has direct benefit to the environment, public health and people's income. The recycle of manure in the primary sector can be used as a sustainable vermiculture tool to produce organic fertilizer and thus reducing environmental pollution (Yuvaraj et al., 2020; Romero-Romano et al., 2018; Indrani-Ramnarain et al., 2019). The mixture of organic and inorganic fertilizers would increase the yield and quality of cucumber fruits grown under greenhouse conditions. Therefore, the objectives of this study consisted of evaluating different percentage of organic fertilizer (worm leachate) with inorganic fertilizer (Steiner solution) in order to reduce the use of chemical fertilizers and increase the yield and quality of cucumber fruits.

1. Literature review

Li and Mattson (2019) reported that high rate of manure vermicompost (VC) or a medium rate combined with turkey litter-based compost could be replaced for conventional liquid fertilizer on the cultivation of cucumber seedlings. They also found that stem length, number of leaves, dry biomass and leaf greenness (spad readings) increased as increasing turkey litter-based compost and manure vermicompost applications. On the other hand, Najjari and Gashemi (2018) obtained quality vermicompost by mixing 5% blood powder with sawdust with high values of N, P, K, Fe, Zn and Mn content, lower pH and C:N ratio, which increased significantly the uptake and growth of cucumber. Furthermore, Ahamd et al. (2015) demonstrated that combination of slurry and *Pseudomonas fluorescens* improved the growth, yield and quality of cucumber fruits as compared to sole applications of farm-manure, poultry-manure, slurry or chemical fertilizer.

Mahmoud et al. (2009) evaluated three compost types (plant residues, animal residues and mixed) and found that combination of organic + inorganic fertilizer increased growth, yield and quality of cucumber fruits. Also, they exhibited that organic wastes can replace around the 25% of nitrogen fertilizers. Law-Ogbomo and Osaigbovo (2018) reported that organic fertilizer rates (cattle and poultry manure) increased growth and yield of cucumber and improved soil chemical properties of an Ultisol; therefore, they suggested to apply 10 $t.ha^{-1}$ of poultry manure instead of chemical fertilizers to enhance overall production. Orluchukwu and Amadi (2022) recommended the application of poultry manure on the area of Alakahia, Nigeria, because it enhanced parameters of cucumber growth (vine length, number of leaves, leaf area at 6 and 8 weeks after planting). It also increased the number of fruits (15,000 ha^{-1}) and a yield of 2,650kg ha^{-1} compared to mushroom substrate, NPK 15-15-15 and control.

2. Materials and Methods

The experiment was conducted during the season Spring-Summer 2023 at Campus Montecillo, Texcoco, Mexico (19° 27´ 58" North latitude, 98° 54´ 58" West longitude) and 2431 m above sea level. The material was grown in a polycarbonate greenhouse under hydroponic system with red tezontle as substrate. The planting method consisted of the triangular system "tresbolillo". Seedlings were placed in black polyethylene bags (30 x 30 cm) 40 cm apart from each plant, 40 cm between lines, 10 m long and a density of 3 plants m^{-2}.

Cucumber seeds of Vitaly variety (indeterminate growth habit) were grown in 200 cavity Styrofoam trays. The planting date was realized on March 14 and transplanted on April 12 2023, while the end of harvest was July 26 2023. The experiment was arranged as a randomized complete block design. Each experimental unit was 10 m^2 with 120 plants and 8 replicates; total surface was 40 m^2. Treatments were designed as follow: T1 (100% worm leachate), T2 (35% of NS + 65% organic fertilizer), T3 (50% NS + 50% organic fertilizer) and TEST (100% NS). The irrigation system consisted of a watering line (16 mm diameter) with self-compensating drippers (0.4 m apart), flow rate of 8 L h^{-1} and operating pressure of 68.64 kPa. The irrigation was applied along with Steiner's nutrient solution and had an osmotic potential of -0.036 MPa at vegetative stage, and -0.072 MPa at reproductive stage (table 1). Also, the same table shows the rates of nutrient solution (NS) (inorganic fertilizer) and the organic fertilizer (worm leachate) applied to treatments.

Table 1. Rates of Stainer nutrient solution and worm leachate.

Fertilizer source	Chemical formula	Nutrient solution ($g.L^{-1}$)	
		-0.036 MPa	**-0.072 MPa**
Macronutrients	$Ca(NO_3)_2.4H_2O$	0.413	0.945
	KNO_3	0.253	0.404
	$MgSO_4.4H_2O$	0.089	0.335
	K_2SO_4	0.072	0.247
Micronutrients	$MnSO_4$	0.00708	0.0078
	$ZnSO_4$	0.00264	0.00264
	$FeSO_4$	10 mL	30 mL
	$CuSO_4$	0.00024	0.00024
	H_3BO_3	0.00343	0.000343
Acids	H_2SO_4 (98%)	0.098 ($mL.L^{-1}$)	0.052 ($mL.L^{-1}$)
	H_3PO_4 (85%)	0.049 ($mL.L^{-1}$)	0.067 ($mL.L^{-1}$)
Organic fertilizer	Worm leachate	1 L worm leachate in 20 L of water	2 L worm leachate in 20 L of water

To evaluate physiological variables, 8 plants of each treatment were selected and tagged at transplanting. Plant height was measured from the stem base to the apex, the number of leaves were quantified when they were fully expanded, the number of flowers were also quantified when they were totally developed, the stem diameter was measured with a vernier taking as a reference 3 cm above stem base. All variables were registered every 8 days. In addition, four destructive samplings were done on each treatment to determine dry and fresh biomass. To assess that, 3 plants were extracted to separate roots, flowers and fruits; thereafter, the organs were fresh weighted on a digital scale (Model 5000p) with a resolution of 0.001 g. Once done, those organs were placed on dry air forced oven (60 ºC) for 48 hours until constant weight.

The leaf area index (LAI) was measured with an electronic device (Area Meter Model LI-3100, Decagon Device, Inc) on 3 plants of each treatment and was calculated using the following equation (Reis et al., 2013).

$$LAI = \frac{\text{FA X NP}}{\text{TA}}$$

Where: LAI expressed as $m^2 \cdot m^{-2}$, FA is the middle surface of the leaf (m^2), NP is the number of plants (m^2) and TA is the total area (1 m^2).

The same plants taken to evaluate physiological variables were also used to estimate yield and its components. The number of fruits were quantified when they attained the appropriate diameter, length and color; the weight of fruits was done on a digital scale (Model 5000p) to obtain the average per plant and treatment. The fruit length and diameter were done from one extreme to another using a measuring tape, and the diameter was performed in the middle part of the fruit with a vernier (Truper CALDI-6MP).

Finally, yield was determined when all harvested fruits reached the appropriate diameter ad length.

3. Results and Discussion

Figure 1 shows the performance of crop growth and development during the growing season. It is observed that plants on T2 reached greater height (355 cm), T3 (399 cm), TEST (317 cm) and T1 (269 cm). Also, statistical differences were found between treatments as compared to TEST (control). These results are higher to those reported by Marcano et al. (2012) who obtained values of 177.95 cm in height of cucumber plants. Nonetheless, Núñez-Ramírez et al. (2023) reported lower values (238 cm) in variety Poinsett 76, where 100% of nutrient solution was applied. On the other hand, it was observed that plants on TEST obtained the greatest height as compared to the other treatments up to 92 days after transplant (DAT); after that period, the rate of growth was reduced and was surpassed by T2 and T3. This result is mainly attributed to the fact that nutrient applied contained all essential nutrients that plants needed for growth and development.

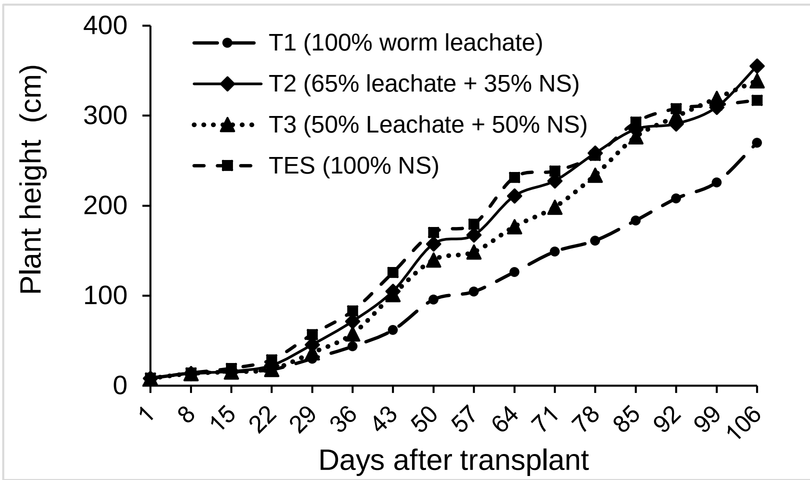

Figure 1. Plant height for all treatments during the growing season.

It was found that TEST showed the highest value (0.8 cm) on stem diameter, while T1 showed the lowest value (0.6 cm). T2 and T3 showed values of 0.7 cm without statistical differences between treatments (table 2). These results are similar to those found by Ayala-Tafoya et al. (2019), who reported values of 0.71 cm in this crop grown at different densities and pruning management. Thus, they also coincide with the reports by Luna and Urbina (2018), who exhibited values of 0.84 cm for this parameter. However, Gabriel-Ortega et al. (2022) found higher values (0.98 cm) on variety "Intimator".

Table 2. Physiological variables of cucumber crop.

Treatment	Diameter (cm)	N. Leaves	N. Flowers
T1 (100% worm leachate)	0.6 a	42 b	53 c
T2 (65% leachate + 35% NS)	0.7 a	50 a	55 b
T3 (50% Leachate + 50% NS)	0.7 a	47 a	62 a

TES (100% NS)	0.8 a	47 a	34 d

Different letters within the same column are statistically different. Tukey mean separation test ($P \leq 0.05$), (OSL Pr> F).

The greatest number of leaves was found on plants of T2 (50 leaves) and the lowest on T1 (42 leaves) (table 3). These results coincide with those found by Ayala-Tafoya et al. (2019) who reported 51 leaves on this crop. Nonetheless, these values are higher by those found by Marcano et al. (2012) and Núñez-Ramírez et al. (2023) who reported 29 and 33 leaves respectively on variety Poinsett 76 grown under greenhouse conditions.

The leaves are important organs that provide information about their capacity to capture photosynthetically active radiation to transform it into chemical energy by assimilating carbon from CO_2 and fixing it into organic compounds (Mendoza-Pérez et al., 2018b; Ayala-Tafoya et al., 2019). Plants on all treatments started to bloom at 26 DAT. It was found that T3 (50% NS + 50% worm leachate) produced greater number of flowers (62), T2 (55) and TEST (34) flowers (table 3). The number of flowers attained on the plants was higher than that of López-Elías et al. (2011) who reported 33 flowers. According to these results, a balanced fertilization (organic + inorganic) can influence a positive response in physiological variables of cucumber plants.

The importance of measuring fresh biomass on plants lies on the knowledge of the amount of water and nutrients that plants are taking up during growth. As a consequence, this information is of great importance on irrigation scheduling and management. Fresh biomass accumulation was similar at transplant for all treatments. It was observed that root biomass started at 23 DAT and TEST began to accelerate its growth. At 43 DAT, T2 and T3 were similar in growth to the TEST; while T3 attained the highest fresh biomass accumulation at 64 DAT as compared to TEST and the rest of treatments. Finally, T3 had the same pattern of biomass accumulation throughout the season (figure 2a).

With respect to shoot biomass, T2 and TEST attained the highest weight throughout the season (figure 2b). Moreover, fresh biomass on leaves was higher on the TEST at 23 and 43 DAT, while T2 and T3 were similar to the TEST at 64 DAT. Finally, T3 attained the highest fresh biomass accumulation on leaves (21 g), TEST (14 g), T2 (13 g) and T1 (10 g) (figure 2c). The results

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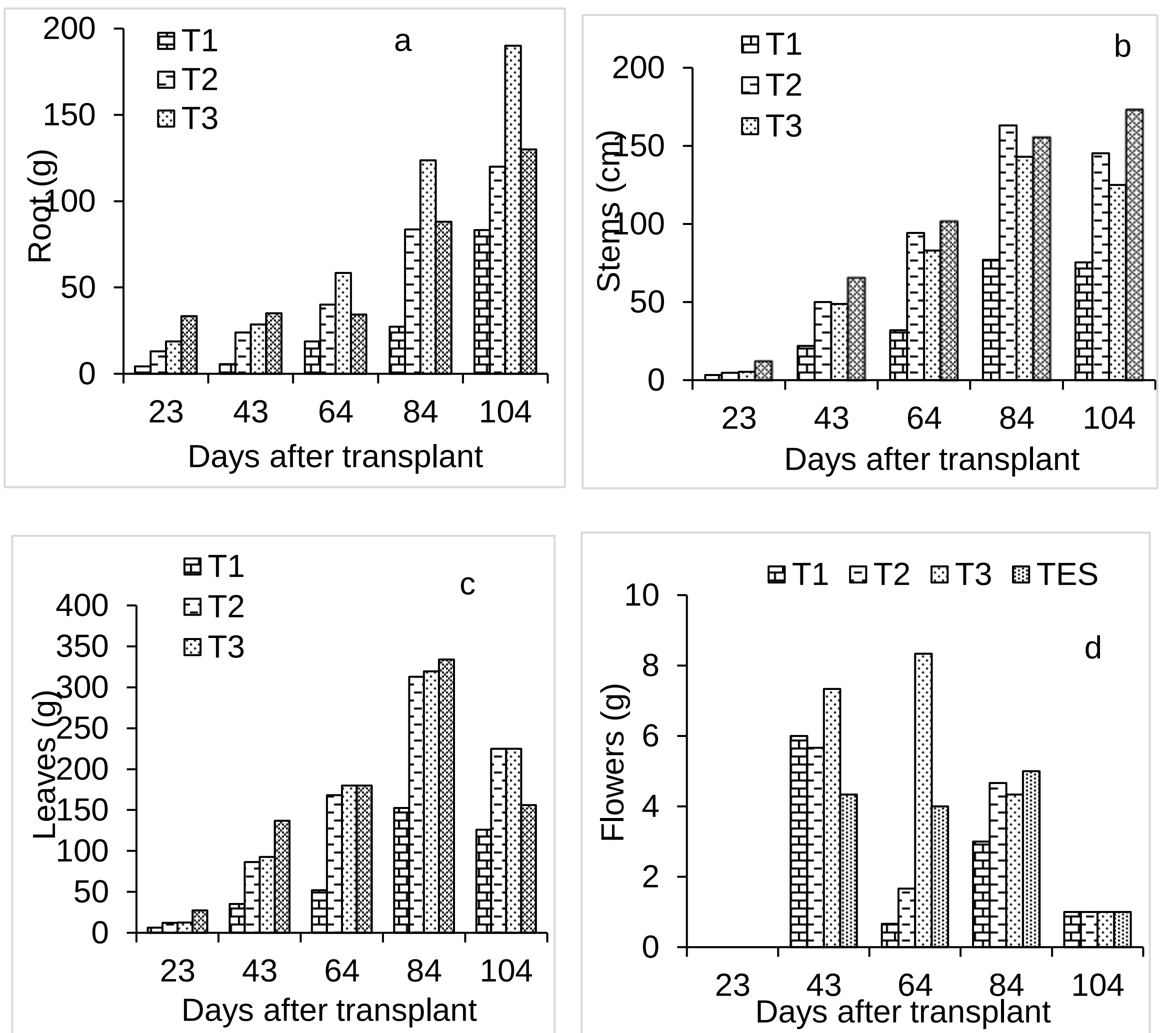
obtained on these variables may be due to the nutrient solution applied on TEST that contained nutrients in the ionic form (balanced number of cations and anions), which also allowed the plants to absorb all nutrients during fertigation (Galindo-Pardo et al., 2014). These values were higher to those reported by Núñez-Ramírez et al. (2023) who found root biomass of (45 g), shoots (158 g) and fruits (1731 g); but they found higher values on leaf biomass accumulation (524 g).



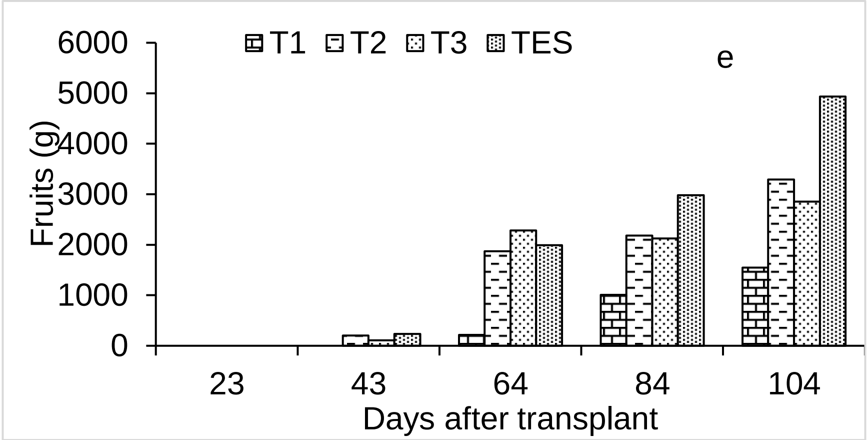


Figure 2. Root fresh biomass (a), stem (b), leaves (c), flowers (d) y fruit (e)

The leaf area index (LAI) is a fundamental variable to track crop growth and development. It is also the basis to estimate water and nutrient demand, as well as to determine potential pest damage. There is a close relationship between the LAI and the interception of solar radiation associated to photosynthesis and transpiration processes; both strongly linked to biomass accumulation and productivity. Therefore, LAI is a variable to quantify growth and agronomic yield of crops (Mendoza-Pérez et al., 2020). Data showed that LAI at vegetative stage was of 0.1, 0.35, 0.35 and 0.5 $m^2.m^2$ for T1, T2, T3 and TES respectively. Values of 1.08, 2.54, 2.36 and 2.42 $m^2.m^2$ for T1, T2, T3 and TES were obtained at maximum water and nutrient demand (figure 3). These values were statistically different. It can be seen that a sole application of worm leachate does not contain the balanced nutrients to meet crop demand; thus, it is required to apply an additional fertilization of the missing nutrients contained in the leachate. The results are similar to those of Ayala-Tafoya et al. (2019) who found LAI of 1.28, 2.1, 1.81 and 3.09 $m^2.m^2$ in cucumber plants as a function of stems. These authors state that there is an acceptance about the leaf area as one of the most important parameters in the evaluation of plant growth; hence, an appropriate determination is the basis for correct interpretation of processes in any plant species.

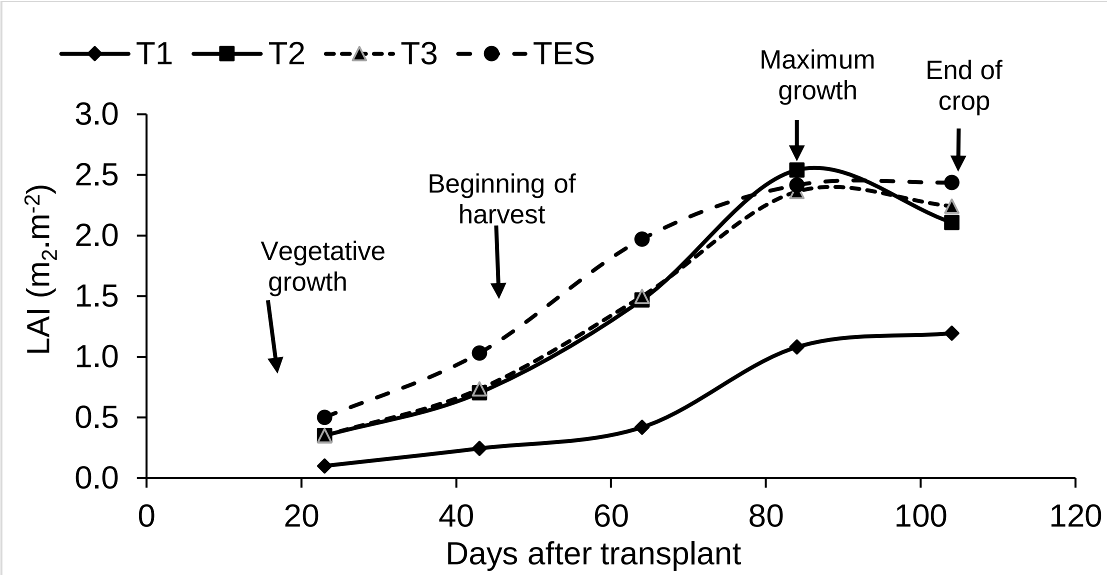


Figure 3. Leaf area index of cucumber crop.

With respect to yield, it was observed that plants on TEST produced higher number of fruits (15 fruits/plant) and the lowest on T1 (6 fruits/plant). Whereas, T2 and T3 produced 11 and 12 fruits/plant respectively (table 3). The results are lower compared to those found by Pérez-Ortiz, (2014) who reported 20 fruits/plant. Additionally, plants on T1 exhibited nitrogen deficiency symptoms; therefore, an additional fertilization was applied to supply the nutrient in question.

Table 3. Yield of cucumber crop.

Treatment	N. Fruits	Fresh fruit weight (g)	Yield ($kg.plant^{-1}$)	Yield ($t.ha^{-1}$)
T1	6 c	271.90 a	1.81 d	54.57 d
T2	11 b	326.37 a	3.5 c	105.2 c
T3	12 b	319.25 a	3.88 b	116.51 b
TES	15 a	281.36 a	4.11 a	123.4 a

Different letters within a column are statistically different. Tukey mean separation test ($P \leq 0.05$), (OSL Pr> F).

The fresh weight of fruits for all treatments was 271.90, 326.37, 319.25 and 281.36 g for T1, T2, T3 and TES respectively. Also, T2 produced fruits with the highest weight; whereas, plants under T1 produced fruits with the lowest weight (table 3). In that aspect, López-Elías et al. (2011) reported similar fruit weights 345, 329, 330, 318, 330 and 325 g respectively. The values obtained in this work are lower to those of Chacón-Padilla and Monge-Pérez (2016) who reported 374.26 g, as an average weight. The yield obtained on the treatments was of 1.81, 3.50, 3.88 and 4.11 $kg.plant^{-1}$ for T1, T2, T3 and TES. With this result, it is seen that the application of combined fertilizer (organic + inorganic) increases nutrient/water assimilation by plants due to humic substances and microorganisms present in the leachate. At the same time, they are capable of stimulating and producing enzymes that act as organic catalyzers in many biological processes, leading the plant to achieve higher quantity and fruit quality. It was also observed that plants on T3 increased the number and size of fruits as well as yield as compared to TEST (table 3). The yield per unit surface was of 54,57, 105,2, 116,51 and 123,4 $t.ha^{-1}$ for T1, T2, T3 and TES respectively (table 3). These values are higher to those found by Montaño-Mata et al. (2018) who registered 1,014 $kg.plant^{-1}$ and a yield of 91,283 $t.ha^{-1}$ for this crop approximately.

According to size parameter, T3 attained the highest proportion of large fruits (100%), T2 (97.60%), T1 (96.20%) and TEST (94.8 %). In that sense, Núñez-Ramírez et al. (2023) found values of 82, 6, 12 and 0% for large, medium, small and tiny. T2 attained the greatest fruit length (25.1 cm), TEST (22.5 cm), T3 (22.3 cm), and T1(21.1 cm). These values are lower than those obtained by Chacón-Padilla and Monge-Pérez (2016) who exhibited a range from 31.58 to 35.77 cm.

Table 4. Length and fruit diameter for all treatments.

Treatment	Length (cm)	Diameter (cm)
T1	21.1 a	4.4 b
T2	25.1 a	4.7 b
T3	22.3 a	4.8 a
TES	22.5 a	4.5 b

Different letters within a column are statistically different. Tukey mean separation test ($P \leq 0.05$), (OSL Pr> F).

With respect to this parameter, all four treatments attained values of 4.4, 4.7, 4.8 and 4.5 cm for T1, T2, T3 and TES respectively. It is observed that the highest numerically value was on T3 (50% organic + 50% NS) (table 4). The values are similar to those registered by Chacón-Padilla and Monge-Pérez (2016) who found values from 4.3 to 6 cm of fruit diameter.

Conclusions

The application of different mixtures (organic + inorganic fertilizer) enhanced physiological and productive variables; it also represents a viable alternative to cucumber production under greenhouse conditions.

T2 showed better performance on all physiological variables. It also attained the highest fruit weight and higher percentage of large fruits for export purposes.

The application of 100% organic fertilization does not meet plant demand, thus, an additional inorganic fertilization is required to achieve better quality of fruits and yield.

Organic fertilizers reduced approximately 65% of synthetic fertilization cost without affecting the number and size of fruits and yield.

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Conflicto de interés

Los autores de este manuscrito declaran no tener ningún conflicto de interés.

Declaración ética

Los autores declaran que el proceso de investigación que dio lugar al presente manuscrito se desarrolló siguiendo criterios éticos, por lo que fueron empleadas en forma racional y profesional las herramientas tecnológicas asociadas a la generación del conocimiento.

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