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Effect of bioinputs on milpa production, in three communities of the Sierra Nevada, Puebla

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ABSTRACT
Objective: To evaluate the effect of the Supermix bioinput on milpa yield, using local technologies practiced by producers from three communities of the Sierra Nevada.
Design/Methodology/Approach: The milpa —a polyculture that consists of maize, beans, and squash— provides a diversity of nutritious foods for families, with production ranges that are constant throughout the region. Applying bioinputs opens the possibility of improving these ranges. The Supermix was applied in five 30-m long rows in 9 producer-managed milpa plots, in order to carry out an exploratory measurement of its effect on the productive levels of the polyculture. For comparative purposes, the average yields of the milpa were estimated, both in the 5 rows in which the Supermix was applied and in the rest of the plot (control).
Results: In the three communities under study, the milpa produced in average 2.51 t of maize, 170.6 kg of beans, and 122.9 kg of squash seed per hectare; meanwhile, the control produced 2.57 tons of maize, 159.3 kg of beans, and 99.6 kg of squash seed. The total yield of the milpa system (sum of all products) to which the Supermix was applied was 2,804 kg ha^{-1}, while the control system recorded 2,828 kg ha^{-1}.
Study Limitations/Implications: Drought, pest damage, and previous bean harvests influenced the results.
Findings/Conclusions: The average yields of beans and squash to which Supermix was applied were higher than with the control, opening opportunities for innovation. Additionally, work in the milpa is mostly carried out by women.

Keywords: family farming, milpa polyculture, natural minerals, weeds.

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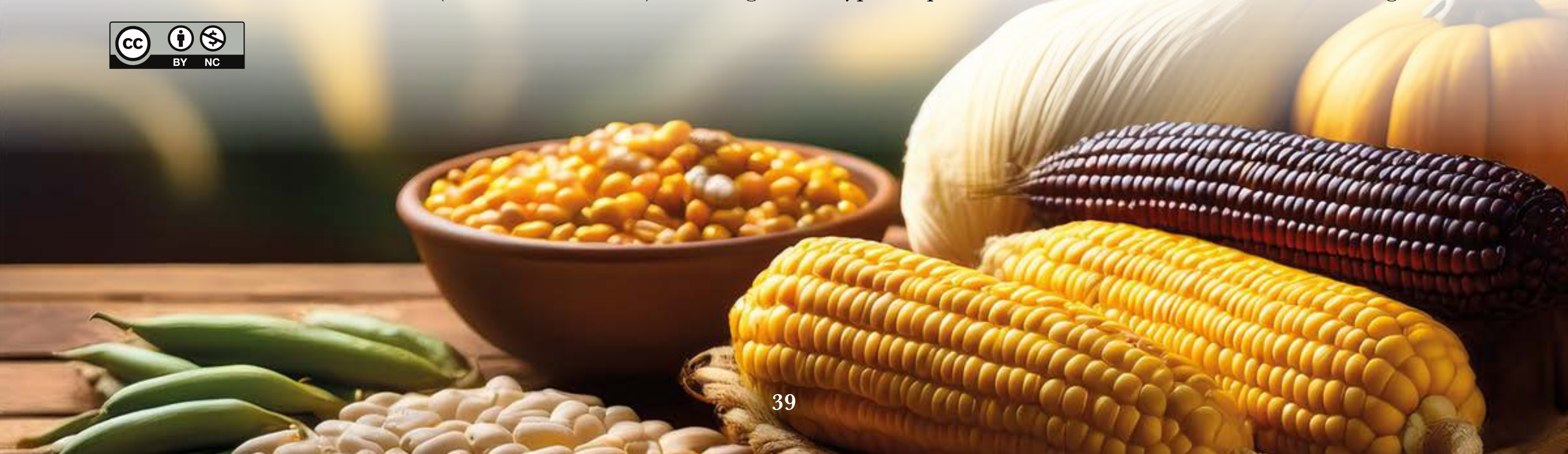
INTRODUCTION

Family Farming (FF) is a type of agricultural production that has been implemented since time immemorial and is the basis of the economy of many rural families and communities all over the world. Its main characteristics include: 1) limited access to land and capital resources; and 2) predominant use of family workforce (Rosette and Hernández, 2014). In Mexico, FF is practiced in approximately 81.3% of the Rural Economic Units (SAGARPA, 2012). Through this type of production, farmer families have managed to



develop highly complex production systems, such as the milpa system (MS) —known as the "Mesoamerican triad," because it is mostly composed of maize and several species of beans and squash (INIFAP, 2022), as well as chilis, tomatoes, weeds, and many other regional species (CONABIO, 2016). Several studies have proven the importance of the MS, highlighting its productive, social, economic, and environmental aspects. From a sustainability point of view, Aguilar-Jiménez *et al.* (2011) determined that this dynamic polyculture ecosystem favors beneficial environmental interactions, reflecting traditional agricultural lore and practices and preserving species diversity. Based on a study carried out in the municipality of Jesús Carranza, Veracruz, Ortiz-Timoteo *et al.* (2014) considered that a more efficient management of self-consumption crops could improve milpas. For their part, Ebel *et al.* (2017) determined that all combinations of maize, squash, and beans were superior to monocultures in Piedras Blancas, State of Mexico. Meanwhile, Briones-Aranda *et al.* (2024) studied the sustainability of a maize agroecosystem in Chignautla, Puebla, with two management systems, and determined that, with regard to most of the study variables, the polyculture maize system had better results than the monoculture. They concluded that maize polyculture has a greater tendency towards a sustainable management and highlighted the importance of revaluating this type of agroecosystems, since their productive potential strengthens food sovereignty. Families that participate in the milpa system have access to various nutrient-rich foods, income, and labor, just like in the municipalities of Atzitzihuacan, Cohuecan, and Tochimilco, in the Sierra Nevada, Puebla. According to CONAHCYT (2023), the food sovereignty of those municipalities is guaranteed by the percentage (21.57%) of the cultivation area of the production units (milpas). However, several factors —including the inadequate use of agrochemicals and the loss of soil quality— threaten the productive efficiency of the local milpas. In response to this issue, the aim of this study was to evaluate the effect of the Supermix bioinput on the yield of the milpa system in the Sierra Nevada region. This product is a mixture of ZeoFert™, leonardite, diatoms, and vermicompost. These organic products play a crucial role in agriculture, providing essential nutrients for plant growth and soil health. Aguilera and Morales (2011) produced ZeoFert™ combining zeolite with cattle manure, with the aim of measuring its effect on the yield of common beans and the chemicals properties of the soil. The results showed that its application significantly increased the yield of beans, the P_2O_5, K_2O, and organic matter content, and the pH of the soil. Espinosa *et al.* (2021) concluded that the use of ZeoFert™ increased the yield of tomato by ≈38%, as well as its quality (fruit diameter). Additionally, it increased the N, P_2O_5, K_2O, Ca^{++}, and organic matter content of the soil, as well as its pH values. Salvatierra (2024) studied the origin of leonardite-based humic and fulvic acids, as well as their extractive processes and their agricultural use. He evaluated their application as an alternative source of organic matter for the soil, determining that humic acids have a favorable effect on the development of new roots. Soriano-Rodríguez (2020) points out that diatoms are microscopic fossil algae, composed of a transparent silica cell wall and an internal pectin layer. Properly crushed, the skeletons of this unicellular algae turn into microscopic silicon needles, sharp enough to damage insects. Preciado-Muñoz (2024) points out that silicon nanostructures have become a promising agricultural alternative. Their novel properties optimize the use of the planet's natural resources, making them vehicles for the controlled delivery of active substances to the plant, including pesticides and fertilizers. Chatterjee *et al.* (2021) made vermicompost (VC) from agricultural waste and manure. They found that the application of VC to green chili crops improved their yield and quality; additionally, it improved soil fertility conditions, constantly providing a greater amount of nutrients, during the growth period of the plant. Mantuano-Morales and Zambrano-Gavilanes (2023) conducted an extensive literature review on the effect of VC in 11 crops and determined that VC is a microorganism-rich manure that provides assimilable nutrients to crops. It has positive effects on the soil and plants, allowing a good development and generating high productivity.

MATERIALS AND METHODS

The study was carried out in three communities: San Mateo Coatepec (Atzitzihuacan), San Francisco Tepango (Cohuecan), and Santiago Tochimizolco (Tochimilco). The Atzitzihuacan, Cohuecan, and Tochimilco municipalities have a surface of 130.203, 47.606, and 219.631 km^2, respectively (INEGI, 2017). They had 13,298, 5,283, and 19,576 inhabitants, respectively (Secretaría de Bienestar, 2024). The soil use in all three municipalities is mainly agricultural: 69.44% (Atzitzihuacan), 76.36% (Cohuecan), and 43.89% (Tochimilco). The study area is located in the foothills of the Popocatepetl volcano, in the Sierra Nevada of Puebla, a transitional zone between the subhumid temperate climate and the warm weather regions. Its favorable climatic conditions allow the growth of maize, beans, amaranth, chia, sorghum, and other crops. An agreement was reached in 2023 with 9 producers (4 men and 5 women) from these communities to generate direct field data, with the aim of following-up the management that farmers do to their milpa system plots. Each of these plots were labelled as Milpa Follow-Up Plots (MFP). As part of the second "task", the Supermix was applied to five 30 m long furrows in each of the nine MFP, to identify any differential response in the production levels. The Supermix was prepared with the following commercial products and doses: a) 500 kg ha^{-1} of ZeoFert™; b) 200 kg ha^{-1} of leonhardite; and c) 100 kg ha^{-1} of diatoms. The doses were taken from the technical information of each product provided by the manufacturer (Zeolitech, 2020). The three products were mixed with 2.5 t ha^{-1} of vermicompost. Table 1 shows the mineral content of the four products.

A series of variables (related to the maize, bean, and squash yield) were physically estimated in each of the 9 MFP to analyze their production, following the methodology proposed by Domínguez-Torres *et al.* (2022). The yield and plant density (DP) were estimated both in the 5 furrows treated with the Supermix and in the rest of the plot managed by the producer, using the control treatment.

RESULTS AND DISCUSSION

In average, the producers of the FF units were 53 years old (age range: 41 to 59 years). In terms of their education, 2 and 6 producers finished primary school and junior high school, respectively, while only one graduated from high school. All the producers stated that they were farmers, although 3 out of the 5 participating women declared that they were "homemakers/farmers". The nine participants sowed in average 0.37-ha milpas, with

Table 1. Mineral content of each component of the Supermix (kg ha^{-1}).

Product/ composition	N	P_2O_5	K_2O	CaO	SO_3	SiO_2	MgO	Humic and fulvic acids
Zeofert	19	47	10	80	15	0	17	0
Leonhardite	8	0	9	3	0	0	2	36
Diatoms	0	0	0	0	0	82	0	0
vermicompost	15	47	45	0	0	0	38	250
Total	42	94	64	83	15	82	57	286

Source: Table developed by the authors based on the technical information for each product.

a maximum of 1.2 ha and a minimum of 0.10 ha. In fact, 4 producers sowed a single 10-ha "task," while 2 producers sowed 5, 4, and 3 "tasks," equivalent to 0.50, 0.40, and 0.30 ha, respectively. Regarding fertilization, 7 producers informed that they used Diammonium phosphate (DAP) in the first "task" and urea in the second. Two producers used cattle and sheep manure mixed with the NPK formula known as "Triple 16". The producers applied various fertilizer doses: 72 to 230 N units, 36 to 180 P_2O_5 units, and 0 to 36 K_2O units. The average NPK doses was 157-84-06. Given the exploratory nature of this study, no field demonstration of the effect of the Supermix was carried out. However, one producer requested information about the bioinput and how to get hold of it. The producer was informed that, during the first year, the research team would help the producers to get hold of the commercial products and would train them in the preparation of the mix. Since the economic aspect was not part of the study, the Supermix and the control treatments were not compared in this regard. Nevertheless, the mix would cost $1,316 Mexican pesos per "task" (0.10 ha). Meanwhile, in terms of production results, the plant density per ha fluctuated between 28,500 to 55,000 maize plants, 1,500 to 22,917 bean plants, and 320 to 3,000 squash plants. The yield per ha ranged from 0.99 to 7.54 t of maize, 20 to 365 kg of beans, and 26 to 243 kg of squash seed (Table 2).

Table 3 shows the yields and average range per crop achieved with the Supermix and control treatments in the three communities. The average maize yield was similar under both conditions: 2.57 t ha^{-1} (control) and 2.51 t ha^{-1} (Supermix). Finally, the average yield of maize and beans in San Mateo were higher than in the other two communities, unlike the yield of squash.

The average difference between beans in the three communities does not seem to be significant with the Supermix (170.6 kg ha^{-1}) and the control (159.3 kg ha^{-1}). However, the atypical data recorded in Tochimizolco (282 kg ha^{-1}) perturbed the average results. For its part, the response of beans to the Supermix in San Mateo was higher in all cases (340 kg ha^{-1}) and was 45% higher than the control (190 kg ha^{-1}). In the case of the average yield of squash in the three communities, the Supermix recorded more seeds (122.8 kg ha^{-1}) than the control (99.66 kg ha^{-1}). Based on the analysis of the yield data per treatment and community, production almost doubled with the Supermix, both in San Mateo and Tepango. Meanwhile, the highest average yield of squash seed in Tochimizolco was obtained with the control: the plant density (PD) of squash in plot No. 7 recorded 2,000 specimens with the Supermix treatment, while the control reached 3,000 plants (Table 3). Based on

Table 2. Plant density and yields per crop and treatment in the 9 MFP (2023 agricultural cycle).

Community	Number of MFP/treatment	Maize plants ha^{-1}	Maize t ha^{-1}	Beans plants ha^{-1}	Beans kg ha^{-1}	Number of squash ha^{-1}	Pumpkin seed kg ha^{-1}
San Mateo	1 Supermix	48,367	7.54	16,531	**	1,224	99
San Mateo	1 control	38,095	6.08	16,190	**	952	77
San Mateo	2 Supermix	31,667	3.02	17,917	315	1,250	101
San Mateo	2 control	36,957	3.72	16,522	190	435	35
San Mateo	3 Supermix	42,083	1.61	22,917	365	667	54
San Mateo	3 control	44,800	1.77	22,400	190	320	26
Tepango	4 Supermix	40,889	2.03	12,000	123	***	***
Tepango	4 control	41,333	2.37	12,000	125	***	***
Tepango	5 Supermix	50,000	1.58	*	*	2,500	203
Tepango	5 control	55,500	1.54	*	*	1,000	81
Tepango	6 Supermix	33,778	0.99	8,000	**	*	*
Tepango	6 control	36,444	1.01	9,333	**	1,778	144
Tochimizolco	7 white maize Supermix	45,333	1.47	12,000	58	*	*
Tochimizolco	7 control	42,000	2.14	10,667	127	*	*
Tochimizolco	7 red maize Supermix	37,000	2.73	*	*	2,000	162
Tochimizolco	7 control	43,000	2.69	*	*	3,000	243
Tochimizolco	8 Supermix	41,500	1.31	9,000	20	500	41
Tochimizolco	8 control	32,381	1.11	8,571	79	*	*
Tochimizolco	9 Supermix	28,500	2.32	1,500	69	500	41
Tochimizolco	9 control	35,714	2.94	8,095	282+	476	39

Source: Table developed by the authors based on field data from the 9 MFP. *Not sown/Undetected. **Previously harvested. ***Damaged by badgers. +Atypical data.

the analysis of the average production in all the milpa systems of the three communities, the Supermix (2.804 t ha^{-1}) and the control (2.828 t ha^{-1}) treatments were determined to have similar results, through the summation of the grain yields for the three species. However, the treatments per community and between communities have major differences. The Supermix and the control treatments recorded the highest results in San Mateo, with 4.485 and 4.096 t ha^{-1}, respectively. The yields were similar in Tepango. Meanwhile, in Tochimizolco, control was apparently higher than Supermix; however, both the bean and squash yields in this community were atypical, as a consequence of the specific conditions of the follow-up plots. Given the management of each MFP under natural conditions, crops faced several major limitations. Additionally, various circumstances influenced the study cases. In Tepango, more than half of the plot was damaged by badgers (*Nasua narica* L.). Some producers did not sow some of the crops. Other producers harvested beans earlier, in response to atypical rains in late autumn. A control treatment in a plot from Tochimizolco recorded an atypically high bean yield. Another major event that impacted the production results was the severe drought that took place in September, when bean pods were still growing and maize was fully developing its grains. This drought mainly impacted the municipalities of Cohuecan and Atzitzihuacan.

Table 3. Yields and average range of the milpa polyculture per treatment and community (2023 agricultural cycle).

Cultivation/Treatment	San Mateo	Tepango	Tochimizolco	Average yield for the three communities
Maize Supermix (t ha^{-1})	4.06	1.43	1.96	2.51
Ranges	1.6-7.6	1.0-2.03	1.29-2.75	1.0-7.6
Maize control (t ha^{-1})	3.86	1.64	2.22	2.57
Ranges	1.8-6.1	1.01-2.35	1.11-2.92	1.01-6.1
Beans Supermix (kg ha^{-1})	340.0	123.0	49.0	170.6
Ranges	315-365	123-123	20-69	20-365
Beans control (kg ha^{-1})	190.0	125.0	162.70+	159.3+
Ranges	190-190	125-125	58-282+	58-282
Pumpkin seed Supermix (kg ha^{-1})	84.81	202.50	81.33	122.9
Ranges	54-101	144-203	41-162	41-203
Pumpkin seed control (kg ha^{-1})	46.10	112.51	140.78+	99.7
Ranges	26-77	81-81	39-243	26-243
Milpa polyculture Supermix Total grain production (t ha^{-1})	4.485	1.755	2.090	2.804
Milpa polyculture Control Total grain production (t ha^{-1})	4.096	1.877	2.524+	2.828+

Source: Table developed by the authors based on field data from the 9 MFP. +Atypical data.

Based on the analysis of the data of the 9 MFP, the total yield of the milpa system with the control treatment was 2.828 t ha^{-1}; meanwhile, the Supermix bioinput reported 2.804 t ha^{-1}. Therefore, control had a favorable difference of 76 kg. The milpa species of each plot obtained the following average yields: 2.54 t ha^{-1} of maize, 0.165 t ha^{-1} of beans, and 0.111 t ha^{-1} of squash seed. For comparison purposes, the results for squash seeds were converted into squash fruit, obtaining a 2.8 t ha^{-1} yield, based on an average 0.041 fruit-to-seed conversion factor. In this context, Ebel *et al.* (2017) proved that the maize, beans, and squash (fruit) polyculture can yield up to 7.9, 1.9, and 6.2 t ha^{-1}, respectively; therefore, the results for the 9 MFP were below the figures reported by the said research team. For their part, Rojas-Victoria *et al.* (2017) studied the yield of the association of ayocote beans and maize and, based on the number of plants per plot, determined that plant density improved the yield of both crops and that, in terms of production levels, milpas recorded better results than monocultures. Therefore, studying several technical management variables in Sierra Nevada may result in significant innovations for family farming. Since this was an exploratory study, checking management variables was discarded. Given the importance of milpas in the Sierra Nevada region, the yield obtained by local producers was documented and compared with the yield resulting from the application of the Supermix in a part of their plots. Finally, the plant density and the yield of beans and squash had a positive relation. In the case of maize, MFP 1 recorded 7.54 t ha^{-1} with the Supermix, while control reached 6.08 t ha^{-1}, resulting in a difference of 1.47 t ha^{-1} in favor of the former. The MFP 1 producer used an improved maize variety in her plot. Therefore, her production averages were also much higher than the averages of the rest of the producers. The analysis of the overall milpa system (three-crop sum) showed an analogous grain production in the whole system, except for one community. Therefore, the Supermix bioinput would seem to have no effect at all. However, the community and intercommunity analysis showed that the said input does have positive effects. During the knowledge exchange workshop, one of the producers (Judith Torres, 2023, personal communication) said that: "The use of organic fertilizers is effective for the milpa, although it is a little slow, it is very beneficial for human health, because my family consumes a 100% of fresh products and grains that I harvest from my plot." Meanwhile, another producer (Victor Casique, 2023, personal communication) considered that "…using organic products is important for soil recovery, if we use chemical fertilizers or products every year, the soil becomes thinner, higher doses will be required every time to obtain a satisfactory effect in the soil, meanwhile, organic products have more benefits, because, for starters, the soil can recover, and we improve it, so we can get better harvest in the following years, as the life in the soil increases..."

CONCLUSIONS

The Supermix and the control treatment had a similar result regarding the total yield of the milpa. However, the bioinput had a positive effect on bean and squash yields. In the case of maize yield, the Supermix only had a positive effect in the plot of the producer who sowed an improved variety. Additionally, women had a major participation in the management of the milpas in the region. In view of the results, further experimental studies must be carried out under the natural conditions of the Sierra Nevada producers, in order to develop local production technologies. This type of participatory experiences with producers leads to an enhanced productivity, through good agroecological practices, and contributes to the safekeeping of both their livelihood and the cultural hold of the milpa system in the region.

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