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INTENSIFICATION OF MILPA IN THE STATE OF MEXICO: NET INCOMES, FOOD SECURITY AND LAND EQUIVALENT RATIO

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ABSTRACT

The historical milpa has contributed to food security of small farmer families due to its biodiversity. The objective was to evaluate indicators of food access [basic food baskets (BFB), minimum wages (MW) and real food security index (RFSI)], Land Equivalent Ratio (LER), and maximum net income (NI) obtained from the polyculture of native maize-husk tomato-squash in two farm plots in the State of Mexico. The experiment was set up in San Pedro del Rosal (SPR) and San Juan Coajomulco (SJC), irrigated and rainfed, respectively, in the spring-summer cycle 2020. An experimental design in divided plots was used to evaluate two topological patterns: two rows of maize intercalated with one row of tomato and one of squash (MMTS) and one row of maize intercropped with one of husk tomato, one of maize and one of squash (MTMS). Five levels of fertilization with nitrogen, phosphorus and manure were tested. LER was evaluated with the yields of the three species in MMTS, MTMS and in monocropping at the same levels of inputs. BFB, MW, and RFSI were estimated using the regression equation that resulted in the maximum NI. In the two localities, the intercalated crops had higher LER than the monocrops. Comparing the two topological intercropping patterns, the maximum NI was obtained with MTMS in SJC and SPR (MXN \$ 113 686.30 and MXN \$ 204 649.70 ha^{-1} y^{-1}). With the NI of the MTMS pattern in SJC and SPR, seven and 14 people, respectively, can be provided with BFB for a year. The highest daily MW were obtained with MTMS. In terms of land equivalent ratio, the highest LER were obtained with the MMTS pattern in SJC (2.78) and SPR (1.64). In economic terms, the better topological pattern is MTMS, and in function of LER, MMTS was better.

Keywords: redesign of agro-systems, milpa intercropped with fruit trees − MIFT, Mazahua milpa, *Physalis ixocarpa*, *Cucurbita pepo*, native maize.

INTRODUCTION

The State of Mexico is the third largest producer of maize in Mexico (Ramírez-Jaspeado *et al.*, 2020). In the study region, 75 % of the production is rainfed (SIAP, 2020), predominantly native maize (white conic) for home consumption. Between 12 and 26 % of the small farmers of the Mazahua community plant milpa together with native

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maize, beans, Faba beans, peas, and squash. The rest of the farmers grow maize as monocrop (Albino-Garduño *et al*., 2021). In the Atlacomulco district, which comprises the study region, in the 2020 agricultural cycle 147 412 ha maize, 398 ha husk tomato and 16 ha squash were cultivated (SIAP, 2020). Paulino-Flores *et al*. (2017) recognize that the ecological dimension is the greatest strength of the small farmer plots in the region, and their weaknesses are the aspects of production and lack of organization for commercialization. Other unfavourable aspects are the loss of agrobiodiversity and the small areas for food production, which fluctuate between 0.4 and 1.1 ha, and up to 5 ha in a few cases (Paulino-Flores *et al*., 2017; Albino-Garduño *et al*., 2021). It is estimated that 82 % of the farmers use mineral fertilizers, a mixture of manures, or a combination of both (Paulino-Flores *et al*., 2017). Optimizing land use and fertilizers is an alternative to improve productivity of the agroecosystem.

The paradigm of intensification that guides this study is based on the optimum entry of inputs into the agro-system and the use of biodiversity (Mungai *et al*., 2016). Polyculture is a strategy of long-term agricultural intensification (Tilman, 2020), recommended for farmers with small plots (Lulie, 2017; Cheng-Dong *et al*., 2019). Intercropping two or more species simultaneously in the same cropping space (Francis and Porter, 2016) produces higher yields and economic incomes per unit of land and fertilizer than monocropping (Tilman, 2020). The land equivalent ratio with intercropping is between 16 % and 29 % higher than with monocrops and between 19 % and 36 % higher than with the use of fertilizers (Li *et al*., 2020). In general, productivity of intercropping is attributed to the differences in how the distinct species acquire nutrients, moisture, and solar radiation and to the complementarity, facilitation, and exchange of resources among them (Cheng-Dong *et al*., 2019; Nassary *et al*., 2019).

The global meta-analysis of Li *et al*. (2020) of the productivity of intercalated crops (in 934 registers of 226 experiments in 132 publications) shows that maize (a C4 plant) is the studied species with the most positive response to intercalation with C3 plants. The average increase in yield is 2.1 ±0.1 Mg ha^{-1} compared with monocropping. Previous studies reported that hybrid maize responds positively to intercalation since the land equivalent ratios (LER) are above 1 when it is intercropped with beans (Nassary *et al*., 2019; Li *et al*., 2020) and squash (Mahmud *et al*., 2018).

In the agro-system of milpa intercropped with fruit trees (MIFT), maize is intercalated with low stature species called understory crops (Turrent *et al*., 2017). In MIFT, net incomes and LER are higher than in monocrops (Albino-Garduño *et al*., 2015), even with native maize in small farm plots (García and Ronquillo, 2018). However, most of the combinations of intercalated species have not been studied (Lulie, 2017) despite their potential (Evers *et al.,* 2019), even in the MIFT system in small farmer plots.

The basis for achieving food security, in terms of maize, lies in production systems that provide availability, access, utilization, and stability at all times (Tanumihardjo *et al*., 2020). One indicator is the Real Food Security Index (RFSI), which evaluates the scope of maize production systems (Damián and Toledo 2016). To estimate the RFSI, a human *per capita* maize consumption of 109.5 kg in rural areas is considered (Bourges, 2013). Another factor is the basic food basket, which is the set of foods needed to satisfy the nutrient needs of an average home. It is considered that the price of a monthly basic food basket per person is MXN $ 1202.87 in rural areas (CONEVAL, 2021). Finally, minimum daily wages (MXN $ 141.79) earned through agricultural activity vary in accordance with the economic zone of the country (DOF, 2021).

To attain food security, it is necessary to increase the productive potential of maize and of the species with which it is intercropped in the milpa system. However, most of the studies on maize productivity are conducted in research centres and focus on obtaining maximum yields and incomes with hybrids grown in monocrop. Few studies use native maize seed with the factors that limit productivity (Ren *et al*., 2020) or in the context in which farmers live and produce (Cheng-Dong *et al*., 2019). The objective of this study was to quantify the maximum net income, food security and land equivalent ratio of the intercropped milpa (maize-husk tomato-squash), in two small farmer plots, one with irrigation and the other rainfed, in the State of Mexico. The hypothesis was that the association maize-husk tomato-bush squash in two topological patterns, under the same management and in small farm plots would increase LER, relative to monocrops in two agro-systems in northern State of Mexico, Mexico.

MATERIALS AND METHODS

Description of the study site

The field experiment was conducted in two farm plots in northern State of Mexico from March to November 2020 (spring-fall crop cycle). One of the plots, in the community of San Juan Coajomulco (19° 44′ 19.0″ N, 99° 57′ 18.7″ W, elevation 2650 m), was rainfed and the other, in San Pedro del Rosal (19° 46′ 42.9″ N, 99° 49′ 04.7″ W, elevation 2600 m), was irrigated. Both sites have subhumid temperate climate with summer rains. The soil type is Luvisol. The weather station of the Atlacomulco region in 2020 recorded a mean annual temperature of 14 °C and precipitation of 917 mm (SMN, 2021). Soil analyses indicate that the soil in San Juan Coajomulco (SJC) is loam-clay-silt, pH of the arable layer is 5.5, and organic matter is 3.1%. In San Pedro del Rosal (SPR) the soil is silty, pH 5.1, and organic matter is 2.3 %. The plant material used was maize (*Zea mays* L.), native white conic, husk tomato (*Physalis ixocarpa* Brot. ex Horm) variety "Manzano", and squash (*Cucurbita pepo* L.) variety "Grey Zuchinni", Weeds Sart®.

Experimental design and treatments

The experimental design was split plots with three replications. In the large plot, two topological planting patterns were explored (Figure 1A, B): A: two rows of maize intercalated with one of husk tomato and one of squash (MMTS) and B: one row of maize intercalated with one of husk tomato, followed by one of maize and one of squash (MTMS). These patterns of understory crops are recommended for the MIFT system (Albino-Garduño *et al*., 2015; García and Ronquillo, 2018). In the small plot, 15 treatments of the matrix "Central Composite Design" were tested. The matrix allowed

Figure 1. Topological planting patterns tested in intercropped milpa. A: two rows of maize intercalated with one of husk tomato and one of squash (MMTS). B: one row of maize intercalated with one of husk tomato, followed by one of maize and one of squash (MTMS).

exploration of five levels of fertilization with nitrogen (N), phosphorus (P) and pre-composted cattle manure as the source of organic matter (OM). The exploration spaces were 103 to 233 kg N ha^{-1} (with intervals of 30 units), 20 to 100 kg P_2O_5 (with intervals of 20 units) and 0 to 7200 kg MO ha^{-1} (with intervals of 1800 kg). The dose used by farmers of the region (Albino-Garduño *et al.*, 2021) was considered the central dose of the matrix (163-60-40-3600 kg N-P-K-MO ha^{-1}), from which higher and lower doses were evaluated in the indicated intervals. The same doses of fertilization were evaluated in the three species (maize, squash, and husk tomato). An additional treatment was tested with the central dose in monocropping. Each experimental unit was 6.4 m^2 (2 rows 4 m long and 0.8 m wide).

Crop management

The cultural labours were ploughing, sowing, two cultivations with oxen, and manual weeding on the same dates as those used in farmer management at the study sites. Maize population density was 62 500 plants ha^{-1} and that of squash and husk tomato was 20 800 plants ha^{-1} each. Fertilization was applied at three times: First, ¼ of the N, all of the P and OM at planting; Second, 2/4 of the N at cultivation; and Third, ¼ of the N at tomato and squash fruit set and maize grain fill. In the experimental plot of San Pedro del Rosal, the understory crops were maintained without moisture restriction by drip irrigation during March-June. Rainfed maize (SJC) was harvested at 215 d after seeding and irrigated maize (SPR) at 254 d after seeding.

Evaluated variables

Grain yield (Ym) at 14 % moisture was estimated in 0.5 ha of the area of maize in intercropped milpa. Grain moisture was determined with a portable meter (Grain Moisture Tester John Deere 5300®). Maize residue stalks (Yr) were cut and weighed on harvest day; moisture was determined by the gravimetric method with a laboratory drying oven (Lumiteell HTP-42®). Yield of husk tomato and squash by treatment was obtained from six plants in complete competition. Husk tomato was harvested every week at harvest maturity. To determine husk tomato yield (Yt), the number and weight of fresh mature fruits were recorded at each picking and per plant. Squash was picked every other day. To determine squash yield (Ys), the number and weight of fresh fruits per plant were recorded at each picking. Yt and Ys was calculated in 0.25 ha, the area they occupied in the intercropped milpa.

Net income (NI) was calculated with the regression equation (using the optimization program described above), with the formula NI=TI-TC, where TI is the total income obtained by multiplying the yield of each crop by their respective prices at a selling point and subtracting the cost of de-graining or preparation and transport to the selling point. TC is the sum of the fixed costs (FC) plus variable costs (VC). The fixed cost was MXN \$37 361.83 and MXN \$45 650.65 ha^{-1} in SJC and SPR, respectively (Table 1). The VC of each treatment corresponded to the sum of the quantities of N, P and OM multiplied by their respective price (Table 2).

With the maximum NI of each topological pattern and community, the number of Basic Food Baskets of the Agro-system (BFBA). This indicates the number of people that could fill their basic food baskets in the rural environment with the incomes obtained from the agro-system:

$$BFBA = \frac{\text{NI of th agrosystem}}{\textit{per capita} \text{ value of rural food basket}}$$

Table 1. Fixed costs of the experimental topological patterns in San Juan Coajomulco (SJC) and San Pedro el Rosal (SPR), State of México, Mexico in the Spring-Summer cycle, 2020.

Concept	Price per ha (cycle) in SJC (MXN \$ ha^{-1})	Price per ha (cycle) in SPR (MXN \$ ha^{-1})
Land rent.	1000.00	1000.00
Farm insurance (12 %).	760.00	760.00
Land preparation: ploughing, harrowing, furrowing.	5400.00	4000.00
Crop management, planting and transplanting, 1st and 2nd cultivation, re-seeding, labor days for cultivation, manual fertilization, manual weeding, labor days for irrigation, and labor days for tutoring.	15 148.00	17 189.00
Water for auxiliary irrigation (price of water consumed L ha^{-1}): \$ 0.12 L water, 4 L per plant per irrigation application and two ausiliary irrigations in SJC.	9999.36	650.00
Work tools. Tutoring materials. Drip irrigation in SPR (considering fuel and water pump).	4007.00	21 005.00
Maize, squash and husk tomato seed, MXN \$241.46 for 34500 maize seeds with 85% germination; 1 kg certified squash seed has 5991 seeds with 85% germination and costs MXN \$539.19; 5731 husk tomato seedlings cost MXN \$266.	1046.65	1046.65
Total	37 361.01	45 650.65

SJC= San Juan Coajomulco. SPR= San Pedro el Rosal. MXN \$ (Mexican pesos).

Table 2. Variable costs of the experimental topological patterns in San Juan Coajomulco (SJC) and San Pedro el Rosal (SPR), State of México, Mexico in Spring-Summer cycle, 2020.

Concept	Cost in SJC (MXN $)	Costo en SPR (MXN $)
Unit of nitrogen, considering 46% N en urea and MXN $ 8400 per Mg[†].	22.01	22.01
Unit of phosphorus, considering that triple calcium superphosphate has 46% P and costs MXN $ 9300 per Mg[†].	24.53	24.53
Unit of potassium, Potassium chloride has 60% K and costs MXN $ 9000 per Mg[†].	18.16	18.16
Organic matter, ($ per kg of composted organic matter), considering MXN $1200 per 6-ton truck and MXN $ 750 labor d of composting for 15 d[†]	0.57	0.49
Baling and hauling (MXN $ ha^{-1}), Considering that 1 Mg stalks=40 bales weighing 25 kg each).	1240	1240
Maize harvesting, transport, de-graining and hauling (MXN $ Mg^{-1}).	2361	2361
Husk tomato picking, transport, packing and sale (MXN $ Mg^{-1}).	1650	1650
Squash picking, transport, packing and sale (MXN $ Mg^{-1}).	1985	1805

[†] Cost includes transport and interest.

LER is a comparison of the yields from polyculture with those from monocropping in the same cultural conditions. The yield generated per unit of area is compared, and LER is calculated with the following equation (Li e*t al*., 2020):

$$LER = \frac{Ymi}{Ymm} + \frac{Yti}{Ytm} + \frac{Ysi}{Ycm};$$

where: Ymi, Yti, Ysi are the respective yields of intercropped maize, husk tomato and squash; Ymm, Ytm, Ysm are the corresponding yields of maize monocrop, husk tomato, and squash.

The maize equivalent yield (MEY) was calculated. To this end, we considered the TI from husk tomato and squash in polyculture (in 0.5 ha that the two species occupy in the system). With this TI value, the quantity of maize that could be bought was estimated (reference: MXN $5600.00 Mg^{-1} of maize, regional sale price). In the intercalated milpa, the MYE from 0.5 ha and Ym produced in 0.5 ha were summed to have a comparable estimation in 1 ha of monocropping. Thus, the yield of the intercropped species was compared with that of the species in monocrop in function of maize yield.

The RFSI was calculated from MEY; this index indicated whether food security exists in terms of the family maize supply. To calculate RFSI, we used the following mathematical expression:

$$\text{RFSI} = \frac{(\text{Y})\ (\text{PA})\ /\ \text{NMF}}{547.5\ ^{*}}$$

where: RFSI = Real food security index. Y = Yield in kg ha^{-1}. PA = planted area (ha). NMF = Number of members of the farmer's family (Damián and Toledo, 2016). *Factor considering the food needs of the family are satisfied (SAF) when each member of the family has access to 109.5 kg of maize per year (Damián-Huato *et al*., 2013). In this study we made the calculation for five people. The resulting value should be ≥ 1 if food security exists.

Data analysis

The Yg, Yr, Yt and Ys data observed were subjected to error normality tests with the Shapiro-Wilk test ($p <$ W 0.05, 204 observations) and variance homogeneity with the Bartlett test ($p >$ ChiSq 0.05, 204 observations). For each of these variables a multiple regression equation was composed with the variables N, P, OM, topological pattern and community in simple effect and interactions: "backward" (sls=0.05) to eliminate the variables that did not show important effect and "stepwise" (sls=0.05) to determine the model ($p < 0.05$, 180 observations). The equation permitted exploring the estimated yields in combinations of fertilization limits of 300-100-8000 kg N-P-MO ha^{-1}. With the resulting equation, an economic optimization program was constructed in SAS® version 9.0 (SAS Institute, Inc. Cary, N.C. USA) which rendered the fertilizer combination that yielded the maximum net income (NI) in each community and intercropped topological pattern MMTS and MTMS.

RESULTS AND DISCUSSION

Net income, basic food basket, and real food security index

In this study, under both irrigation and rainfed conditions, the highest NI was obtained in the MTMS topological pattern. Under irrigation, the highest NI (MXN $ 204 649.70) in MTMS was achieved with the highest estimated dose, 300-100-40-8000 kg of N-P-K-MO ha^{-1} (Table 3). The maximum net income with irrigation can obtain the equivalent of 12 and 14 rural basic food baskets with the topological patterns MMTS and MTMS, respectively. In other words, 3.3 and 3.9 minimum wages per day can be obtained. Both in SPR and in SJC, the milpa with intercropped maize, husk tomato and squash produced higher net incomes than the maize in monocrop. Mahmud *et al*. (2018) reported similar results when they grew maize intercropped with squash.

The maximum NI of the rainfed intercropped milpa was lower than that under irrigation. However, the rainfed milpa with the maximum income from MTMS can supply seven people with the basic food basket per year, or four people with the MMTS topological pattern (Table 3). Daily minimum wages obtained with MMTS were 1.2 and 3.3, while with MTMS, they were 2.1 and 3.8, in SJC and SPR, respectively. These results are similar to those obtained by García and Ronquillo (2018) with rainfed intercropped maize-beans-Faba beans; they reported 1.8 and 1.2 daily minimum

Table 3. Maximum net incomes, basic food baskets, and minimum daily wages obtained from milpa with intercropped maize-husk tomato-squash in two topological patterns, evaluated in small farmer plots in the State of Mexico, Mexico.

Intercropping	N	P_2O_5	OM	Maize	stalks	Husk tomato	Squash	NI[¤]	BFB[††]	MW[¶¶]	LER[§§]	RFSI[ÞÞ]
	kg ha^{-1}			(Mg 0.5 ha^{-1})		(Mg 0.25 ha^{-1})		($)				
MMTS[†] *t*[§]	300	0	8000	2.6	3.5	12.2	10.2	62 813.00	4.3	1.2	11.2	4.0
MTMS[¶] *t*[§]	300	0	8000	2.5	3.9	19.5	7.5	113 686.30	7.8	2.1	20.3	7.4
MMTS[†] *r*[Þ]	300	0	50	5.6	3.0	23.8	14.4	174 467.90	12.0	3.3	31.1	11.3
MTMS[¶] *r*[Þ]	300	100	8000	6.1	12.8	28.1	13.2	204 649.70	14.1	3.9	36.5	13.3

[†]MMTS: two rows of maize intercropped with one of husk tomato followed by one of squash. [¶]MTMS: one row of maize intercropped with one of husk tomato, one of maize and one of squash. [§]t: rainfed (San Juan Coajomulco). [Þ]r: irrigation (San Pedro el Rosal). [¤]NI: net income. [††]BFB: basic food baskets *per capita* acquired from the agro-system. [¶¶]MW: minimum wages *per capita* earned with the intercropped milpa. [§§]MEY: maize equivalent yield (tons, t). [ÞÞ]RFSI: index of real food security expressed in number of families with five members on average that can be supplied with food.

wages, and the highest value was obtained when they intercalated one row of maize followed by one row of an understory crop. Innovation with topological patterns and maize intercropped with annual commercial species can offer a way to satisfy the food and income needs of farm families.

Acquisition of basic food baskets with NI is an analysis of the gains from intercropping with two assumptions: the entire harvest is sold and the massification of this proposal would require the participation of the government to make commercialization feasible. Regarding this Paulino-Flores *et al*. (2017) recognize that the region does not have commercialization networks for the sale of maize since most is used for home consumption, to feed animals, or for seed.

In our study, the highest net income was generated from the sale of the understory crops: squash and husk tomato (Table 3). However, the maize crop is the cornerstone of agriculture and food in the central region of Mexico (Murray-Tortarolo *et al*., 2018). For this reason, another form of analysing the potential of polyculture was through calculating the maize equivalent yield (MEY) and the real food security index (RFSI) (Table 3). With the net income generated by the crops in each locality, MEY and RIFS were calculated. This accumulated yield of each system showed that the intercropping pattern MTMS resulted in higher yields than the MMTS pattern, both under irrigation and rainfed conditions. In MMTS, accumulated yield of the crops is equivalent to 11.2 (rainfed) and 31.1 (irrigated) Megagrams of maize. As a reference, with this topological pattern, Mahmud *et al*. (2018) calculated MEY at 18.39 tons (Megagrams) per hectare (Mg ha^{-1}) with two rows of maize intercalated with two rows of squash. With the maize yield equivalent, the RFSI was calculated in terms of maize. In both SPR and SJC, the RFSI indicates that the topological patterns MMTS and MTMS can supply the maize consumed by more than four people per year (Table 3).

The optimal estimated dose at the highest level of inputs explored, in rainfed and irrigated MTMS and in rainfed MMTS, suggest that the fertilization exploration space can be increased in future studies, attending to environmental aspects. As a reference, the optimal dose in maize (variety SY30 and HL40×YJ7) in China is 405, 135 and 135 kg ha^{-1} N, P_2O_5 and K_2O, respectively (Li *et al*., 2020). At the local level, ICAMEX (2021) recommends, for the high valleys, fertilization of 115-46-30 kg ha^{-1} NPK, distributed in two applications 46-46-30 kg ha^{-1} NPK at planting and 69-00-00 kg ha^{-1} NPK at the second cultivation.

Land equivalent ratio

With a global meta-analysis with intercalated crops, Li *et al*. (2020) corroborated that intercropped maize systems produce average LER values of 1.29 ± 0.02 and are lower in the cases in which species other than maize are intercalated. In our study, the intercropped system that had the highest LER was MMTS (Table 4) under irrigation and rainfed conditions, 1.64 and 2.78, respectively. These LER values indicate that 1.64 and 2.78 hectares of monocropping are needed to equal the yields obtained on

Table 4. Land equivalent ratios of the three topological patterns of maize, husk tomato and squash cultivated in two communities of the State of Mexico, Mexico in the Spring-Summer cycle, 2020.

Intercropped milpa	Rainfed (SJC)			Irrigated (SPR)		
	Yield	Partial LER	Final LER	Yield	Partial LER	Final LER
Maize in MMTS$^{\dagger\ y}$	2.7±0.5	0.60	2.78	3.7±0.4	0.53	1.64
Maize monocrop $^{\text{¤}}$	4.5±0.5			7.1±1.2		
Stalks from MMTS$^{\dagger\ \text{Þ}}$	2.7±0.5	0.49		6.1±0.6	0.60	
Stalks from monocropping$^{\text{¤}}$	5.6±0.9			10.0±1.6		
Husk tomato MMTS$^{\dagger\ \S}$	1.9±0.0	0.19		8.4±0.2	0.21	
Husk tomato monocrop $^{\text{¤}}$	10.1±1.5			40.5±2.4		
Squash in MMTS$^{\dagger\ \S}$	5.9±2.5	1.51		15.1±0.3	0.30	
Squash monocrop	3.9±1.2			50.5±9.1		
Maize in MTMS$^{\P\ \text{Þ}}$	3.0±0.5	0.67	1.85	3.2±0.5	0.46	1.34
Maize monocrop^{z}	4.5±0.5			7.1±1.2		
Stalks from MTMS$^{\P\ \text{Þ}}$	4.7±1.1	0.84		4.8±0.9	0.48	
Stalks from monocropping$^{\text{¤}}$	5.6±0.9			10.0±1.6		
Husk tomato in MTMS$^{\P\ \S}$	1.4±0.4	0.14		7.2±1.0	0.18	
Husk tomato monocrop$^{\text{¤}}$	10.1±1.5			40.5±2.4		
Squash in MTMS$^{\P\ \S}$	0.8±0.4	0.20		11.1±1.2	0.22	
Squash monocrop ^{z}	3.9±1.2			50.5±9.1		

Values are the average of three replications and six sampling ± SE. SJC: San Juan Coajomulco. SPR: San Pedro el Rosal. Yields obtained with the fertilizer dose 163-60-40-3600 kg N-P-K-MO ha^{-1}. †MMTS: two rows of maize intercalated with one of husk tomato followed by one of squash. ¶MTMS: one row of maize intercropped with one of husk tomato, one of maize and one of squash. §: yield observed in 0.25 ha. $^{\text{Þ}}$: yield observed in 0.5 ha. $^{\text{¤}}$: yield observed in 1 ha. LER = land equivalent ratio.

one hectare of irrigated and rainfed intercalated MMTS, respectively. The partial LER values of maize (Table 4) in our study are lower than those obtained by Xu *et al*. (2021), who showed that the partial LER of maize oscillated between 0.78 and 0.97. Thus, the final LER obtained was above one, indicating a productive advantage of polyculture over monocropping, provided by the low stature species (husk tomato and squash).

The LER in rainfed MMTS (2.78) had a contribution of 1.51 from the partial LER of squash. This means that in the pattern of two rows of tall plants (maize) and two of low plants (husk tomato adjacent to squash), squash made a greater contribution to species yield. The results are similar to those obtained by Mahmud *et al*. (2018), who showed that intercalating two rows of maize and two rows of squash has the highest land equivalent ratio (1.62), compared with other topological patterns. The lower yield of the MTMS pattern, compared with MMTS and monocrops, is attributed to competition among the species for light, water, and nutrients (Mahmud *et al*., 2018). Albino-Garduño *et al*. (2015) report similar results for intercalating one row each of maize and beans; the low yields of the short crops are attributed to shading by the maize and the extensive distribution of maize roots.

The analysis of regression equations shows the agronomic response of the crops. The ordinates at the origin of the regression equations reveals that the yield of the three crops is higher under irrigation than under rainfed conditions (Table 5). The equations also show that under irrigation (SPR) there is a positive effect of N and P fertilization on maize grain yield in rainfed conditions (SJC); the patterns of rain can affect N

Table 5. Regression equations of yields of maize grain, husk tomato and zucchini squash intercropped in two topological patterns in small farmer plots, irrigated and rainfed, in the State of Mexico.

Crop	Agrosystem	Regression equation	R^2
Maize	MMTS[†] *t*[§]	$\hat{Y}g$[¤]$= 2.55556$	0.855
	MTMS[¶] *t*[§]	$\hat{Y}g$[¤]$= 2.82 + 0.11042P$	
	MMTS[†] *r*[Þ]	$\hat{Y}g$[¤]$= 5.05334 + 0.12396N$	
	MTMS[¶] *r*[Þ]	$\hat{Y}g$[¤]$= 5.31778 + 0.12396N + 0.11042P$	
Husk tomato	MMTS[†] *t*[§]	$\hat{Y}t$[††]$= 1.76546 + 0.50150N^2$	0.784
	MTMS[¶] *t*[§]	$\hat{Y}t$[††]$= 1.76546 + 0.50150N^2 + 0.48125NOM + 0.32009OM^2$	
	MMTS[†] *r*[Þ]	$\hat{Y}t$[††] $= 7.2487 + 0.50150N^2 - 0.67188N + 0.92708POM + 0.40529P^2$	
	MTMS[¶] *r*[Þ]	$\hat{Y}t$[††] $= 7.2487 + 0.50150N^2 - 0.67188N + 0.92708POM + 0.40529P^2 + 0.48125NOM + 0.32009OM^2$	
Squash	MMTS[†] *t*[§]	$\hat{Y}c$[¶¶]$= 5.48050 + 0.81875OM + 0.46255OM^2$	0.756
	MTMS[¶] *t*[§]	$\hat{Y}c$[¶¶]$= 2.7505 + 0.81875OM + 0.46255OM^2$	
	MMTS[†] *r*[Þ]	$\hat{Y}c$[¶¶]$= 12.8305 + 0.12917OM + 0.46255OM^2$	
	MTMS[¶] *r*[Þ]	$\hat{Y}c$[¶¶]$= 10.1005 + 0.1291OM + 0.46255OM^2$	

Stepwise regression (sls=0.05) to determine the model: $p < 0.05$, 180 observations. [†]MMTS: two rows of maize intercropped with one of husk tomato and one of squash [¶]MTMS: one row of maize intercropped with one of husk tomato followed by one row of maize and one of squash. [§]t: rainfed. [Þ]r: irrigation. [¤]$\hat{Y}g$: maize grain yield estimated in 0.5 ha. [††]$\hat{Y}t$ and [¶¶]$\hat{Y}c$: husk tomato and squash yields estimated in 0.25 ha; N: nitrogen. P: phosphorus. K: potassium. OM: organic matter.

uptake by the maize plant, as suggested by nitrogen fertilization models (Fletcher *et al*., 2021). In the two study conditions husk tomato yield is higher in the topological pattern MTMS than in MMTS. In SJC this is attributed to the effect of N, OM, and the interaction of the two. In SPR, the effect of P also contributed. The topological pattern that favoured squash yield was MMTS, under both irrigation and rainfed conditions. In the two conditions, organic matter favoured yield increase.

CONCLUSIONS

Native maize in rows intercropped with husk tomato and squash generates net incomes sufficient to acquire the basic food baskets and maize required by an average farm family. These indicators, as well as the minimum daily wages that this intercropped milpa agro-system generates, are higher with intercalated maize-husk tomato-maize, squash than with maize-maize-husk tomato-squash, in both irrigation and rainfed conditions; the sale of husk tomato and squash generates higher economic incomes than maize.

Intercalating two rows of maize, followed by one of tomato and one of squash obtained higher land equivalent ratios than monocropping these species or planting adjacent rows of each species. The cultivation of native maize intercropped with husk tomato and squash is an option for small farmers who produce with irrigation or in rainfed conditions in north-western State of Mexico, Mexico.

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