

Agroecological management for the restoration of soil quality

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Abstract

In the Agro-ecological Center “Las Cañadas” located in Huatusco, Veracruz, the agro-ecological management of production systems has been implemented for approximately 20 years, as an alternative to the negative effects caused by conventional agriculture; however, the beneficial effect and the magnitude with which each of these systems has contributed to the restoration of soil quality since its implementation is unknown. In the present work, the current state of the quality of the soil of the different agroecological production systems, as well as of the natural forest through its chemical and physical properties and the diagnosis of the state of soil fertility for crop production, were assessed. Composite soil samples were taken from the ten production systems, as well as from two areas of restored and natural vegetation, to determine their chemical and physical properties, the local inputs used in the fertilizer of the crops were also chemically characterized. In general, ecological production systems; through the addition of local organic matter, minimal tillage of the soil and complementary additions of inputs have contributed to the regeneration of the natural quality of the soil in its chemical properties, but the recycling of nutrients from local inputs is insufficient to cover the nutritional needs of crops for optimal production. Agroecological management has also contributed to the fact that physical properties such as microporosity, usable humidity and stable aggregates have managed to reach the original level in the soil.

Keywords: biointensive management, chemical properties, compost, physical properties.

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Introduction

In the Huatusco Region, shade-grown coffee is predominantly cultivated and extensive livestock farming is practiced for dual purposes, activities that over time have displaced the cloud forest vegetation, reducing the space for endemic flora and fauna, and of the quality of the environmental services that these natural systems provide. Diversified production systems as an alternative to conventional cultivation seek to achieve system resilience; that is, that the socio-ecosystem recovers from the disturbances caused by conventional agricultural practices and harvesting.

In the Agro-ecological Center “Las Cañadas” located in Huatusco, Veracruz, the agro-ecological management of production systems has been implemented for approximately 25 years, as an alternative to the negative effects caused by conventional agriculture. This transformation was based on the principles of closed systems, that is, what is extracted from the soil through production, is returned through the use of organic waste produced in the same system.

In addition, they also consider agroecological pillars (Gliessman, 1998, 2002; Altieri and Nicholls, 2007), that is, diversified low-input systems and organic soil management. Las Cañadas can be considered almost organic, forming a nutrient recycling system with minimal losses. Food production and satisfaction of human needs while maintaining the health of natural resources is the main objective of the Agroecological Center.

La Cañada, therefore, have implemented various production techniques: silvopastoral systems to cover dairy needs, alley cultivation and with little soil tillage for the production of corn, beans and tubers, as well as firewood; biointensive method (John *et al.*, 2006) for the production of vegetables and carbon, edible forest for the production of fruits, seeds, spices, medicinal plants.

These cultivation techniques based on the principles of nutrient recirculation and the conservation of natural resources (Gliessman, 1998, 2002). However, the beneficial effect and the magnitude with which each of these systems has contributed to the restoration of soil quality over 20 years of implementation is unknown. The objective of this work was to assess the current state of soil quality of the different agroecological production systems, as well as the natural forest, through its chemical and physical properties and diagnose the state of soil fertility for crop production.

The importance of evaluating the impact of the afore mentioned technologies will not only provide information on the effectiveness of agricultural practices on soil quality, it will also allow corrective measures to be applied to improve crop productivity. With the purpose of contributing to the well-being of the ecological system from the point of view of food production and to cover human nutritional needs. It will also be an example of a new form of production with low application of disposable external energy that can be replicated in other regions of Mexico for the purpose of restoration and social welfare.

Materials and methods

Site description

Las Cañadas Agroecological Center is located in the municipality of Huatusco, Veracruz, located in the central area of the state on the eastern Sierra Madre, at the geographical coordinates of 19° 09' north latitude and 96° 58' west longitude, at a height between the 1 300 and 1 500 masl. It comprises an area of 306 ha, of which 265 ha are destined for forestry use, the rest for agriculture, a space in which the study agroforestry systems are developed.

The soils are of volcanic origin classified as Andosol mollic + Luvisol chromic, with a frank texture, dark in color, slightly stony and acidic. The relief is steep, rugged and slopes (Rey and Bustamante, 1982; Cisneros, 2000). The climate of the study region is humid semi-warm with an average temperature of 19.1 °C, mean annual rainfall of 1 763 mm (Hernández, 2006).

Description of ecological systems

The production of food and satisfaction of human needs while maintaining the health of natural resources is the main objective of the Agroecological Center, which is why they have implemented various production techniques: silvopastoral systems to meet the needs of dairy, cultivation in alleys and with little tillage of the soil for the production of corn, beans and tubers. As well as firewood, a biointensive method (John *et al.*, 2006) to obtain vegetables and carbon; edible forest for fruits, seeds, spices and medicinal plants.

Table 1 describes the ecological farming systems practiced in the Agro-ecological Center. Likewise, the management history of each production system was recorded (Table 2).

Table 1. Description of the ecological farming systems implemented at the La Cañada Agroecological Center.

No.	System	Years of management	Handled	Crops implemented	Area
1	Misty forest		Without use	Fragment of cloud forest native ecological reserve	30 ha
2	Acahual forest	20	Without use	Secondary native vegetation	
3	Edible forest	10	Zero tillage	Management by islands in which trees, shrubs and herbs are combined: fruit trees (citrus, banana, cocoa, coffee, loquat, macadamia, sapote, tubers, blackberry, blueberry, legumes as nitrogen fixers.	7 442 m ²
4	Corn-Ixcuabil plot	10	Yoke pass	Milpa (corn variety jasmine) interspersed with beans (variety Tlalchete)	2.5 ha

No.	System	Years of management	Handled	Crops implemented	Area
5	Corn-tejocote plot	10	Yoke	Corn variety jasmine, oats (<i>Avena sativa</i> L.) as green manure and live barriers of elder (<i>Sambucus mexicana</i> L.)	2 233 m ²
6	Araucaria corn-bean plot	6	Fallow made with tractor; furrow made with yoke	Corn variety Jasmine bean variety Tlalchete	2.5 ha
7	Alley cultivation Tuber forest	4	Soil without tillage	809 taro plants (<i>Xanthosoma sagittifolium</i>) and cassava (<i>Yuca spp</i>), associated with 60 timbre trees (<i>Acacia angustissima</i> (Mill.) Kuntze) and illites (<i>Alnus acuminata</i> Kunth)	1 500 m ²
8	Biointensive orchard (annual and perennial crops)	19	Biointensive method (rotation and associations)	Spring: pepper, peas, cabbage, gigantón, beans, soybeans, lettuce, sweet potatoes, tomatoes, sorrel, eggplant; summer: peas, peppers, lemon grass, corn, beans, carrots, corn, beans, lettuce, sweet potatoes, gigantón, sorrel, and green tomato; winter: chard, pepper, sorrel, spinach, green beans, gigantón, lettuce, lemon grass, peas and carrots.	548 m ²
9 y 10	Silvopastoral system ² 1 and 2	8	Minimum tillage of the soil	illites (<i>Alnus acuminata</i> Kunth), star grass (<i>Cynodon plectostachium</i>)	10 ha
11	H. B. Gigantón	19	Biointensive method	Giganton cultivation (<i>Thitonia diversifolia</i>) for the production of C for the preparation of composts and addition to the soil in the systems.	304 m ²
12	H. B. King Grass	19	Biointensive method	King Grass cultivation (<i>Penisetum purpureum</i>) as a source of C to produce compost from human excrement.	304 m ²

²= the silvopastoral system;1= was characterized by good forage production; 2= with low forage production.

Table 2. Fertilized made in ecological systems between 2010-2012.

System	Applications								
1 Silvopastoral-1 (kg ha ⁻¹)	Lime dolomite	Phosphoric rock	B	Profer-G14	FeSO ₄	MnSO ₄	CuSO ₄	ZnSO ₄	
	808	500	17	64	42.5	18.2	2.2	30	
2 Silvopastoral-2 (kg ha ⁻¹)	RP	MgSO ₄	B	Profer-G14	MnSO ₄	CuSO ₄	ZnSO ₄		
	500	7.5	17	57.5	11	2.2	32		

System	Applications							
3 Edible forest (g ha ⁻¹)	CaCO ₃	Phosphoric rock	Sulfur	ZnSO ₄	MnSO ₄	CuSO ₄	Boron	
	97.5	305	9.5	9.9	33.9	228.4	3.8	
4 Ixcuabil	Fermented foliar fertilizer 200 L		Phosphoric rock 23 810 kg ha ⁻¹					
5 Tejocote (kg ha ⁻¹)	C- human	Lime dolomite	Phosphoric rock	Sulfur	ZnSO ₄	MnSO ₄	Boron	Fresh oatmeal
	10.1	498.9	226.6	5.7	6.0	24.7	2.8	53 000
6 Araucaria y maize (kg ha ⁻¹)	C- human	Phosphoric rock		Sulfur	ZnSO ₄	MnSO ₄	CuSO ₄	
	767	460		127	76.5	50	28.8	
7 Forest of tubers	Fermented urine 4 662.5 L			Ground bone 6.4 kg ha ⁻¹				
8 Biointensive orchard (kg ha ⁻¹)	C- kitchen	Ground bone	Phosphoric rock	MnSO ₄	Sulfur	Boron		
	78 000	60	0.227	19.3	7.4	2.6		
11 and 12 H. B. Giganton and King Grass (kg ha ⁻¹)	C- perennial crops	Urine human	Ground bone	Phosphoric rock	MnSO ₄	Sulfur	Boron	
	78 000	200 L	60	227	19.3	7.4	2.6	

Micronutrients added as: ferric salts = profer-G14; Fe= profer11-21; B= granubor; Mn= prosulman-C 30% Mn); Zn= prozinc-C(24% Zn); Fe= profer11-21; C-= human compost, kitchen, perennial.

In 2015, composite soil samples (from 15 to 20 subsamples) were collected from the ten production systems; as well as two areas of vegetation, acahual and natural, to determine their chemical and physical properties. Soils were analyzed for the following chemical properties: organic matter (Walkley and Black), olsen extractable P; interchangeable K, Ca and Mg in 1N ammonium acetate neutral pH; S extractable with ammonium acetate 0.05 M NH₄O and determination by turbidimetry; Zn, Cu, Fe and Mn extracted with DTPA, B extracted with CaCl₂ 1.0 M, according to the methodologies described in Alvarez and Marin (2015).

The following physical properties were also determined: texture (Bouyoucos hygrometer), bulk density (test tube method), total porosity, macro and microporosity (Flores, 2010), moisture retention (membrane method); stable water aggregates (sieve method), hydraulic conductivity (permeameter method) according to the methodologies indicated by Elrick and Reynolds (1992) and USDA (1999). The local inputs used in the fertilizer of the crops were also chemically characterized according to the methodologies for the analysis of plant material (Alvarez and Marın, 2015).

Results and discussion

Chemical characteristics of the agricultural inputs used in Las Cañadas

Table 3 shows the concentrations of the elements considered essential for the development of plants in agricultural inputs that are used in La Cañada to fertilize crops.

Table 3. Nutritional composition and pH of the organic inputs used in the Agro-ecological Center.

Origin sample	N	P	K	Mg	Ca	Na	S	Cu	Mn	Zn	Fe	B	pH
	total	%						ppm					
Compost kitchen	1.4	0.28	0.8	0.16	1.02	0.04	0.061	35.5	1453.1	210.6	41088	221.3	7
Compost kitchen	2.2	0.57	1.4	0.46	2.04	0.08	0.142	46	980.3	481.8	21738	64.2	8.2
Compost human	1.9	0.39	1.9	0.28	2.54	0.22	0.072	26.8	395.9	306.1	14463	55.1	8
Compost-perennial crops	1.9	0.26	0.7	0.17	1.1	0.03	0.1	33.5	1484.4	100.1	41575	224.3	6.2
Ash firewood	nd	1.88	6.9	3.17	20.1	0.12	0.064	142.1	1434.6	386.1	4795	553.6	11.4
Burned bone	nd	3.47	0.6	0.61	31.1	2.07	0.053	8.3	184.8	219	2078	31	10.2
Giganton foliage	3.4	0.21	3.7	0.19	0.8	0	0.058	10.4	32.8	35.8	130	40	nd
King Grass	2.6	0.26	4.2	0.17	0.6	0.02	0.1	10	69.5	35.8	226	0	nd
Human urine	1.6	0.01	0.6	0.00	0.05	0.17	0.028	0.9	0.1	0.2	50	3.8	9.3

nd= undetermined.

As can be seen in Table 3, the concentrations of N, P, Ca, Mg and in general of micronutrients in agricultural inputs that are used in La Cañada to fertilize crops, in general, are very low and would require enormous amounts compost to cover the needs of crops. In addition, nutrients such as Ca and P could not be covered, since these in themselves are deficient in the system due to the genesis of the soil and climate conditions.

Agroecological management and changes in the chemical properties of the soil

In the Table 4 shows that with most types of agroecological management, not only has soil resilience been achieved, the original levels of indicated soil chemical properties in the cloud forest have also been exceeded. It can be seen that the pH from being moderately acidic in mature and acahual forest became neutral in the biointensive system, King Grass bed and giganton bed.

Table 4. Chemical properties of the soil in the farming systems of the Agro-ecological Center.

Identification	pH ^z	MO ^y	Ni ^x	P ^w	Ca ^v	K ^u	Mg ^s	SO ₄ ^r	Mn ^q	Fe ^p	Zn ^o	Cu ⁿ	B ^m	CIC ^l
		(%)	(ppm)										(me 100 g ⁻¹)	
Acahual forest	5.6	8.7	23.5	7.3	1206	244	330	33	7.48	84.1	1.92	0.9	0.18	32.8
Interp ¹⁰	ma	m	m	m	m	a	m	a	ad	ad	ad	ba	mb	
Mature forest	5.4	7.4	19.6	1.9	1140	194	261	26	8.1	62.8	1.2	0.8	1.01	35.9
Interp	ma	m	m	b	m	m	m	a	ad	ad	ad	b	b	
Edible forest	6.04	12.5	15.7	2.7	1322	494	358	34	6.4	48.4	3.3	1.1	0.12	34.3
Interp	ma	a	b	b	m	a	m	a	ad	ad	ad	b	b	
Corn-ixcuabil	5.63	11.42	15.7	3.2	1092	494	201	29	1.9	60.2	1.4	1.5	1.37	28.6
Interp	ma	a	b	b	m	a	m	a	ad	ad	ad	b	b	
Corn-Tejocote	5.37	8.7	27.4	4	4728	444	154	93	4.8	70.9	3.1	1.9	0.24	30
Interp	ma	m	m	b	a	a	b	a	ad	ad	ad	b	b	
Corn-Araucaria	5.69	11.92	27.4	5.1	1154	544	247	39	4.64	49.8	2.3	1.9	0.12	31.2
Interp	ma	a	m	b	me	a	m	a	ad	ad	ad	b	b	
Tuber forest	5.68	8.6	19.6	0.8	1268	514	207	53	3.4	73.4	1.9	1	0.54	32.2
Interp	ma	m	b	b	m	a	m	a	ad	ad	ad	b	b	
Biointensive	6.61	9.1	27.4	11.3	2196	954	706	19	8.4	65.9	19.7	2.1	0.06	36.4
Interp	n	m	m	m	a	a	a	a	ad	ad	ad	ad	b	
Pasture-milking 1	5.66	8.3	27.4	3.5	920	494	258	23	20.8	78.6	2.6	1.7	0.72	26
Interp	ma	m	m	b	b	alt	m	a	ad	ad	ad	b	b	
Pasture-milking 2	5.72	10.3	19.6	4	902	424	258	21	68.3	104.6	2.8	1.7	0.12	29.6
Interp	ma	m	b	b	b	a	m	a	ad	ad	ad	b	b	
Kin grass bed	6.06	10.8	27.4	4.3	1158	344	264	26	2.9	37.2	1.3	0.7	0.54	29.1
Interp	ma	m	m	b	m	a	m	a	ad	ad	ad	b	b	
Giganton bed	6.38	4.3	23.5	8.4	2024	774	375	24	5.5	38.4	8.7	1.3	0.06	33.3
Interp	ma	b	m	m	a	a	a	a	ade	ad	ad	b	b	

Extraction with CaCl₂ 1.0 M.; ma= moderately acidic; n= neutral; a= high; b= low; mb= extremely low; ade= suitable; m= medium.

This due to the continuous addition of compost prepared from kitchen waste and ground bone ash resulting in a pH of 7, the application of phosphoric rock in these systems also generates an alkaline effect (Chien, 2003) with the passage of weather. In none of the systems did salt problems appear, which varied in the range of 80.9 μ S in mature forest to 142.3 μ S in the biointensive.

The OM content is an indicator that strongly reflects the effects of management in different systems. The mature forest that can be considered as the witness of the original natural conditions in equilibrium (soil-climate-vegetation), shows an organic matter content of 7.42%, with the different managements throughout approximately 20 years of its establishment, it's have substantially exceeded this content.

This did not occur in the gigantic bed, management with which it has contributed to accelerate the oxidation of native organic matter; these beds are solely for carbon production and aerial biomass is continuously being extracted for use as a carbon source in composting, with almost no return; this system can be illustrative of what happens in the production of a monoculture in a conventional system, with the consequences of exhausting the reserves of organic matter even below the mature forest.

Inorganic nitrogen levels were medium to low. This is to be expected due to the rainfall in the area, which is high (1763 mm per year), which promotes inorganic nitrogen leaching (NH_4+NO_3) even when good management practices are carried out (Stopes *et al.*, 2002). Regarding the availability of phosphorus, with the exception of the acahual forest, biointensive o. and gigantón bed, the phosphorus levels in the soil are low (<5.5-11 ppm).

Depending on the values of iron available in the soil, which far exceed the value considered adequate (> 4.5 ppm), this could be the causal factor of P fixation (Jensen *et al.*, 1992). This limiting factor could be overcome at a mean P level with the management and addition of phosphoric rock plus ground bone in the biointensive system; in the gigantón bed a process of availability may be occurring thanks to the relation of the gigantón (*Thitonia diversifolia*) with the fractions of the fixed phosphorus (Eckert, 1987; Jama *et al.*, 2000).

Those nutrients identified as deficient, in part due to the climatic conditions and genesis of the soil, have been introduced sporadically and in insufficient quantities to cover this need (Table 2). For example, in the corn-araucaria system (Table 2) with the human compost, only 5.8 kg ha^{-1} of MgO would be applied from a corn fertilization need of 29 kg ha^{-1} MgO, in terms of nitrogen deficit it would be 65 kg ha^{-1} .

The fertilization recommendations that were estimated for each production system (not presented in this document), indicate that in addition to local inputs, it must be complemented with external products for better crop performance.

Agroecological management and changes in the physical properties of the soil

In contrast to chemical properties, different agroecological management has been less consistent in restoring the physical properties of the soil to the equilibrium level represented by mature forest. This system presented the highest percentage of porosity, (66.87%) and although it is lower in the rest of the systems, including acahual (Table 5), there is a relationship between the content of organic matter derived from management and total porosity as shown in Figure 1a.

Table 5. Physical properties of the soil in the cultivation systems of La Cañada.

System ^z	Porosity (%)	Porosity (%)		Moisture constants (%)			Da (g cm^{-3})	Aggregates stable (%)	CH (cm h^{-1})
		Microf	Macrof	PMP	CC	HA			
Acahual forest	60.5	51.09	9.42	38.8	54.2	15.4	0.94	77.22	25.1
Mature forest	66.87	45.57	21.3	43.5	57.4	13.9	0.79	70.03	25.7
Edible forest	63.18	52.22	10.96	46.5	64.8	18.2	0.81	76.51	13.1

System ^z	Porosity (%)	Porosity (%)		Moisture constants (%)			Da (g cm ⁻³)	Aggregates stable (%)	CH (cm h ⁻¹)
		Microf	Macrof	PMP	CC	HA			
Corn- ixcuabil	59.05	50.37	8.69	36.7	53.4	16.7	0.94	69.66	12.7
Corn-araucaria	60.85	55.67	5.18	37.3	61.2	23.9	0.91	73.43	8.4
Corn-tejocote	58.75	50.99	7.75	38.2	56.1	17.9	0.91	77.17	21
System. Tubers	59.76	49.8	9.97	38.3	57.8	19.5	0.86	72.83	8.8
Biointensive orchad	60.88	47.75	13.13	41.6	54.4	12.9	0.88	82.08	14.5
Silvopastoral-1	58.83	44.46	14.37	37.2	48.9	11.7	0.91	76.25	78.3
Silvopastoral-2	57.8	50.34	7.45	39.6	54.4	14.8	0.93	73.87	19.9
Giganton bed	59.53	53.82	5.71	41	59.2	18.2	0.91	76.68	13.6
King Grass bed	60.18	57.24	2.94	40.7	64.1	23.4	0.89	62.55	22.5

^z= the loam soil texture for all systems; CH= hydraulic conductivity.

On average, from approximately 7% of OM, porosity increases as its content increases in production systems, as a result of the continuous addition of organic fertilizers, confirming that agroecological management tends to reduce the negative effect due to the change in land use from forest to agriculture (Chauveau *et al.*, 2015).

The total pore space is made up of macropores (*Macrof*) and micropores (*Microf*). The former is responsible for the drainage and aeration of the soil, also constituting the main space in which the roots develop (Prasad and Power, 1997). The mature forest presents the highest macroporosity with a percentage of 21.3 and none of the management conditions has restored this property (Figure 1b).

This effect is also reflected in hydraulic conductivity, where mature and acahual forests maintain the highest values at 25.7 and 25.1 cm h⁻¹, respectively. Studies carried out in systems with tillage and without tillage, show that macro-porosity is the property most affected by cultivation conditions and with it water conduction (Soracco *et al.*, 2012; Dal Ferro *et al.*, 2014).

According to Dexter (1987, 2004) the volume occupied by a root corresponds to a decrease of equal magnitude in the volume of the pore space surrounding the root, the soil adjacent to it is compressed to the minimum possible porosity, which is a constant for a given soil, between this zone of minimum porosity and the body of the soil, the porosity increases exponentially, the distance from the root to which the soil density is affected is proportional to its diameter.

Consequently, continuous cultivation can be said to promote root growth that leads to soil compression (Dexter, 2004), favoring microporosity to the detriment of macroporosity, as observed in all cultivation systems.

Micropores (Microf) are responsible for water retention, part of which is available to plants. With the exception of biointensive o. and silvopastoral, all systems have contributed to increasing the water-holding capacity of the soil in terms of CC and HA (Figures 1c and 1d). This effect is largely attributed to the considerable contributions of organic matter.

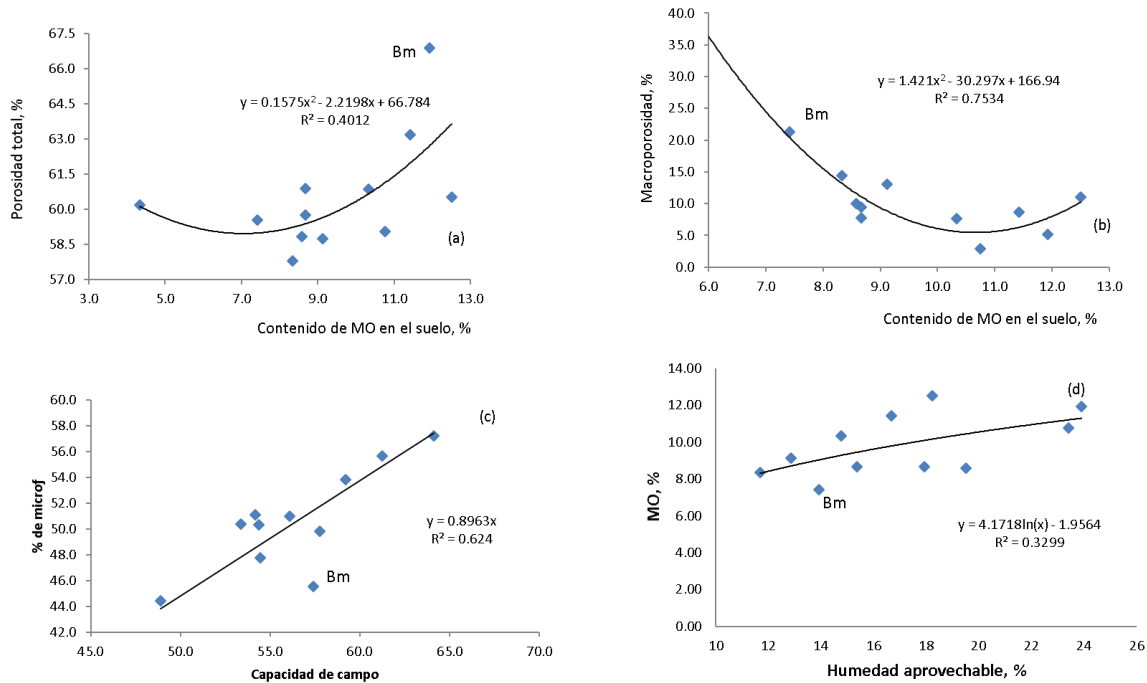


Figure 1. Relationship between organic matter content (OM) and a) total porosity; b) macroporosity; c) field capacity and microporosity; d) OM and usable humidity in different agroecological production systems.

In the form of compost that have also favored the microporosity of the soil (Prasad and Power, 1997), responsible for capillary water (Salcedo-Pérez *et al.*, 2007), which is confirmed by an increase in the stability of aggregates still above of the mature forest (Table 5). Agroecological management of production systems have failed to restore the apparent density to its original level (0.79 g cm^{-3}) of mature forest.

It is important to note that silvopastoral systems 1 and 2 present densities similar to those of the corn crop (0.91 g cm^{-3}), in which the tillage of the soil is very reduced. According to Touchton *et al.* (1989); Dal Ferro *et al.* (2014). From basal area and body weight data, it is possible to estimate that grazing animals apply pressures on the ground in the range between 150 (300 kg steer) and 350 kPa (adult sheep), values notoriously higher than those corresponding to agricultural tractors, which exert pressures of the order of 80 (high flotation tires) to 160 kPa (single radial tires) (Wood *et al.*, 1991).

Consequently, the degree and extent of soil densification are expected to be greater when caused by animals (Sánchez *et al.*, 1989) than by tractors; however, the effect between systems has been similar. The percentage of stable aggregates was higher in the biointensive o. system (82.08%) compared to the value in mature forest (70.03%) and the lowest in King Grass bed (62.55 %).

The OM participates in the formation and stability of the different sizes of aggregates, a process where the maintenance of the level of aggregation depends on the way and the frequency with which the OM is incorporated, in addition to this, the dimension of the soil aggregates would be a function of the size, geometry and mode of deposition of the same (Golchin *et al.*, 1998; Dexter, 2004).

Conclusions

In general, the ecological production systems through the addition of local organic matter, minimal tillage of the soil and complementary additions of inputs have contributed to the regeneration of the natural quality of the soil, but recycling of nutrients from the inputs local, it is insufficient to cover the nutritional needs of crops for optimal production.

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