

Analysis of The Equivalent Land Use (ELU) in the Milpa System Intercalated with Fruit Trees (MIAF) in Axochio, Veracruz

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ABSTRACT: The Intercropped Maize and Fruit Tree System (MIAF) represents an agroecological alternative aimed at improving the productivity, sustainability, and resilience of tropical agroecosystems in the face of the limitations of traditional monocultures. In this context, Land Use Equivalent (LUE) is a fundamental indicator for evaluating the productive efficiency of diversified systems. The objective of this research was to evaluate the Land Use Equivalent in the MIAF system established in Axochio, Veracruz, in order to determine its efficiency compared to monocultures. The research was conducted during the years 2024, 2025, and 2026 at the MIAF-INIFAP Module in Axochio, San Andrés Tuxtla, Veracruz. The evaluated system consisted of 16 species, including fruit trees and annual crops. To determine the LUE, the yields obtained in association within the MIAF system and the national yields for monoculture reported by SIAP and SIACON were used. The results showed high productive diversity, highlighting species such as sapodilla, Persian lime, starfruit, and maize. The total land use efficiency (LUE) obtained was 4.83, a value greater than one, indicating that the integrated agroforestry system (MIAF) uses land more efficiently than monocultures. The largest contributions to the UET came from maize and starfruit. It is concluded that the MIAF system promotes ecological complementarity among species, optimizes resource use, and constitutes a viable strategy for strengthening sustainability and food security in tropical regions.

KEYWORDS: beans, fruit trees, corn, soil, terrace

INTRODUCTION

Sustained global population growth, coupled with intensifying pressure on natural resources, has driven the need to develop more efficient, resilient, and sustainable agricultural systems. Historically, agricultural production has been dominated by monoculture systems, which optimize the yield of a particular species. However, this approach has revealed several limitations, including soil degradation, reduced biodiversity, increased incidence of pests and diseases, and a high dependence on external inputs such as fertilizers and agrochemicals (Altieri, 1999; Altieri *et al.*, 2017). In response to these challenges, diversified agricultural systems have gained increasing importance by integrating practices such as polycultures, intercropping, and agroforestry systems. These practices all promote greater resource efficiency, improve productive stability, and strengthen the resilience of agroecosystems to environmental disturbances (Gliessman, 2018).

Intercropping systems are defined as the simultaneous association of two or more species in the same area, where ecological interactions among the system's components can generate synergistic effects that increase the efficiency of resource use, such as solar radiation, water, and nutrients. These systems rely on mechanisms such as niche complementarity, interspecific facilitation,



and the temporal and spatial partitioning of resources, which contribute to improving the overall productivity of the system and reducing the incidence of adverse biotic factors, such as pests, diseases, and weeds (Tilman, 2020). Consequently, dependence on external inputs is reduced, and the sustainability of agroecosystems is strengthened (Vandermeer, 1989). Within this framework, intercropping systems have shown greater prevalence and success in tropical regions, where a significant proportion of agricultural production continues to be based on polyculture arrangements. This trend is related to the structural limitations in access to agrochemical inputs by small producers, which has led to the development of low external input production strategies, based on the use of ecological processes and traditional knowledge (Altieri & Anderson, 1986).

In Veracruz, Mexico, the Milpa Intercalada con Árboles Frutales (MIAF) system was developed in 1988 by researchers from INIFAP and the Colegio de Postgraduados using Living Wall Terrace (TMV) technology, with *Gliricidia sepium* hedges, reinforced by a runoff filter whose function was to obstruct the free passage of water and delimit strips dedicated to annual crops, where a terrace is gradually formed (Ruiz Mendoza *et al.*, 2012 and Cortés-Flores, 2007); therefore, this multi-objective production technology mainly seeks to increase net income and family employment, protect the soil against water erosion, promote interaction between crops, and increase carbon capture; Furthermore, it shows multiple benefits in biological, technical, and socioeconomic aspects, highlighting for example the increase in productivity, improvement of soil fertility, conservation of soil and water, regulation of the microclimate, biodiversity, and sustainability (Meza, (2019).

Land Equivalent Ratio (LER), internationally known as *the Land Equivalent Ratio*, is one of the most widely used indicators for evaluating the productive efficiency of diversified agricultural systems, particularly intercropping or polyculture systems. This index allows for a comparison of the productivity of a multicropping system with that of monocultures, determining how much additional monoculture land would be needed to achieve the same yield as in an intercropped or diversified system. Conceptually, the LER is defined as the sum of the yield proportions of each crop in intercropping relative to its yield in monoculture. This index was proposed to compare the productivity of intercropping systems with that of monocultures, allowing for the estimation of the monoculture area needed to achieve the same production as in a diversified system (Mead & Willey, 1980). In general terms, UET values greater than one indicate that the intercropped system uses the land more efficiently than monocultures, while values equal to or less than one reflect similar or lower efficiency (Willey, 1979).

On the other hand, modern agriculture has historically been dominated by monoculture systems, which, although they can maximize the yield of a specific crop, often present limitations related to soil degradation, loss of biodiversity, vulnerability to pests and diseases, and a greater dependence on external inputs (Altieri, 1999). In contrast, diversified systems, such as polycultures, agroforestry systems, and integrated agroecosystems, promote positive ecological interactions among species, which can improve the efficiency of resource use, including light, water, nutrients, and space (Vandermeer, 1989).

In addition to its usefulness in evaluating the relative productivity of agricultural systems, Land Use Equivalent (LUE) is an important tool for the design and management of sustainable agroecosystems, as it allows for the identification of crop combinations that maximize yield per unit area and optimize the use of environmental resources. In tropical and subtropical regions, where traditional agricultural systems often integrate multiple plant and animal species, LUE analysis is particularly relevant for evaluating the productive and ecological efficiency of diversified agroecosystems. In this context, the study of Land Use Equivalent allows us to understand how the integration of different productive components within an agroecosystem can generate ecological and productive synergies, contributing to increased productivity, system stability, and agricultural sustainability. Therefore, the objective of this research was to evaluate Land Use Equivalent in the Intercropped Maize and Fruit Trees (MIAF) system in Axochio, Veracruz, and thereby determine the productive efficiency of the system.

MATERIALS AND METHODS

Study area. The research was conducted at the “Dr. Antonio Turrent Fernández Productive Conservation Technology Research and Transfer Module” (MIAF-INIFAP Module), established in 2003, located in the town of Axochío, municipality of San Andrés Tuxtla, Veracruz, at an altitude of 60 m, at 18° 20' 0.5” North Latitude and 95° 17' 57.7” West Longitude. The Los Tuxtlas region is characterized by a warm sub-humid climate with summer rains (Aw2), and precipitation ranges between 1500 and 2000 mm (García, 2004). The geomorphology consists of hills with slopes of 10 to over 20%, and the soils have been formed by alluvial sediment

deposition and volcanic activity. The soil where the research was conducted had a pH of 5.7, electrical conductivity of 0.67 dS m⁻¹, silty loam texture, 1.93% OM, and organic carbon of 1.12% respectively (Zetina-Lezama *et al.*, 2023).

Field data collection. The information presented in this research was collected during the years 2024, 2025, and 2026 in the MIAF-INIFAP Module, which consisted of characterizing this system comprised of 16 different species, mainly fruit trees and staple crops (Table 1). Each species was considered as a treatment, with the purpose of estimating the Land Equivalent *Ratio* (LER). For this purpose, both monoculture crops and their combinations in intercropping or association systems were considered, in order to analyze the relative efficiency of land use in the MIAF-INIFAP system. The treatments evaluated included: a) Crop A in monoculture; b) Crop B in monoculture and c) Association of crop A + crop B. This type of design is widely used in studies of associated cropping systems to evaluate land use efficiency (Mead and Willey, 1980; Willey, 1979).

Table 1. List of species that make up the evaluated agroecosystem

Species	Amount	Unit of measurement
Soursops (<i>Annona muricata</i>)	50	Trees
Carambola (<i>Averrhoa carambola</i>)	105	Trees
Sapodilla (<i>Manilkara zapota</i>)	216	Trees
Persian lemon (<i>Citrus latifolia</i>)	120	Trees
Mamey sapote (<i>Pouteria sapota</i>)	1	Trees
Tangerine (<i>Citrus reticulata</i>)	4	Trees
Mexican lime (<i>Citrus aurantiifolia</i>)	1	Trees
Tamarind (<i>Tamarindus indica</i>)	4	Trees
Mango (<i>Mangifera indica</i>)	8	Trees
Avocado (<i>Persea americana</i>)	4	Trees
Jaboticaba (<i>Plinia cauliflora</i>)	4	Trees
Annatto (<i>Bixa Orellana</i>)	4	Trees
Cassava (<i>Manihot esculenta</i>)	50	Trees
Bananas (<i>Musa paradisiaca</i>)	30	Floors
Maize (<i>Zea mays</i>) (only considering 7500 m ²)	3800	Kilograms
Common bean (<i>Phaseolus vulgaris</i>) (only considering 1250 m ²)	120	Kilograms

Variables evaluated. For each species included in the MIAF-INIFAP system, various variables were recorded for both annual crops and fruit trees, including grain and fruit yield (kg ha⁻¹), as well as the number of plants of the analyzed species. Grain yield was estimated from the harvest of the usable area of each plot and its subsequent conversion to units per hectare; fruit yield, on the other hand, was determined considering the total number of productive trees and the species present in the MIAF system.

Determination of Land Equivalent Use. Land Equivalent Use was determined from the yields obtained in monoculture existing in the SIAP, 2024 and SIACON, 2026 databases; as well as the yields of fruit trees and annual crops produced in association in said MIAF system, using the following equation proposed by R. Mead and R. Willey (1980):

$$LER = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$$

Where:

Y_{ab} = yield of crop A in association

And Y_{ba} = yield of crop B in association

Y_{aa} = yield of crop A in monoculture

Y_{bb} = yield of crop B in monoculture



Calculation of Land Equivalent Use (LEU). This index was proposed to evaluate multiple and intercropped cropping systems, and calculated according to the equation mentioned below and interpreted as follows: $LEU \geq 1 \rightarrow$ the intercropping system uses land more efficiently than monocultures; $LEU = 1 \rightarrow$ there is no difference between systems; and $LEU \leq 1 \rightarrow$ monoculture is more efficient.

$$LER = \sum_{i=1}^n \frac{Y_{iA}}{Y_{iM}}$$

where:

Y_{iA} = yield of crop i in association

Y_{iM} = yield of crop i in monoculture

n = number of species evaluated

Partial LER calculation. To interpret the contribution of each species within the association system, partial land use equivalent indices (partial LERs) were calculated, allowing for the analysis of competitive or complementary interactions among the cultivated species, according to the formula presented below. The total LER of the MIAF system was determined by summing the partial LERs of each crop, expressed as $LER = LERA + LERB$ $LER = LER_A + LER_B$ $LER = LERA + LERB$. This indicator allows for the evaluation of the degree of competition or complementarity among the associated crops, as well as the estimation of the system's efficiency in land use.

$$LER_A = \frac{Y_{ab}}{Y_{aa}} \text{ and } LER_B = \frac{Y_{ba}}{Y_{bb}}$$

Where:

Y_{ab} = yield of crop A in association with crop B

Y_{aa} = yield of crop A in monoculture

Y_{ba} = yield of crop B in association with crop A

Y_{bb} = yield of crop B in monoculture

Statistical analysis. The information obtained was organized and processed using the statistical package InfoStat 2022, following the procedures described by Di Rienzo. *et al.* (2020). To evaluate the productive efficiency of the MIAF system, the Land Equivalent (LE) was estimated by calculating the partial values for each of the 16 species included in the system and then the total LE by summing the partial values. The analysis was based on the yields obtained in the MIAF system, as well as the corresponding monoculture yields for each species obtained from the Agri-Food and Fisheries Information Service (SIAP) and the Agri-Food Information Consultation System (SIACON). The results were analyzed descriptively to determine the relative contribution of each system component to the total LE and to evaluate the efficiency of the MIAF-INIFAP system in land use. The index was interpreted considering that LE values greater than 1 indicate greater efficiency of the diversified system compared to monocultures, while values equal to or less than 1 indicate equivalent or lower efficiency, respectively.

RESULTS AND DISCUSSION

Table 2 presents the estimated production of the diversified MIAF-INIFAP system, comprised of 16 species, including fruit trees and annual crops. It also includes three main variables: estimated yield per unit (kg), national yield in monoculture ($t\ ha^{-1}$), and estimated yield in intercropping ($t\ ha^{-1}$) within the MIAF system. The results demonstrate a high diversity of fruit and agricultural species in the evaluated agroecosystem, highlighting the coexistence of perennial and annual species within the same production system, which reflects the complexity and multifunctionality of the MIAF model.

Among the tree species, the sapodilla (*Manilkara zapota*) had the largest number of individuals (216 trees), followed by the Persian lime (*Citrus latifolia*) with 120 trees and the star fruit (*Averrhoa carambola*) with 105 trees. Bananas (*Musa paradisiaca*) numbered 30 plants, while the annual crops of corn (*Zea mays*) and beans (*Phaseolus vulgaris*) yielded 3,800 and 120 kg, respectively. These results demonstrate that the system integrates components of self-consumption and commercial production, promoting productive diversification and the efficient use of agricultural land.

In terms of yield and relative contribution, mamey sapote (*Pouteria sapota*) showed one of the highest values per individual, with 22.21 tons/ha^m in monoculture, although with a low representation within the system (0.10 t/ha^s). Similarly, Mexican lime (*Citrus*



aurantifolia) showed a high unit value in monoculture (24.24 tons/ha⁻¹) but with a limited presence in the MIAF system. In contrast, species such as Persian lime, sapodilla, and starfruit combined greater abundance with significant productive contributions, indicating better adaptation and greater economic relevance within the agroecosystem. On the other hand, maize contributed the largest total production volume (3800 kg in 0.75 ha), reflecting its fundamental role as a staple crop and a strategic component for family food security.

The observed species distribution confirms that diversified systems reduce production and economic risks, as the presence of multiple crops increases the stability of the integrated agroforestry system (MIAF) in the face of climatic and market factors. Several authors indicate that agroforestry and polyculture systems exhibit greater efficiency in the use of resources such as light, water, and nutrients, thus promoting agricultural sustainability (Altieri, 1999). Furthermore, combining fruit trees with staple crops, such as maize and beans, helps maintain soil productivity and improve the income of rural producers (Nair, 1993).

The predominance of tropical fruit species such as sapodilla, starfruit, soursop, and citrus suggests a favorable adaptation to the region's agroecological conditions. This aligns with findings reported by traditional agroforestry systems in humid tropical zones of Mexico, where plant diversity is a strategy for resilience and biodiversity conservation (Jose, 2009). Furthermore, the simultaneous presence of species with different production cycles allows for staggered harvests throughout the year, fostering a steady flow of food and income for farming families. Overall, the results indicate that the evaluated system possesses characteristics of a diversified and multifunctional agroecosystem, where the integration of agricultural and fruit species contributes to both food security and productive sustainability.

In comparative terms, the national yield values reported for monocultures were higher than those obtained in intercropping systems for most of the species evaluated. This difference is expected because in monoculture systems each species occupies the entire available area, while in diversified systems the productive space is shared among multiple species. However, several studies have shown that intercropping systems can exhibit greater efficiency in the use of environmental resources, such as light, water, and nutrients, due to the functional complementarity between species (Willey, 1979).

Table 2. Yield per unit, national yield in monoculture and estimated yield in association of the MIAF system of Axochio, San Andrés Tuxtla, Veracruz made up of 16 plant species (SIAP, 2024; SIACON, 2026).

Species	Amount	Unit of measurement	Estimated yield per unit (kg)	National yield in monoculture (t/ha ⁻¹)	Estimated yield in association (t/ha ⁻¹)
Soursops (<i>Annona muricata</i>)	50	Trees	20	9.29	1.0
Carambola (<i>Averrhoa carambola</i>)	105	Trees	90	6.00	9.45
Sapodilla (<i>Manilkara zapota</i>)	216	Trees	50	16.51	10.8
Persian lemon (<i>Citrus latifolia</i>)	120	Trees	45	16.49	5.4
Mamey sapote (<i>Pouteria sapota</i>)	1	Trees	100	22.21	0.10
Tangerine (<i>Citrus reticulata</i>)	4	Trees	30	16.35	0.12
Mexican lime (<i>Citrus aurantiifolia</i>)	1	Trees	8	24.24	0.008
Tamarindo (<i>Tamarindus indica</i>)	4	Trees	4	7.95	0.01
Mango (<i>Mangifera indica</i>)	8	Trees	100	6.74	0.80
Avocado (<i>Persea americana</i>)	4	Trees	84	10.00	0.33
Jaboticaba (<i>Plinia cauliflora</i>)	4	Trees	15	12.00	0.06

Annatto (<i>Bixa Orellana</i>)	4	Trees	10	1.35	0.04
Cassava (<i>Manihot esculenta</i>)	50	Trees	5	12.10	0.25
Bananas (<i>Musa paradisiaca</i>)	30	Floors	80	20.50	2.4
Maize (<i>Zea mays</i>) (only considering 7500 m ²)	3800	Kilograms	3800	2.28	3.8
Common bean (<i>Phaseolus vulgaris</i>) (only considering 1250 m ²)	120	Kilograms	120	0.81	0.12

National monoculture yield data were obtained from SIAP, 2024. Available at: https://nube.agricultura.gob.mx/cierre_agricola/ ; as well as from SIACON, 2026, available at: <https://www.gob.mx/agricultura/dgsiap/documentos/siacon-ng-161430>

Determination of Land Use Equivalent (LUE) in the Axochio Integrated Agroforestry System (MIAF). This indicator was used to evaluate the productive efficiency of the MIAF system compared to monocultures. This allowed us to determine what proportion of monoculture land area would be needed to obtain the same yield achieved in an intercropping system. The LUE was calculated by dividing the yield obtained in intercropping by the corresponding yield in monoculture for each species. The total LUE of the MIAF system was obtained by summing the partial LUEs of the 16 species evaluated. Therefore, based on the yield values reported in Table 2, the following approximate partial LUEs were obtained (Table 3).

In this regard, Table 3 shows the partial Land Use Equivalent (LUE) values for 16 species established in a diversified agroforestry system of the Intercropped Milpa with Fruit Trees (MIAF) type. The total LUE obtained was 4.83, a value greater than one, indicating that the intercropped system showed greater land use efficiency compared to individual monocultures. According to the LER concept, a LUE value greater than 1 reflects that the intercropped system uses land resources more efficiently, allowing for higher combined yields on the same cultivated area.

The species with the greatest contributions to the UET were maize (*Zea mays*) with 1.67 and starfruit (*Averrhoa carambola*) with 1.58, demonstrating high adaptation and complementarity within the agroforestry system. To a lesser extent, sapodilla (*Manilkara zapota*) with 0.65 and Persian lime (*Citrus latifolia*) with 0.33 also stood out. These results suggest that some species made more efficient use of available resources, particularly light, water, and nutrients.

On the other hand, species such as mamey sapote (*Pouteria sapota*), Mexican lime (*Citrus aurantiifolia*), and tamarind (*Tamarindus indica*) registered values close to zero, indicating a low contribution to the overall system yield. This could be associated with factors such as the young age of the trees, low population density, interspecific competition, or limited adaptation to site conditions. Likewise, maize and beans, traditional components of the milpa, presented values of 1.67 and 0.15, respectively, confirming the importance of these crops in the overall productivity of the system. Furthermore, the high contribution of maize coincides with various studies where this species functions as a dominant component in tropical agricultural associations.

Table 3. Equivalent Land Use determined in the Milpa Intercalada en Árboles Frutales de Axochio system, San Andrés Tuxtla, Veracruz, made up of 16 different species

No.	Species	Amount	Unit of measurement	UET
1	Soursops (<i>Annona muricata</i>)	50	Trees	0.11
2	Carambola (<i>Averrhoa carambola</i>)	105	Trees	1.58
3	Sapodilla (<i>Manilkara zapota</i>)	216	Trees	0.65
4	Persian lemon (<i>Citrus latifolia</i>)	120	Trees	0.33
5	Mamey sapote (<i>Pouteria sapota</i>)	1	Trees	0.00
6	Tangerine (<i>Citrus reticulata</i>)	4	Trees	0.01
7	Mexican lime (<i>Citrus aurantiifolia</i>)	1	Trees	0.00
8	Tamarind (<i>Tamarindus indica</i>)	4	Trees	0.00

9	Mango (<i>Mangifera indica</i>)	8	Trees	0.12
10	Avocado (<i>Persea americana</i>)	4	Trees	0.03
11	Jaboticaba (<i>Plinia cauliflora</i>)	4	Trees	0.01
12	Annatto (<i>Bixa Orellana</i>)	4	Trees	0.03
13	Cassava (<i>Manihot esculenta</i>)	50	Trees	0.02
14	Bananas (<i>Musa paradisiaca</i>)	30	Floors	0.12
15	Maize (<i>Zea mays</i>) (only considering 7500 m ²)	3800	Kilograms	1.67
16	Common bean (<i>Phaseolus vulgaris</i>) (only considering 1250 m ²)	120	Kilograms	0.15
Total, UET				4.83

The total UET value of 4.83 demonstrates a high biological efficiency of the evaluated MIAF system. An LER value greater than 1 indicates that polyculture requires less land to produce the same amount of biomass or yield as separate monocultures (Mead and Willey, 1980; Riley, 1984). Furthermore, Mead and Willey (1980) established that this index is one of the main criteria for evaluating agronomic advantages in intercropped systems.

The high values observed in maize and starfruit suggest ecological complementarity processes between species, particularly temporal and spatial differentiation in resource use. Meta-analytic studies have demonstrated that niche differentiation significantly increases the LER (Resource Extraction Rate) in intercropped systems, due to more efficient capture of light, water, and nutrients (Yu *et al.*, 2015). This result also coincides with research conducted in integrated agroforestry systems in Mexico, where the integration of staple crops with perennial species increases productivity per unit area and improves food security for small-scale farmers. Vidal-Padilla *et al.* (2022) reported agronomic and economic advantages derived from the intensification of milpa (traditional Mesoamerican intercropping) through diversified agroforestry arrangements.

The low contribution of some tree species could be related to their phenological stage or establishment time. In agroforestry systems like MIAF, fruit trees typically exhibit limited yields during the first few years while they develop their vegetative structure and productive capacity (Keesman *et al.*, 2007). Furthermore, competition for solar radiation and space can differentially affect less adapted species (Federer and Schwager, 1982). In this sense, from an agroecological perspective, the results reflect that productive diversification favors system stability and optimizes land use, since several authors indicate that intercropped systems offer ecological advantages related to energy efficiency, nutrient recycling, and resilience to adverse environmental conditions (Riley, 1984; Yu *et al.*, 2015).

Several studies have shown that intercropping systems typically exhibit UET values greater than 1 due to the ecological complementarity between species, which allows for improved utilization of available resources in the agroecosystem (Yu *et al.*, 2015). Furthermore, Brooker *et al.* (2015), in a global meta-analysis, reported that intercropping systems have average UET values greater than 1, confirming the existence of productive advantages derived from crop diversification. Similarly, more recent research has demonstrated that integrating species into intercropping systems can increase nitrogen use efficiency, improve soil nutrient availability, and boost the overall productivity of the agricultural system (Zhang *et al.*, 2023; Dimande *et al.*, 2024). Furthermore, recent studies have shown that diversified systems like MIAF contribute to optimizing land use and improving the efficiency of fertilizer and other productive resource use (Li *et al.*, 2025). In this context, diversified agroecological systems like MIAF have proven to be a viable strategy for improving agricultural sustainability, particularly in tropical regions where traditional systems often integrate multiple plant and animal species.

CONCLUSIONS

The MIAF system evaluated presented a Land Equivalent Use (LEU) of 4.83, demonstrating a high efficiency in the use of the land resource compared to conventional monocultures.

The species with the greatest contribution to the UET were corn and starfruit, which demonstrates processes of ecological complementarity and a better use of resources such as light, water and nutrients within the agroecosystem.



Diversification of fruit species and staple crops within the MIAF system promotes productive sustainability, reduces economic risks, and strengthens food security for rural families in tropical regions.

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