

## FERTILIZATION OF NATIVE MAIZE INTERCROPPED WITH HUSK TOMATO IN PEASANT FARMING PLOTS: YIELD, INCOME, AND FOOD SECURITY

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### ABSTRACT

The objective of this study was to explore the effect of mineral fertilization and mineral fertilization with cattle manure on income, yields, and food baskets generated by intercropping maize (*Zea mays* L.) and husk tomato (*Physalis ixocarpa* Brot. ex Horm.) in three locations in the State of Mexico. Three experimental plots were established with farming families from El Ejido, Santa Rosa de Lima, and San Mateo in 2015. Using a split-plot design, two large plots were tested, one without manure and the other with precomposted cattle manure (10 Mg ha<sup>-1</sup>). In a small plot, nine nitrogen (N) and phosphorus (P) combination treatments were tested at five levels. Husk tomato, grain, and maize stover yields were evaluated. Net income (in MXN), the maize food security index, and the basic food basket were estimated. In all three locations, husk tomato, grain, and maize stover yields were higher with mineral fertilization plus manure compared to mineral fertilization alone. The highest net incomes from the maize-husk tomato intercropping system in El Ejido (27 498 MXN), Santa Rosa (37 436 MXN), and San Mateo (58 081 MXN) were obtained with 140-85, 140-35, and 150-40 kg of N-P<sub>2</sub>O<sub>5</sub> and 10 Mg of manure ha<sup>-1</sup>, respectively. These incomes can cover two to five basic food baskets for the three communities, as well as the family's corn consumption in El Ejido and San Mateo.

**Keywords:** *Zea mays* L., *Physalis ixocarpa* Brot. ex. Horm., milpa, mazahua, MIAF.

### INTRODUCTION

Maize (*Zea mays* L.) is the most widely cultivated crop in the State of Mexico. In 2015, the state produced 2 036 339 Mg of maize grain with an average yield of 3.82 Mg ha<sup>-1</sup> (SIAP, 2023). For farming families in the northwest of the state, maize holds significant cultural, nutritional, and symbolic value. The Mazahua people inhabit this region and

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predominantly cultivate native rainfed maize in monoculture on plots of less than 1 ha as a supplementary activity due to its low profitability, while practicing some traditional ceremonies (Monroy-López *et al.*, 2018). Furthermore, the husk tomato (*Physalis ixocarpa* Brot. ex Horm.) is one of the component species of the traditional Mexican milpa and predominates in monoculture and for commercial purposes. In the State of Mexico, husk tomato production in 2015 was estimated at 44 156 Mg, with an average yield of 16 Mg ha<sup>-1</sup> (SIAP, 2023).

Research has shown the productive, economic, and nutritional potential of native maize intercropped with bush beans (*Phaseolus vulgaris* L.) when using various doses and sources of fertilization within the Milpa Intercropped with Fruit Trees (MIAF) system and has been studied under different conditions in Mixe (Ruiz-Mendoza *et al.*, 2012), Mazatec (Santiago-Mejía *et al.*, 2008), and Chiapas (Cadena-Iñiguez *et al.*, 2018) peasant farming systems. However, there is limited information about the conditions of Mazahua peasant farming and the cultivation of husk tomatoes.

Nitrogen (N), phosphorus (P), and potassium (K) are essential elements for crop growth, development, and production and can be supplied through mineral fertilizers or organic sources (Battisti *et al.*, 2023). The use of synthetic chemical fertilizers is the preferred option to meet the immediate nutritional needs of crops; however, they have high production costs and an environmental impact when used excessively (McLeod *et al.*, 2020). Combining organic and mineral fertilizers can be an effective way to improve the availability of yield-limiting nutrients (Roohi *et al.*, 2022; Zhang *et al.*, 2022). Laub *et al.* (2023), at four experimental sites in Kenya, observed the positive effect of fertilization with mineral nitrogen (120 kg ha<sup>-1</sup>) combined with manure (4 Mg ha year<sup>-1</sup>) on maize yield over 16 years. The increase in the yield of intercropped crops when using manure has been attributed to the improvement of soil structure and the increase in pH, porosity, water retention capacity, and the supply of macro- and micronutrients (Roohi *et al.*, 2022).

The technical recommendation for maize monoculture in the Atlacomulco region is 115-46-30 kg ha<sup>-1</sup> of N-P-K, respectively (ICAMEX, 2023). This fertilization ratio was developed at an experimental center specializing in maize hybrids. In the study region, farmers apply fertilizers based on sources and doses determined by collective experience. In the nearby localities of Fresno Nichi, San Juan Coajomulco, and San Pedro el Alto, maize monoculture is fertilized with 119-77-3080, 162-60-1810, and 158-15-4940 kg ha<sup>-1</sup> of N-P-manure (Albino-Garduño *et al.*, 2021). Roohi *et al.* (2022) recommend that each site should utilize a tailored combination of inputs, which should be assessed for effectiveness.

A challenge for sustainable agricultural production is to make the most of the resources available to farming families to generate sufficient food and income; therefore, it is important to understand the optimal combination of production inputs. In Mexico, studies have been conducted on the economic optimization of maize hybrids (Barrios-Ayala *et al.*, 2008; Albino-Garduño *et al.*, 2016) and native maize varieties (Padilla-Fidencio *et al.*, 2022). Although peasant farming primarily produces for

self-consumption, it is important to identify the combination of inputs and planting arrangements to ensure sufficient maize for family consumption and higher income from the sale of surplus intercropped crops. Some indicators evaluated for production in the diversified agroecosystem include crop yields, family maize supply, relative land efficiency, net income, minimum wages, and the cost of basic food baskets (Mahmud *et al.*, 2018; Li *et al.*, 2020; Padilla-Fidencio *et al.*, 2022).

The benefits of polyculture production can be limited without proper fertilization and agronomic management (Roohi *et al.*, 2022). Intercropping takes advantage of the complementarity of species to achieve sustainable intensification, increasing yield per unit of land with reduced production inputs (Xu *et al.*, 2020). The production of native husk tomato and maize in intercropped systems on smallholder farms in the State of Mexico has been studied very little, and information on this production method is unavailable. Therefore, the importance of conducting research on small farms is highlighted to obtain technical recommendations appropriate to local conditions.

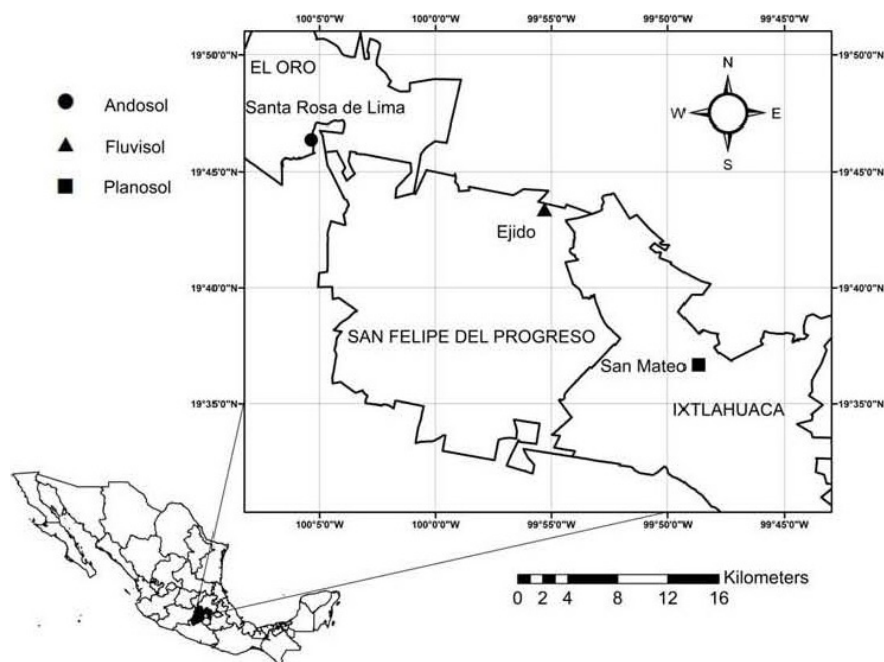
The objective of this research was to study the effect of mineral fertilization and cattle manure on the yield, net income, food baskets, and family food supply of native maize, intercropped with husk tomato, in three different soils of the Mazahua region of the State of Mexico. The planting design in this study is similar to that of annual crops in MIAF systems, so the results could contribute to their adaptation to this system.

## MATERIALS AND METHODS

### Experimental site

The study was conducted on three farm plots in municipalities of the Mazahua region in the State of Mexico: 1) El Ejido, in San Felipe del Progreso; 2) Santa Rosa de Lima, in El Oro; and 3) San Mateo, in Ixtlahuaca (Figure 1). The plots were established with three farming families interested in collaboration, who participated in the community outreach program of the Intercultural University of the State of Mexico. The experimental plots were representative of each location in terms of size, slope, soil type, and management practices. The climate in all three sites is temperate sub-humid with summer rains.

The plot in El Ejido belongs to the Muñoz-Ruíz family and features Fluvisol soil with a slope greater than 20 %. It is situated at an altitude of 2563 m and receives 1235 mm of annual rainfall, with an average temperature of 14 °C (in 2015). In Santa Rosa de Lima, the plot was established with the Segundo-Rojas family, on Andosol soil with a slope greater than 20 %, at an altitude of 2822 m, with 1001 mm of annual rainfall and an average temperature of 15 °C. In San Mateo, work was carried out on the plot of the Lucas-Álvarez family, on Planosol soil with a slope of less than 20 %, at an altitude of 2532 m, 882 mm of annual precipitation, and an average temperature of 10 °C. All plots use tillage methods with animal traction (CONAGUA, 2023; INEGI, 2023).



**Figure 1.** Location of the experimental plots in the northwest of the State of Mexico, Mexico.

### Experimental design

A split-plot design was used (Table 1) with two large-plot treatments and nine small-plot subtreatments, which were tested in a maize-husk tomato intercropping system with two rows of each species (Figure 2A). The large-plot treatments were 1) fertilization with  $10 \text{ Mg ha}^{-1}$  of cattle manure and 2) no manure. The nine subtreatments were generated in a central composite design (Volke *et al.*, 2005) with the combination of N and P factors (Table 1).

Each large plot was treated with the central dose and no potassium ( $120\text{-}80\text{-}0 \text{ kg ha}^{-1}$  of  $\text{N-P}_2\text{O}_5\text{-K}_2\text{O}$ ) to determine the effect of this element. Husk tomatoes received the same fertilization treatments as maize. Subtreatments were randomly assigned to each replicate. The experimental unit ( $8 \text{ m}^2$ ) consisted of two rows, each 0.8 m wide by 5 m long, in each of the three replicates. The usable plot area was  $7 \text{ m}^2$ , with plants outside the boundaries of each experimental unit not being harvested.

### Crop management

Fallowing and furrowing were done using animal traction (Figure 2B). The furrows were 0.8 m wide. Sowing was done manually with a shovel, as is customary for families. During the second week of April 2015, in each location, native white conical maize seed from each collaborating farming family was used. The planting density for maize and husk tomato was 30 000 and 15 625 plants per 0.4 ha, respectively.

**Table 1.** List of fertilization treatments in the intercropping of native maize (*Zea mays* L.) and husk tomato (*Physalis ixocarpa* Brot. ex Horm.) in three peasant plots in the State of Mexico.

Large plot		Small plot		
Cattle manure	Coded levels		Dose* (kg ha <sup>-1</sup> )	
(Mg ha <sup>-1</sup> )	N	P	N	P <sub>2</sub> O <sub>5</sub>
10	-1	-1	90	50
10	+1	-1	150	50
10	-1	+1	90	110
10	+1	+1	150	110
10	-2	0	60	80
10	+2	0	180	80
10	0	-2	120	20
10	0	+2	120	140
10	0	0	120	80
0	-1	-1	90	50
0	+1	-1	150	50
0	-1	+1	90	110
0	+1	+1	150	110
0	-2	0	60	80
0	+2	0	180	80
0	0	-2	120	20
0	0	+2	120	140
0	0	0	120	80

\*In all treatments of the experimental matrix, 40 kg ha<sup>-1</sup> of K<sub>2</sub>O were used.



**Figure 2.** A: Plantation arrangement in El Ejido, in the municipality of San Felipe del Progreso, State of Mexico; B: agricultural work with animal traction in Santa Rosa de Lima, in the municipality of El Oro, State of Mexico.

Husk tomatoes were sown in seedbeds and transplanted between 56 and 62 days after sowing (DDS) maize. At maize sowing and husk tomato transplanting, 1/3 of the nitrogen (N) and all of the phosphorus (P) and potassium (K) were applied. The remaining N was applied to the maize at the first weeding and to husk tomatoes at the second weeding of maize at 80 DDS. The mineral fertilizers used were triple superphosphate ( $\text{Ca}(\text{NH}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ ), urea ( $\text{CO}(\text{NH}_2)_2$ ), and potassium chloride (KCl). The manure used had been decomposing outdoors for six months and was moistened two months before planting, covered with black plastic, and mixed once a week. Manure was applied during maize planting across the entire plot, including the area where the husk tomatoes were later transplanted. Weed control was done manually. The husk tomato harvest took place between 118 and 148 days after sowing (DDS) maize (first to last week of August), and the maize harvest between 220 and 226 DDS.

### Variables evaluated

#### Grain and stubble yield

To assess grain yield, all ears of maize from each plot were harvested, counted, weighed, and shelled manually. Ears, kernels, and cobs were weighed separately on a digital scale (Torrey). Grain moisture was determined using a John Deere portable moisture meter (SW5300, III). To determine stubble yield, all plants in each experimental unit were counted, cut, and weighed on the same day as the ear harvest. Stubble weight at harvest was obtained using a digital hanging scale (Torrey). Stubble biomass was calculated after dehydration in a drying oven (LUMISTELL HTP-42), with three samples per replicate. Grain yield was estimated at 14 % moisture.

#### Husk tomato yield

The husk tomato harvest was done in four cuttings. The weight of the fruit was recorded in each plot and the yield was estimated.

#### Maize Food Security Index (MFSI)

It was calculated according to López-González *et al.* (2018) using the following equation:

$$MFSI = \frac{(R)(SS)}{(NMF)(196.4)}$$

where  $R$  is the maize yield ( $\text{kg } 0.5 \text{ ha}^{-1}$ ) estimated using the regression equation (detailed in the statistical analysis);  $SS$  is the planted area (ha);  $NMF$  is the number of members of the producing family, considering five as the average; and 196.4 is the per capita maize consumption (kg). MFSI values  $<1$  indicate the absence of food security, while MFSI  $>1$  reflects its presence.

### Basic food basket (BFB)

This represents the number of people who could afford their basic food basket with the income generated from the crops. It was calculated using the following formula:

$$BFB = \frac{NI}{11\ 256.24}$$

where  $NI$  is the net income generated from the intercropping, and 11 256.24 corresponds to the cost of the annual basic food basket per person (in MXN) in 2015 (CONEVAL, 2023).

### Statistical analysis

A split-plot analysis of variance was performed using the SAS program (SAS Institute, Cary, NC, USA) as well as a multiple comparisons test of means for interactions between treatments and subtreatments, using the following model:

$$Y_{ijk} = \mu + B_i + T_j + \varepsilon_{ij} + S_k + TS_{jk} + e_{ijk}$$

where  $Y_{ijk}$  is the response variable,  $\mu$  is the overall mean effect,  $B_i$  is the effect of the  $i$ -th block,  $T_j$  is the effect of the  $j$ -th treatment,  $\varepsilon_{ij}$  is the large plot error,  $S_k$  is the effect of the  $k$ -th treatment,  $TS_{jk}$  is the interaction effect of the  $j$ -th treatment with the  $k$ -th treatment, and  $e_{ijk}$  is the small plot error (Castillo, 2011).

Regression models were fitted for maize grain yield and husk tomato fruit yield as a function of N, P, manure, and location. The regression procedure (stepwise, SLE = 0.2; SLS = 0.1) included significant effects ( $p \leq 0.05$ ) for each dependent variable. Auxiliary variables with values of 0 and 1 were used in the overall yield equation:  $a_1$  for the manure factor and  $s_1$  and  $s_2$  for locations. The assignments were:  $a_1 = 0$  for mineral fertilization without manure and  $a_1 = 1$  for mineral fertilization with cattle manure;  $s_1 = 0, s_2 = 0$  for El Ejido;  $s_1 = 1, s_2 = 0$  for Santa Rosa; and  $s_1 = 0, s_2 = 1$  for Ixtlahuaca. Graphs were created in SigmaPlot (version 15) with the significant effects identified in the regression equation for each location.

### Net income

The economic analysis was performed using the discrete method (Martínez-Garza and Martínez-Damián, 1996). An economic optimization program was developed in SAS using the regression equation, which determined the maximum net income (NI) and the corresponding combination of nitrogen (N), phosphorus (P), and manure. Applying the model, the combination of N and P that estimated the highest income (in MXN) within the evaluated range was identified, between 60–180 kg of N ha<sup>-1</sup> and 20–140 kg of P ha<sup>-1</sup>, in increments of five units, with and without sheep manure. The formula used was:

$$NI = IT - CT$$

where  $IT$  is the total revenue obtained by multiplying the yields of husk tomato and maize (grain and stubble) by their selling prices, and  $CT$  is the total cost, which corresponds to the sum of fixed and variable costs. For the calculation of total revenue, the following prices per Mg were considered, which include transportation, shelling, baling, and harvesting: 2290 MXN for maize grain, 1860 MXN for stubble, and 5010 MXN for husk tomato.

Fixed production costs were MXN 14 300.39 ha<sup>-1</sup>, broken down as follows: MXN 1120 for land rent, MXN 3700 for land preparation (fallow, harrowing, furrowing, and weeding), MXN 6038.40 for labor (planting, replanting, weeding, manual weeding, fertilization, transplanting, and husk tomato staking), and MXN 3441.99 for tools and supplies (hoe, weeder, shovel, mower, staking materials, seeds, seedlings, and potassium). Variable costs were calculated using the following prices per kilogram: MXN 13.51 for N, MXN 18.32 for P<sub>2</sub>O<sub>5</sub>, and MXN 0.3166 for pre-composted manure. All prices and costs correspond to 2015.

## RESULTS AND DISCUSSION

### Effect of fertilization on the yield of intercropped maize and husk tomato

There was a significant effect (Table 2) of the study factors N, P, and manure, both individually and in interaction. The combination of mineral fertilizers with manure increased the grain and stover yield of intercropped maize and husk tomato compared to treatments with mineral fertilization alone (Figure 3). This positive effect was corroborated in the regression equations, where the manure factor increased yield (0.97 and 2.17 Mg 0.5 ha<sup>-1</sup> of maize and husk tomato, respectively) (Table 3) compared to mineral fertilization alone at the three experimental sites.

The increased yield of maize intercropped with other crops and with the application of mineral and organic fertilizers has also been demonstrated in recent studies (Fan *et al.*, 2020; Roohi *et al.*, 2022; Laub *et al.*, 2023). Roohi *et al.* (2022), in their study of maize intercropped with cowpea in Pakistan, attribute this phenomenon to the slow-release fertilization pattern (N-P-K combined with enriched compost), which could promote adequate nutrient supply. Laub *et al.* (2023), in their maize intercropping study in sub-Saharan Africa on tropical soils, also argue that the synchronization of nitrogen release from manure with plant demand may explain the high yield when applied to the crops.

The positive effect of combining mineral fertilizers with manure on husk tomato yield aligns with the findings of Aguiñaga-Bravo *et al.* (2020) in a Leptosol soil in Conkal, Yucatán. In their study involving two varieties of *Physalis* sp. grown in monoculture, the authors recommended the use of cattle manure at a rate of 20.85 Mg

**Table 2.** Analysis of variance of husk tomato (*Physalis ixocarpa* Brot. ex Horm.) yield and maize grain and stubble yield (*Zea mays* L.) in response to N and P<sub>2</sub>O<sub>5</sub> doses, with and without manure, in three experimental sites.

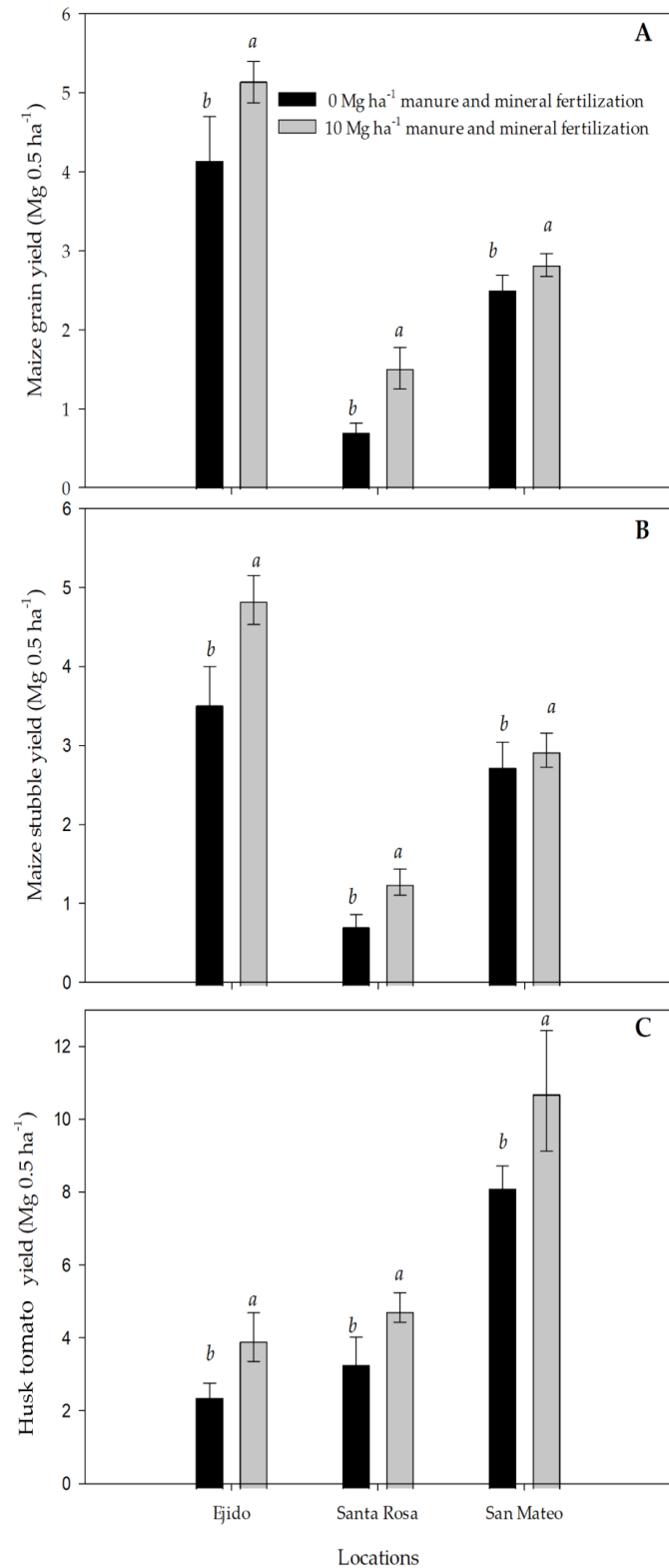
Source of variation (Treatments*)	Degrees of freedom	Maize				Husk tomato	
		Grain		Stubble		MS	FC
		MS	FC	MS	FC		
El Ejido							
Block	2	0.0641	1.39	0.0056	0.16	0.1446	8.33**
Large plot (LP)	1	13.4970	292.11***	23.1555	637.36***	32.2449	1857.66***
Error in large plot (a)	2	0.0480	1.04	0.1492		0.0508	
Small plot (SP)	8	0.9400	20.35***	1.3500	37.16***	3.2723	188.53***
LP × SP	8	2.5666	55.55***	1.5684	43.17***	1.6889	97.30***
Error in small plot (b)	32	1.4785		1.1625		0.5554	
Total	53						
Santa Rosa de Lima							
Block	2	0.0033	1.28	0.0002	0.20	0.1785	3.16*
LP	1	8.7137	3341.68***	3.8747	3289.46***	28.0786	497.75***
Error a	2	0.0013		0.0002		0.003	
SP	8	0.5638	216.23***	0.5337	85.05***	4.4332	78.59***
LP × SP	8	0.2215	84.96***	0.2512	213.28***	0.8071	14.31***
Error b	32	0.0834		0.0376		1.8051	
Total	53						
San Mateo							
Block	2	0.0879	4.69*	0.0014	0.07	0.1566	0.81
LP	1	1.4314	76.38***	0.5075	26.09***	89.6319	462.53***
Error a	2	0.0030		0.0038		0.6171	
SP	8	0.3404	18.16***	1.0266	52.79***	14.4744	74.69***
LP × SP	8	0.1075	18.16***	0.1672	8.60***	13.6840	74.69***
Error b	32	0.5997		0.6223		6.2011	
Total	53			53		53	

\*Large plot: 0 and 10 Mg of manure ha<sup>-1</sup>; small plot: five levels of two factors (60–180 kg N ha<sup>-1</sup> and 20–140 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>).

\*, \*\*, \*\*\* Significant differences at  $p \leq 0.05$ , 0.01, and 0.001, respectively. MS: mean squares; FC: calculated F.

ha<sup>-1</sup> combined with mineral fertilizer (10-75-50 N-P-K). This combination enhanced nitrogen accumulation in the plants and increased the levels of fats, total phenols, and essential minerals (Cu, Fe, P, Ca, and K) compared to fertilization methods that did not include cattle manure. Higher husk tomato yields have been observed with organic fertilization (10.66 Mg ha<sup>-1</sup>) when the soil has 34.85 g dm<sup>-3</sup> of organic matter and the manure contains 2.65 % N (Ariati *et al.*, 2017).

**Figure 3.** Effect of cattle manure combined with mineral fertilization on the yield of A) grain, B) maize stover (*Zea mays* L.), and C) husk tomato (*Physalis ixocarpa* Brot. ex Horm.) in three locations in the State of Mexico. Yields correspond to 0.5 ha of maize and 0.5 ha of husk tomato intercropped within 1 ha. The plotted values represent the mean of the small plot in its sub-treatments  $\pm$  standard error. Different letters between bars within each location indicate significant differences ( $p \leq 0.05$ , Tukey-Kramer).



**Table 3.** General yield equations for maize (*Zea mays* L., grain and stubble) and husk tomato (*Physalis ixocarpa* Brot. ex Horm.), integrating locations and large plot treatments.

Variable	Equation	R <sup>2</sup>
$\hat{Y}_M =$	$4.2998^{***} + 0.9704a_1^{***} - 0.4872N^{***} - 3.2785s_1^{**} - 1.6437s_2^{***}$ $- 0.1149N_2^{**} + 0.6081a_1N^{***} + 0.0831a_1N_2^*$ $- 0.0719a_1P_2^* + 0.4589s_1N^{**} + 0.1176s_1a_1P^*$ $- 0.1239s_1P_2^* + 0.6087s_2N^{***} - 0.6597s_2a_1^{***}$ $- 0.6387s_2a_1N^{***} - 0.2153s_2NP^{**}$ $- 0.4367a_1s_1N^{***} - 0.1256a_1s_1N_2^{**}$	0.93
$\hat{Y}_R =$	$3.5315^{***} + 1.1664a_1^{***} - 0.2191N^{***} + 0.0752P^* - 2.7991s_1^{***}$ $- 0.6412s_2^{***} + 0.1074a_1N_2^* + 0.2593s_1N^{**}$ $- 0.7739s_1a_1^{***} + 0.2061s_2N^{**} + 0.1610s_2^2P^*$ $- 1.1159s_2a_1^{***} - 0.1076s_2N_2^*$	0.91
$\hat{Y}_T =$	$3.0978^{***} + 2.1713a_1^{***} + 3.8424s_2^{***} - 0.1242N_2^* - 0.2657P_2^*$ $+ 0.5575a_1N^{**} + 0.19070a_1P^* - 0.2380a_1N_2^*$ $- 0.3492a_1P_2^* + 3.5964s_1a_1^{***} - 0.5408s_1a_1N^{***}$ $- 1.0617s_1NP^{***} + 0.5686s_1P_2^{***} - 0.1547s_2P$ $- 1.4235s_2a_1P^{***} + 0.6876s_2N_2^{***}$ $+ 0.6043s_2P_2^{***} + 0.3749a_1s_1N_2^{**}$ $- 0.4621a_1s_1P^{**} + 0.6268a_1s_1P_2$ $- 0.8634a_1s_2N^{***} + 0.9715a_1s_2N_2^{***}$ $- 2.2843a_1s_2NP^{***}$	0.95

$\hat{Y}_M$ : estimated maize yield (Mg 0.5 ha<sup>-1</sup>);  $\hat{Y}_R$ : estimated maize stover yield (Mg 0.5 ha<sup>-1</sup>);  $\hat{Y}_T$ : estimated husk tomato yield (fresh weight, Mg 0.5 ha<sup>-1</sup>). \*, \*\*, \*\*\* Terms significant at  $p \leq 0.05$ , 0.01, and 0.001, respectively. Terms with  $a_1$  represent the additional effect of manure; terms without  $a_1$  correspond to mineral fertilization. Terms without  $s_1$  or  $s_2$  refer to El Ejido locality; those including only  $s_1$ , to Santa Rosa; and those including only  $s_2$ , to San Mateo.

### Agronomic response, income, food basket, and supply

#### El Ejido

The analysis of the treatment × subtreatment interaction by crop showed that, in El Ejido, the highest yield of maize grain ( $5.86 \pm 0.37$  Mg 0.5 ha<sup>-1</sup>) and stubble ( $5.72 \pm 0.47$  Mg 0.5 ha<sup>-1</sup>) and husk tomato ( $6.19 \pm 0.48$  Mg 0.5 ha<sup>-1</sup>) was obtained at the doses 180-80-40, 60-80-40, and 120-80-40 kg of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O + 10 Mg of manure ha<sup>-1</sup>, respectively. The economic optimization of intercropped maize and husk tomato as a polyculture system indicated that the highest economic income was achieved with a fertilization regimen of 140-85-40 kg of N-P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O, along with 10 Mg of manure ha<sup>-1</sup> (Table 4). With the income generated from this combination of inputs, the basic food basket for two people and the maize consumption of a family of five could be supplied.

**Table 4.** Maximum net income (NI), basic food basket (BFB) and maize food security index (MFSI) generated in the intercropping of maize (*Zea mays* L.) with husk tomato (*Physalis ixocarpa* Brot. ex Horm.), with their respective level of fertilization and yield, in three communities of the State of Mexico.

Location	N	P	Manure	Mgy	Msy	Hty	NI	BFB	MFSI
	(kg ha <sup>-1</sup> )	(kg ha <sup>-1</sup> )	(Mg ha <sup>-1</sup> )	(Mg ha <sup>-1</sup> )	(Mg ha <sup>-1</sup> )	(Mg ha <sup>-1</sup> )	(MXN)		
El Ejido	140	85	10	5.33	4.61	5.49	27 498	2.4	5.42
	85	70	0	4.71	3.77	2.92	15 715	1.4	4.79
Santa Rosa	140	35	10	0.98	0.73	10.94	37 436	3.3	0.99
	150	40	0	1.64	0.99	5.52	16 320	1.4	1.67
San Mateo	150	40	10	2.25	1.65	13.96	58 081	5.2	2.29
	160	50	0	3.75	2.81	8.92	41 241	3.7	3.81

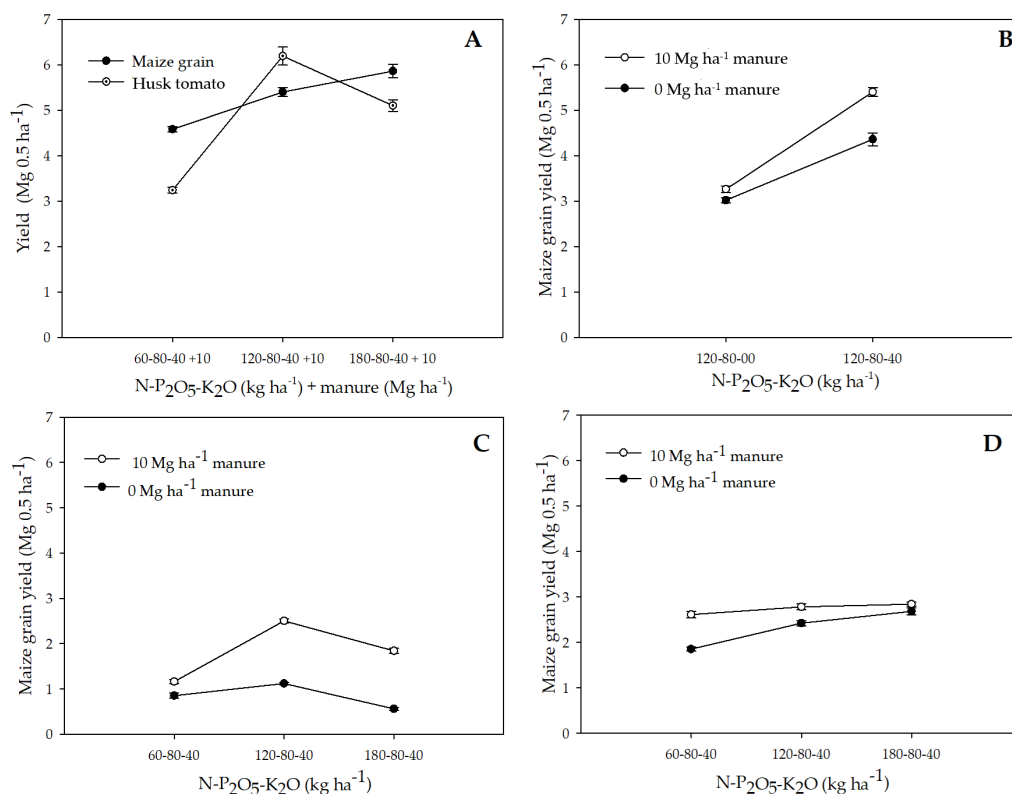
N: nitrogen; P: P<sub>2</sub>O<sub>5</sub>; Mgy: maize grain yield; Msy: maize stover yield; Hty: husk tomato yield.

Among the factors evaluated that correspond to the combination of mineral fertilizer doses with manure, nitrogen (N) and potassium (K) had an effect on crop yield. In this location, a positive response in maize grain yield (Figure 4A) was observed in response to the combined factors of nitrogen × manure fertilization. In other words, when native white maize was fertilized with 10 Mg ha<sup>-1</sup> of cattle manure, the increment of the nitrogen dose (60, 120, 180 kg of N ha<sup>-1</sup>) increased grain yield at constant phosphorus (P) and potassium (K) doses (80–40 kg of P-K ha<sup>-1</sup>). Manure provides nitrogen to maize crops even beyond the year of application, as it releases around 30 % of the total N in the first year (Laub *et al.*, 2023). Therefore, conducting long-term studies to better understand the effects of nitrogen would be advisable.

In El Ejido, a positive effect on maize grain yield was identified with increased potassium (K) at the same nitrogen (N) and phosphorus (P) levels (Figure 4B). Other studies with maize have also observed increased grain yield with increased K at the same N levels (Zhang *et al.*, 2023). Benkova *et al.* (2023) argue that applying compost to maize crops in Fluvisols increases available N and K. The increase in starch and protein content in the grain is attributed to the increased potassium (at the same N levels) (Zhang *et al.*, 2022).

#### Santa Rosa de Lima

In this plot, the maximum net income (37 436 MXN) was estimated for the maize-husk tomato intercropping system using 140-35-40 kg of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O + 10 Mg of manure ha<sup>-1</sup>. The addition of manure with the mineral fertilization resulted in an additional amount of MXN 21 116 compared to the application of 150-40-00 kg of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O ha<sup>-1</sup> (Table 4). In this location, the net income generated was sufficient to purchase the basic food basket for 1–3 people in the rural area with the current level of inputs. The maximum income achieved with the use of manure is attributed to the high tomato yield estimated under these conditions.



**Figure 4.** A: Effect of nitrogen on the yield of husk tomato (*Physalis ixocarpa* Brot. ex Horm.) and maize grain (*Zea mays* L.) with fertilization at 80-40 + 10 000 kg of P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O + cattle manure in El Ejido; B: effect of potassium on maize grain yield with and without the addition of cattle manure in El Ejido; C: nitrogen on maize grain yield with and without manure application in fertilization in Santa Rosa de Lima; D: maize grain yield, intercropped with husk tomato, at three levels of nitrogen fertilization, with and without manure in San Mateo. The values plotted are the average of six samples ± standard error.

Santa Rosa de Lima has Andosol soils characterized by their strong phosphorus fixation caused by active aluminum, iron, and their amorphous clay mineralogy (allophane). The presence of short-range amorphous compounds combined with a high organic matter content gives the Andosol a variable load (Shoji *et al.*, 1993). Low nitrogen use efficiency has been observed in these soils (Bekele *et al.*, 2022), and it is difficult to predict nitrogen fluxes (Deng *et al.*, 2015). This explains why the regression equation (Table 3) indicated a negative effect of nitrogen in Santa Rosa.

Graphical analysis (Figure 4C) showed that increasing the application rate from 120 to 180 kg of N ha<sup>-1</sup> decreased yield, regardless of the addition of manure with the mineral fertilizer. In Andosols of Ethiopia, intensive manure application in maize has been reported to reduce N use efficiency and promote NO<sub>3</sub><sup>-</sup>-N leaching and N<sub>2</sub>O

volatilization (Deng *et al.*, 2015). These results provide an initial understanding of the effect of fertilization on crops; however, further evaluation is needed over several growing seasons, taking into account the year factor.

### San Mateo

In this location, the highest estimated net income from the maize-husk tomato intercropping system was obtained with 150-40-10 kg of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O + 10 Mg of manure ha<sup>-1</sup> (Table 4). The highest net incomes were achieved when mineral fertilization was combined with manure. The economic optimum (58 081 MXN) provides enough for five basic food baskets and more than twice the amount of maize required for family consumption. The profits from the maize-husk tomato intercropping system in San Mateo (Table 4) are attributed to the soil type, year, variety, and climate (Zhang *et al.*, 2022), which are suitable for husk tomato, which provides the highest income.

In San Mateo, nitrogen (N) showed a significant effect on the regression equation for maize grain yield (Table 3). Graphical analysis of the data shows that yield increases with the applied N dose, with or without manure (Figure 4D). The study by Tofa *et al.* (2022) also showed a progressive response of maize grain yield to N application.

## CONCLUSIONS

Combined fertilization (pre-composted cattle manure plus mineral NPK) resulted in increased crop yields for native maize intercropped with husk tomatoes compared to mineral fertilization alone. Additionally, net income from the intercropped system was higher with combined fertilization than with mineral fertilization alone. The native maize-husk tomato intercropping system is capable of providing sufficient food for 1–5 people and covers family maize consumption needs, with the exception of Santa Rosa de Lima.

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