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DESCRIPTIVE STUDY OF THE CAPACITY OF SIX HILLSIDE SOIL MANAGEMENT SYSTEMS IN THE CONTROL OF SURFACE RUNOFF

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ABSTRACT

On tropical hillsides, torrential rains cause surface runoff that removes soil particles, nutrients and agro-inputs. This process limits soil fertility, agrosystem productivity and the rural economy. A descriptive study was conducted on a hillside in Los Tuxtlas, Veracruz, Mexico, to study water runoff and its runoff coefficients in four modalities of the "milpa intercropped with fruit trees" (MIAF) system, traditional and zero tillage, under rainfed conditions. The systems were established with a systematic design of treatments, without repetitions, between 2003 and 2011: 1) Milpa intercropped in chicozapote (*Manilkara zapota*), with sediment filter and minimum tillage (MIAF-CH-CF-LM); 2) Milpa intercropped with Persian lemon (*Citrus x latifolia*), with sediment filter and minimum tillage (MIAF-L-CF-LM); 3) Milpa intercropped in carambolo (*Averrhoa carambola*), with sediment filter and minimum tillage (MIAF-C-CF-LM); 4) Milpa intercropped in carambolo, without sediment filter and zero tillage (MIAF-C-SF-L0); 5) Zero tillage with crop residue distribution over the surface (Lo); and 6) Minimum tillage with crop residue burning and tracking (LM-QR). From August 2016 to February 2018, a 50 m^2 runoff lot was installed in each system. Surface runoff was measured every 24 h; runoff sheet and runoff coefficient. The MIAF.system reduced surface runoff by 46.13 % with respect to that obtained in LM-QR. The MIAF systems with sediment filter and zero tillage without filter presented similar runoff and runoff coefficient values. The MIAF-CH-CF-LM system recorded the lowest runoff value among systems with tillage and filter. The L0 system showed the lowest volume and runoff coefficient.

Keywords: Zero tillage, MIAF, erosion, chicozapote, lemon, carambolo.

INTRODUCTION

Surface runoff is one of the main factors that give rise to the physical and chemical degradation of agricultural soils through erosion (Díaz-Padilla *et al*., 2012). The climatic pressure typical of tropical regions exposes hillside areas to a degradation process that soon limits their fertility and seriously affects the productivity of agricultural systems. This problem limits current and potential land use and is of utmost importance in countries located in the tropics, as producers insist on colonizing marginal areas located on steep slopes.

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Authors such as Bolaños-González *et al.* (2016) and Porta-Casanellas *et al*. (2014) mention that about 64 % of the Mexican territory is exposed to a process of extreme erosion. In the region of Los Tuxtlas, Veracruz, an agricultural area of 61 160 ha was recorded (SIAP, 2018), of which more than 50% was found located in areas with steep slopes in the municipalities of Catemaco, San Andrés and Santiago Tuxtla. In the same year, in these three municipalities, the most important crop was maize (*Zea mays* L.) with an area of more than 44 000 ha, established in two crop cycles (SIAP, 2020). In the Tuxtlas, plantings are normally established in small production units, with low or no use of external inputs, in marginal or restrictive agroecosystems for agriculture (Bermeo *et al*., 2014). In Nayarit, Mexico, in regions similar to Los Tuxtlas, surface runoff levels lead to erosion rates that exceed allowable limits (Nájera-González *et al*., 2016). This leads to a rapid loss of topsoil and increases the risk that the crop will be affected by drought to the extent of making a hillside unproductive (Camas-Gómez *et al*., 2012).

Apart from the benefits that conservation agriculture has demonstrated in agricultural soils (Friedrich *et al*., 2012; Cadena-Iñiguez *et al*., 2018), some research (Martínez-Esponda *et al*., 2016; Turrent-Fernández *et al*., 2017) considers this technology to be poorly functional in small production units located in hillside areas. Turrent-Fernández *et al*. (2017) proposed as a more suitable alternative to the MIAF system as "it is more compatible with traditional agriculture and its resources, particularly with its native seeds and self-production"; it also reduces surface runoff. For this reason, it is important to evaluate and compare crop management systems that can be implemented in hillside areas of tropical regions, in order to identify those that allow the conservation of water and soil resources, to make these agricultural areas profitable and sustainable.

The objective of this work was to evaluate, by means of a descriptive study, the capacity of four modalities of the MIAF system, the local tillage system and the zero tillage system, to control, under natural precipitation conditions, water runoff caused by surface runoff on a hillside cultivated with corn and fruit species in the Los Tuxtlas Region, Veracruz, Mexico. It is proposed that under the climate and soil conditions that occur in that region, the sediment filters used in the MIAF system reduce surface runoff with respect to the values observed in the traditional system that includes residue burning and minimum soil tillage.

MATERIALS AND METHODS

The study was conducted during the period from 2016 to 2018, in a plot with moderate slope less than 20 %, representative of the hillside agroecosystem, in the region of Los Tuxtlas. The site is located in the locality of Axochío, in San Andres Tuxtla, Veracruz, Mexico (18° 20′ 0.5″ N, 95° 17′ 57.7″ W), at an altitude of 60 m with an AW0 climate, mean annual precipitation of 1720.6 mm and a mean temperature of 27.0 °C (de la Vega-Leinert *et al.*, 2018). The soil is a cambisol with vertic properties of clay loam texture, poor in macronutrients, organic matter and slightly acid pH (6.4).

The systems studied were installed in the field starting in 2003 with a systematic design of treatments, without repetitions, in a total area of 10,000 m^2. In 2003, the following treatments were established: 1) Milpa intercropped with chicozapote *(Manilkara zapota*), with sediment filter and minimum tillage (MIAF-CH-CF-LM); and in 2011, 2) Milpa intercropped with Persian lemon (*Citrus x latifolia*), with sediment filter and minimum tillage (MIAF-L-CF-LM); 3) Milpa intercropped with carambolo (*Averrhoa carambola*), with sediment filter and minimum tillage (MIAF-C-CF-LM); and 4) Milpa intercropped with carambolo, without sediment filter and zero tillage (MIAF-C-SF-L0) In addition, treatments 5) Zero tillage with distribution of crop residues over the surface (Lo) and 6) Minimum tillage with burning of crop residues and a trace (LM-QR) were included.

To reduce compaction of the arable layer, all treatments, except 4 and 5, were plowed once a year, with a single pass of heavy harrowing, during the month of May before the onset of the rainy season. In treatments 1, 2 and 3 the sediment filter was formed with the stubble or pruning products of the fruit trees placed horizontally intertwined in the tree trunks. In 4 and 5, the soil was not plowed at any time and the entire corn stubble produced in the spring-summer and fall-winter cycles was left in the field. In all MIAF systems, the tree canopy was adjusted by pruning to one-third of the total area and the corn crop to the remaining two-thirds. Soil preparation for planting and weed control was done with systemic herbicides (Glyphosate and 2,4-D amine) and desiccants (Paraquat); whereas, in treatment 6, preparation was done by burning crop residues at the end of the crop year and rototilling the soil with a heavy harrow at the beginning of the rainy season.

To evaluate surface runoff in each of the six treatments, a runoff lot (LE) of 2 m wide by 25 m long (50 m2), delimited with 20 cm high galvanized zinc sheeting of 22 caliber (0.8 mm), was installed on the slope. The LE discharged downstream into a screen connected to a triangular section with a sloped floor, which was covered with a canvas, as this area was not included in the LE. This section was connected to a 5.08 cm diameter polyduct, which was buried 20 cm deep to convey runoff to a battery of three 100 L capacity collection tanks (Figure 1). The first tank collected a runoff sample, of which one fifth was sent to a second tank, which captured another sample and sent one eleventh to a third tank.

From August 2016 to April 2017 and July 2017 to February 2018, rainfall data were collected, in the morning, every 24 h, with a pair of 70 mm plastic rain gauges, one located at the top of the hillside and the other at the bottom of the experimental site. The data obtained were grouped by rainfall events and accumulated monthly rainfall. After each rainfall event, the runoff height in the tanks was measured, with which the volume (L) was calculated, the runoff volume (mm) and the runoff coefficient (%) was determined by dividing the runoff volume by the daily precipitation. The volume of water lost in each system was calculated as the cumulative sum of the amount of rainfall lost through surface runoff in each of the systems evaluated. Furthermore, the corresponding percentage was calculated in relation to the rainfall that occurred from August 2016 to April 2017 and from July 2017 to February 2018.

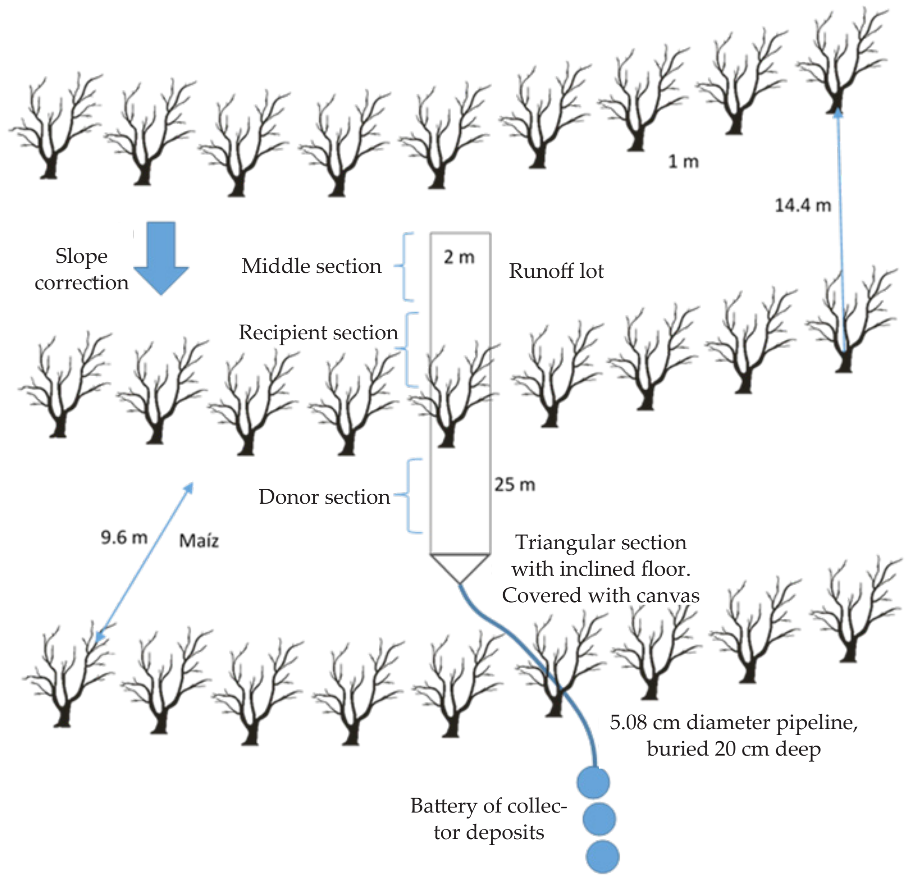

Figure 1. Location of the runoff lot in each of the six management systems studied in hillside soils of the Los Tuxtlas region, Veracruz, Mexico.

The data obtained were concentrated in a spreadsheet to obtain the necessary centralization and dispersion statistics and to be able to describe the capacity of each of the six systems evaluated in the control of surface runoff.

RESULTS AND DISCUSSION

Surface runoff 2016-17 (Q)

In the monthly summary of surface runoff occurred during the period from August 2016 to April 2017, it can be corroborated that the most important surface runoff volumes occurred during the months of August, September and October, coinciding with the wettest months of the year (Figure 2).

Other runoff events of lesser intensity occurred in November, December, March and April. In all cases, the highest Q values occurred in the LM-QR treatment and the lowest in the systems that included zero tillage and distribution of crop residues over the soil surface. The highest value of surface runoff (143.9 mm) was recorded in the

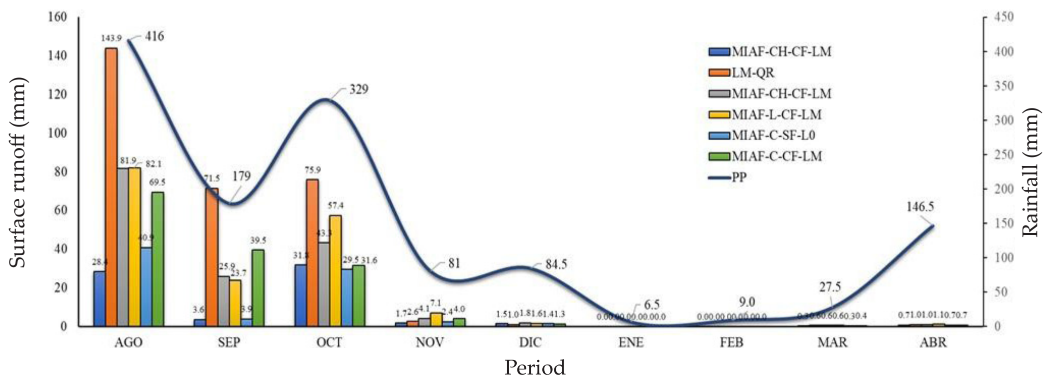

Figure 2. Rainfall and surface runoff recorded at the experimental site from August 2016 to April 2017, in six management systems established on hillside soils in the town of Axochio, municipality of San Andrés Tuxtla, Veracruz, Mexico. L0: Zero tillage with crop residues on the surface; LM-QR: Burning of crop residues and a trace; MIAF-CH-CF-LM: Milpa intercropped in Persian lemon, with filter and a trace; MIAF-L-CF-LM: Milpa interspersed in chicozapote, with filter and a trace; MIAF-C-SF-L0: Milpa intercropped in carambolo, without filter and zero tillage; MIAF-C-CF-LM: Milpa intercropped in carambolo, with a filter and a tracing.

LM-QR treatment during August, the wettest month of the year, with 13 rainy days, of which 11 (84.61 %) resulted in surface runoff of different magnitudes.

In August, on all occasions when rainfall greater than 5 mm occurred, surface runoff was recorded in all management systems. At that time of the year, the corn grown in these plots was in the early flowering stage, so part of the soil surface was not protected by the crop. In October, with a record of 20 rainy days, of which 14 (70 %) caused surface runoff; the crop, close to harvest, and weeds reduced surface runoff.

The runoff sheets recorded during this period ranged from 67.9 to 296.5 mm in the L0 and LM-QR treatments, respectively. On average, the management systems that included the MIAF system had 53% less runoff (139.5 vs. 296.5 mm) than that recorded in the LM-QR treatment equivalent to the traditional maize cropping system in the Los Tuxtlas region (Figure 3). According to González-Cervantes *et al.* (2006), although surface runoff depends on factors such as soil moisture, soil compaction, topography and vegetation cover, the amount and intensity of rainfall is a determining factor, as observed during the first study cycle.

Zero tillage systems stand out for their low runoff values: Lo (67.9 mm) and MIAF-C-SF-L0 (79 mm) since in both cases there was no sediment filter. In these systems, it was observed that crop residues intercepted rainfall before impacting the soil, reduced surface runoff, increased the infiltration rate and consequently reduced soil erosion by interfering with runoff over the entire surface of the land. Similar experiences, related to lower runoff sheet, have been reported in various parts of the world (Llanes-Hernández *et al.*, 2015; Vettorello *et al.*, 2017).

The three MIAF systems with filter that were evaluated presented similar surface runoff values (158.5, 173.6 and 147 mm); their average value was 159.7 mm, which

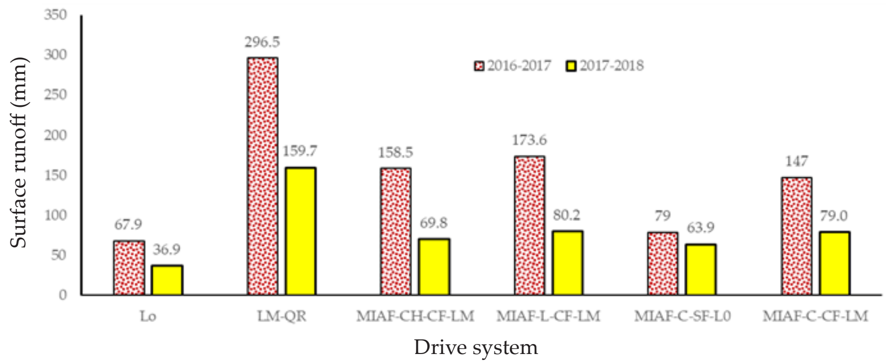

Figure 3. Total surface runoff occurred in the cycle from August 2016 to April 2017 and June 2017 to February 2018 in six management systems established on hillside soils in the town of Axochío, municipality of San Andrés Tuxtla, Veracruz, Mexico. L0: Zero tillage with crop residues on the surface; LM-QR: Burning of crop residues and a trace; MIAF-CH-CF-LM: Milpa intercropped in Persian lemon, with filter and a trace; MIAF-L-CF-LM: Milpa interspersed in chicozapote, with filter and a trace; MIAF-C-SF-L0: Milpa intercropped in carambolo, without filter and zero tillage; MIAF-C-CF-LM: Milpa intercropped in carambolo, with a filter and a tracing.

was 136.8 mm less than that recorded in the LM-QR treatment; that is, the traditional management system recorded a runoff volume that was 85.6 % greater than those observed in the MIAF system.

The total runoff volume (79.01 mm) observed in the MIAF-C-SF-Lo system was 50.2, 54.5 and 46.26 % lower than the MIAF-CH-CF-LM, MIAF-L-CF-LM and MIAF-C-CF-LM treatments, respectively (Table 1). As mentioned in previous paragraphs, the total runoff volume recorded in the MIAF-C-SF-L0 treatment was only comparable to that recorded in the L0 treatment (67.9 mm). Similar results, although not as convincing,

Table 1. Rainwater loss (%) by surface runoff, in reference to the precipitation occurred, from August 2016 to April 2017, in six crop management systems established on hillside soils in the Los Tuxtlas region, Veracruz, Mexico.

Variable	Management system					
	L0	LM-QR	MIAF-CH-CF-LM	MIAF-L-CF-LM	MIAF-C-SF-L0	MIAF-C-CF-L0
Accumulated precipitation (mm)	1204.5	1204.5	1204.5	1204.5	1204.5	1204.5
Lost sheet (mm)	67.9	296.5	158.52	173.61	79.01	147.0
Runoff †	5.64	24.62	13.16	14.41	6.56	12.2

† Percentage of runoff with respect to the total volume of rainfall; L0: Zero tillage with crop residues on the surface; LM-QR: Burning of crop residues and a trace; MIAF-CH-CF-LM: Milpa intercropped in Persian lemon, with filter and a trace; MIAF-L-CF-LM: Milpa interspersed in chicozapote, with filter and a trace; MIAF-C-SF-L0: Milpa intercropped in carambolo, without filter and zero tillage; MIAF-C-CF-LM: Milpa intercropped in carambolo, with a filter and a tracing.

were reported by Camas-Gómez *et al.* (2012) by studying the benefits of the Living Wall Terrace system in a fluvisol with a loamy texture, located on a hillside with a 9 % slope, in the Fraylesca region, Chiapas, Mexico.

The results indicate that in the LM-QR system about 25 % of the rainfall was lost, while in the treatments that included the MIAF system, rainwater loss by surface runoff ranged from 12.2 % in the MIAF-C-CF-L0 system to 14.41 % in the MIAF-L-CF-LM system. The lowest percentages of rainwater loss were 5.64 % in the L0 system and 6.56 % in the MIAF-C-SF-L0 system; in both treatments the soil was not rototilled and crop residues were spread on the soil surface. The LM-QR system recorded a water loss percentage of 24.62 %, which was 120 % higher than the average of the treatments that included the MIAF system (11.58 %).

Runoff coefficient

The lowest coefficients were recorded in the treatments that included zero tillage (L0:0.0341 and MIAF-C-SF-L0: 0.0394) while the highest (0.16) occurred in the LM-QR system (Table 2).

The values obtained in this study for the maize systems with conservation tillage (L0) and MIAF were lower than those observed by Camas-Gómez *et al.* (2012) in a Typic haplustepts with a slope > 30 % and a mean annual precipitation of 1457 mm. Although the topographic and climatic conditions were similar to those recorded in this work, the existing discrepancies in the L0 system (18.6 vs. 3.4) may be attributed to the fact that Camas-Gómez *et al.* (2012) left only 30 % of maize stubble residues (1.3 Mg

Table 2. Runoff coefficients observed in the cycle from August 2016 to April 2017 and July 2017 to February 2018, in six management systems established on hillside soils in the town of Axochío, municipality of San Andres Tuxtla, Veracruz, Mexico.

Managment systems	Observation period	
	August 2016-April 2017	July 2017-February 2018
MIAF-CH-CF-LM	0.084	0.024
MIAF-L-CF-LM	0.097	0.022
MIAF-C-CF-LM	0.112	0.026
MIAF-C-SF-L0	0.039	0.023
LM-QR	0.160	0.069
L0	0.034	0.015
Average MIA^{F†}	0.083	0.024
SD	0.031	0.002

L0: Zero tillage with crop residues on the surface; LM-QR: Burning of crop residues and a trace; MIAF-CH-CF-LM: Milpa intercropped in Persian lemon, with filter and a trace; MIAF-L-CF-LM: Milpa interspersed in chicozapote, with filter and a trace; MIAF-C-SF-L0: Milpa intercropped in carambolo, without filter and zero tillage; MIAF-C-CF-LM: Milpa intercropped in carambolo, with a filter and a tracing. †Includes MIAF systems with filter and trace; SD= Standard deviation.

ha[-1]), which, according to FAO (2000) and Velázquez *et al*. (2002) it may be insufficient to protect the soil from loosening and removal, resulting in a longer exposure time to erosive agents.

Surface runoff 2017-18 (Q)

For this agricultural cycle, the most important surface runoff volumes occurred during September and October; these coincided with the wettest months of the year, which denotes a broad relationship in the levels of precipitation and surface runoff, which generally has a potential and polynomial behavior (Núñez-López *et al*., 2014). Other rainfall events of lower intensity occurred in July and November, resulting in lower runoff levels (Figure 4). Unlike the 2016 cycle, in 2017, August was a dry month and consequently with low surface runoff volume (Q). As in 2016, in all cases the highest Q values occurred in the LM-QR system and the lowest in the systems that included zero tillage and distribution of crop residues over the soil surface (L0 and MIAF-C-SF-L0). The two highest surface runoff values (67.1 and 63.5 mm) were recorded in the LM-QR system in September and October, respectively. It is worth mentioning that both were the two wettest months of the year, and that a total of 33 rainy days occurred during this period, of which 24 (72.7%) resulted in surface runoff of different magnitudes.

In July, precipitation levels greater than 4 mm caused surface runoff in the six management systems studied. At this time of the year, the corn grown in these plots was in the vegetative stage of development, so the soil surface was not yet fully protected by the crop. In dry soil conditions (September), there was surface runoff only on days with rainfall greater than 14 mm; at this time of the year the maize, at

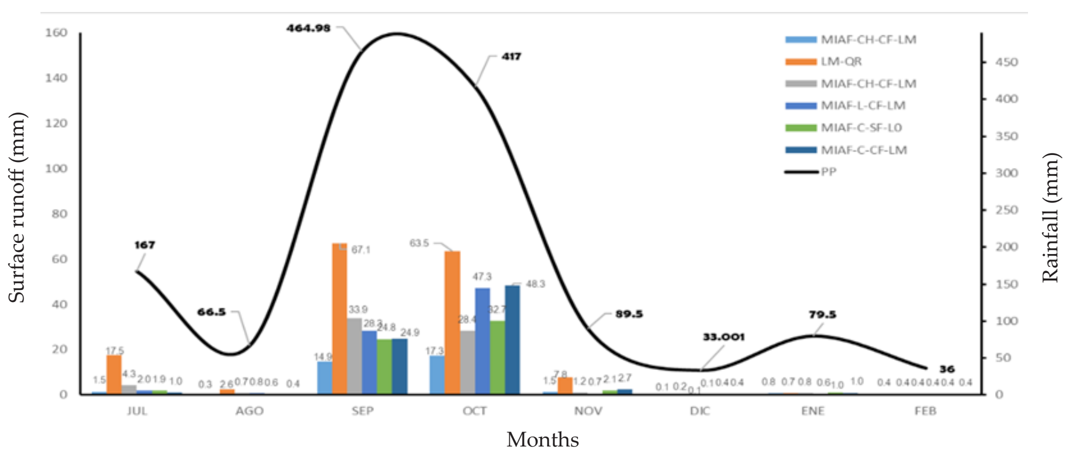

Figure 4. Surface runoff occurred monthly in the cycle from August 2016 to April 2017, in six management systems established on hillside soils in the town of Axochio, municipality of San Andres Tuxtla, Veracruz, Mexico. L0; Zero tillage with crop residues on the surface; LM-QR: Burning of crop residues and a trace; MIAF-CH-CF-LM: Milpa intercropped in Persian lemon, with filter and a trace; MIAF-L-CF-LM: Milpa interspersed in chicozapote, with filter and a trace; MIAF-C-SF-L0: Milpa intercropped in carambolo, without filter and zero tillage; MIAF-C-CF-LM: Milpa intercropped in carambolo, with a filter and a tracing.

the grain filling stage, and the weeds present between the rows reduced the impact of rainfall and surface runoff.

Total surface runoff sheets recorded in the July 2017 to February 2018 cycle ranged from 36.9 to 159.7 mm in the L0 and LM-QR treatments, respectively (Figure 3). For this case, the trend observed in the 2017-18 cycle was preserved. The management systems that included the MIAF system with filter and minimum tillage presented a runoff sheet that varied from 69.8 to 80.2 mm, with a mean 52.2 % lower (76.3 vs. 159 mm) than that registered in the LM-QR treatment, equivalent to the traditional maize cultivation system used in the hillside areas of the Los Tuxtlas region. The difference observed between these treatments is practically the same as that recorded for the 2016-17 cycle (53.0 %).

As was the case in the 2016-17 cycle, the two zero-tillage systems stand out for their low runoff values: L0 (36.9 mm) and MIAF-C-SF L0 (63.9 mm), where the sediment filter was not included and crop residues were placed on the soil surface. The importance of organic residues in the process of reducing surface runoff was discussed in previous pages and technically supported by the work of Llanes-Hernández *et al.* (2015) and Vettorello *et al.* (2019).

During 2017, the total runoff volume recorded in the MIAF-C-SF-L0 system, was slightly lower than that obtained in 2016 (63.9 vs. 79.0 mm); however, in 2017, the absolute differences of this treatment with respect to the other three MIAF systems evaluated were appreciably lower with values of 8.45, 20.32, 19.11 % for the MIAF-CH-CF-LM, MIAF-L-CF-LM and MIAF-C-CF-LM systems, respectively. Although 2017 was a wetter year than 2016, the difference between the mean of the three MIAF systems with filter and minimum tillage with respect to the value obtained in the MIAF system without filter and zero tillage was much lower (15.96 vs. 50.32 %); if this trend is maintained, it is feasible to hypothesize that, in the long term, it may be the same to spread crop residues on the soil surface as to concentrate these residues in a sediment filter.

Regarding the volume of water lost by surface runoff in each of the six management systems, and the percentage of water loss with respect to the total rainfall occurred from July 2017 to February 2018, the results indicate that in the LM-QR system, 11. 8 % of the rainfall occurred, while in the treatments that included the MIAF system the rainwater loss by surface runoff ranged from 4.7 % (MIAF-C-SF-L0) to 5.9 % (MIAF-L-CF-LM). The lowest percentages of rainwater loss were 2.7 % in the L0 system and 4.7 % in the MIAF-C-SF-L0 system; in both systems the soil was not disturbed and crop residues were spread on the soil surface (Table 3).

Runoff coefficient

For this cycle also the lowest coefficients were recorded in the treatments that included zero tillage (L0 = 0.015 and MIAF-C-SF-L0 = 0.023) while the highest (0.069) was in the LM-QR treatment (Table 2). The values obtained in this cycle for the L0 (0.015) and MIAF (mean: 0.024) were also lower than those observed (0.186 and 0.12, respectively)

Table 3. Rainwater loss (%) by surface runoff, with reference to the precipitation occurred, from July 2017 to February 2018, in six crop management systems established on hillside soils in the Los Tuxtlas region, Veracruz, Mexico.

Variable	Managment system					
	L0	LM-QR	MIAF-CH-CF-LM	MIAF-L-CF-LM	MIAF-C-SF-L0	MIAF-C-CF-L0
Accumulated precipitation (mm)	1353.5	1353.5	1353.5	1353.5	1353.5	1353.5
Lost sheet (mm)	36.9	159.7	69.8	80.2	63.9	79.0
Runoff (%)†	2.7	11.8	5.2	5.9	4.7	5.8

†Percentage of runoff with respect to the total volume of rainfall; L0: Zero tillage with crop residues on the surface; LM-QR: Burning of crop residues and a trace; MIAF-CH-CF-LM: Milpa intercropped in Persian lemon, with filter and a trace; MIAF-L-CF-LM: Milpa interspersed in chicozapote, with filter and a trace; MIAF-C-SF-L0: Milpa intercropped in carambolo, without filter and zero tillage; MIAF-C-CF-LM: Milpa intercropped in carambolo, with a filter and a tracing.

by Camas-Gómez *et al.* (2012) in a Typic haplustepts with a slope > 30 % and a mean annual precipitation of 1457 mm. Although the topographic and climatic conditions were similar, the existing discrepancies in the L0 system (0.186 vs. 0.015) may also be due, as cited previously, to the fact that Camas-Gómez *et al.* (2012) left only 30 % maize stubble residue (1.3 Mg ha^{-1}) on the soil surface.

Joint analysis of the 2016-17 and 2017-18 cycles.

Although the management systems and cropping patterns were the same in the two agricultural years studied, the distribution, amount and intensity of rainfall varied slightly. For this reason, the values observed in each of the six management systems for the surface runoff and runoff coefficient variables may vary from one year to another; however, patterns of behavior are expected to indicate the trend followed by both variables in each of the treatments.

According to the results presented in Table 4, if we take as a reference the traditional management system, with reduced tillage and burning of crop residues, per hectare, the MIAF system decreased the volume of surface runoff 46.13 % by reducing the volume of water runoff from 228. 1 (±96.8) to 118.02 (±59.0) mm; that is, under the conditions in which the experiment was conducted, in an agricultural year (PV + OI), the MIAF system was able to infiltrate the soil and consequently retain within the agrosystem up to 110 L of water per square meter. This increased water capture is an important factor in areas where annual rainfed crops are established due to the current trend of climate change that implies lower humidity and higher temperatures. The fact that the MIAF significantly reduces surface runoff indicates that the system is capable of contributing to a substantial reduction in erosion processes, nutrient runoff and agrochemical molecule leakage. Furthermore, by reducing the surface

Table 4. Average values obtained in the six management systems for the variables volume and runoff coefficient in the 2017 and 2018 cycles in hillside soils cultivated with corn in the region of Los Tuxtlas, Veracruz, Mexico.

Managment system	Surface runoff			Runoff coefficient		
	2016	2017	mean	2016	2017	Mean
L0	67.9	36.9	52.4	0.034	0.015	0.024
LM-QR	296.5	159.7	228.1	0.160	0.069	0.114
MIAF-CH-CF-LM	158.5	69.8	114.2	0.083	0.023	0.053
MIAF-L-CF-LM	173.6	80.2	126.9	0.096	0.021	0.059
MIAF-C-SF-L0	79.0	63.9	71.4	0.039	0.023	0.031
MIAF-CF-LM	147.0	79.0	113.0	0.112	0.026	0.069
Mean[†]	159.7	76.3	118.0	0.097	0.023	0.060

L0: Zero tillage with crop residues on the surface; LM-QR: Burning of crop residues and a trace; MIAF-CH-CF-LM: Milpa intercropped in Persian lemon, with filter and a trace; MIAF-L-CF-LM: Milpa interspersed in chicozapote, with filter and a trace; MIAF-C-SF-L0: Milpa intercropped in carambolo, without filter and zero tillage; MIAF-C-CF-LM: Milpa intercropped in carambolo, with filter and one tracer; [†]Includes MIAF systems with filter and one tracer.

runoff process, the water infiltration process is proportionally increased, which favors crop development, the reserve of subway aquifers and the development of soil fauna (Regüés-Muñoz *et al.*, 2012).

Similarly, runoff coefficients imply losses of 6.0 % (±5.0) in the MIAF system, while in the Traditional System losses can total up to 11.47 % (±6.0) of the total rainfall that caused runoff. In this case, the lower runoff values in the MIAF system should be attributed to the presence of the sediment filter placed in the row of fruit trees, while the higher values observed in the traditional system (LM-QR) are justified by the lack of soil protection against the erosive effect of rainfall, since in this system all crop residues and weeds were burned.

The characteristic of the MIAF system of retaining a greater amount of moisture in the sediment filter, located upstream of the row of fruit trees, gives rise to a zone of high microbiological activity, with high mineralization rates, rich in nutrients and organic matter; this zone, in the mid-term, will have the capacity to allow the development of vigorous trees with a high productive capacity. Two years after its implementation, the L0 system, with distribution of crop residues on the soil surface, stands out as the treatment with the lowest average runoff volume (54.4 mm; ±21.9) and the lowest runoff coefficient (2.4 %; ±1.0). A similar, but greater, behavior was also observed in the MIAF-C-SF-L0 system, which has a similar management system, although it was implemented more than 7 years ago, which could justify a greater compaction of the topsoil and therefore greater surface runoff.

Between the MIAF systems that included the sediment filter and zero soil tillage, no differences were found in the averages of both variables (Table 4). Among the three treatments studied, the lowest value (5.3 %; ± 4.0) corresponded to the MIAF-CH-CF-

LM, which is possibly due to greater stability of the system since it is seven years older than the other MIAF systems included in the trial.

CONCLUSIONS

The milpa system intercropped with fruit trees reduced surface runoff by 46.13% with respect to the runoff values obtained in the traditional system with minimum tillage and burning of crop residues. Between the systems that included the sediment filter and zero soil tillage, no differences were found in average surface runoff and runoff coefficient. Of the three systems of milpa intercropped with fruit trees with tillage and sediment filter, the lowest value corresponded to the system with chicozapote, filter and minimum tillage. The zero tillage system with crop residue distribution on the soil surface had the lowest runoff volume and runoff coefficient.

REFERENCES

Bermeo A, Couturier S, Galeana-Pizaña M. 2014. Conservation of traditional smallholder cultivation systems in indigenous territories: Mapping land availability for milpa cultivation in the Huasteca Poblana, Mexico. Applied Geography 53: 299–310. https://doi.org/10.1016/j.apgeog.2014.06.003

Bolaños-González MA, Paz-Pellat F, Cruz Gaistardo CO, Argumedo Espinoza JA, Romero Benítez VM, de la Cruz Cabrera JC. 2016. Mapa de erosión de los suelos de México y posibles implicaciones en el almacenamiento de carbono orgánico del suelo. Terra Latinoamericana 34 (3): 271–288.

Cadena-Iñiguez P, Camas-Gómez R, López-Báez W, López-Gómez H del C, González-Cifuentes JH. 2018. El MIAF, una alternativa viable para laderas en áreas marginadas del sureste de México: caso de estudio en Chiapas. Revista Mexicana de Ciencias Agrícolas 9 (7): 1351–1361. https://doi.org/10.29312/remexca.v9i7.1670

Camas-Gómez R, Turrent-Fernández A, Cortes-Flores JI, Livera-Muñóz M, González-Estrada A, Villar-Sánchez B, López-Martínez J, Espinoza-Paz N, Cadena-Iñiguez P. 2012. Erosión del suelo, escurrimiento y pérdida de nitrógeno y fósforo en laderas bajo diferentes sistemas de manejo en Chiapas, México. Revista Mexicana de Ciencias Agrícolas 3 (2): 231–243. https://doi.org/10.29312/remexca.v3i2.1459

de la Vega-Leinert A. Brenner L, Stoll-Kleemann S. 2018. El café de sombra: ¿una alternativa viable para campesinos en regiones marginadas? El caso de la reserva de la biosfera Los Tuxtlas, México. *In*: Conocimiento, ambiente y poder. Perspectivas desde la ecología política. El Colegio de San Luis, A.C.: San Luis Potosí, México, pp: 235–25. https://www.researchgate.net/publication/337021584_El_cafe_de_sombra_una_alternativa_viable_para_campesinos_en_regiones_marginadas_El_caso_de_la_reserva_de_la_biosfera_Los_Tuxtlas_Mexico (Recuperado: junio 2021).

Díaz-Padilla G, Sánchez-Cohen I, Guajardo-Panes R, Barbosa-Moreno F, Gómez-Cárdenas M, Uribe-Bernal J. 2012. Modelación espacial de la producción de agua superficial de lluvia en la zona sur del estado de Puebla, México. Tecnología y Ciencias del Agua 3: 69–84.

FAO (Organización de las Naciones Unidas para la Agricultura y Alimentación). 2000. Manual de prácticas integradas de manejo y conservación de suelo. Boletín de tierras y agua de la FAO No. 8. Roma, Italia. https://www.midagri.gob.pe/portal/download/pdf/ais-2015/manual-pract-integradas.pdf (Recuperado: junio 2021).

Friedrich T, Derpsch R, Kassam A. 2012. Overview of the Global Spread of Conservation Agriculture. Field Actions Science Reports 2012 (6): 1941.

González-Cervantes G, Estrada-Ávalos J, González-Barrios JL, Cueto-Wong JA, Sánchez-Cohen I, Castillo-Santillán G. 2006. Análisis de los factores que afectan la relación precipitación-escurrimiento en una zona semiárida del norte de México. Terra Latinoamericana 24 (3): 337–345.

Llanes-Hernández JM, Cabrera-Carcedo E, de la Nuez-Hernández E. 2015. Influencia de la agricultura de conservación sobre el suelo y el cultivo del tabaco en San Juan y Martínez, Cuba. Revista Avances 17 (4): 318–326.

Martínez-Esponda FX, Benítez-Keinrad M, Ramos-Pedrueza-Ceballos X, García Maning G, Bracamontes Nájera L, Vázquez Quesada B. 2016. Informe sobre la pertinencia de biocultural de la legislación mexicana y su política pública para el campo. El caso del programa "modernización sustentable de la agricultura tradicional (MasAgro). Centro Mexicano de Derecho Ambiental, A.C.: México. https://www.cemda.org.mx/publicaciones-y-estudios-del-cemda/informe-sobre-la-pertinencia-biocultural-de-la-legislacion-mexicana-y-su-politica-publica-para-el-campo/ (Recuperado: julio 2021).

Nájera-González O, Bojórquez-Serrano JI, Flores-Vilchez F, Murray-Núñez RM, González-García-Sancho A. 2016. Water erosion risk and soil loss estimation in volcanic geomorphological landscapes of Mexico. Cultivos Tropicales 37 (2): 45–55. http://dx.doi.org/10.13140/RG.2.1.3942.5527

Núñez-López D, Treviño-Garza EJ, Reyes-Gómez VM, Muñoz-Robles CA, Aguirre-Calderón OA, Jiménez-Pérez J. 2014. Uso de modelos de regresión para interpolar espacialmente la precipitación media mensual en la cuenca del río Conchos. Revista Mexicana de Ciencias Agrícolas 5 (2): 201–213. https://doi.org/10.29312/remexca.v5i2.960

Porta-Casanellas J, López-Acevedo M, Poch-Claret RM. 2014. Edafología uso y protección de suelos (4a edición). Mundi-Prensa: Madrid, España. 624 p.

Regüés-Muñoz P, Serrano-Muela MP, Nadal-Romero E, Lana-Renaul N. 2012. Análisis de la variabilidad temporal de la infiltración en un gradiente de degradación de usos del suelo en el Pirineo Central. Cuaternario y Geomorfología 26 (2): 9–28.

SIAP (Sistema de Información Agroalimentaria y Pesquera). 2018. Estadísticas de la producción Agrícola 2016. Secretaría de Agricultura y Desarrollo Rural. México. https://datos.gob.mx/busca/dataset/estadistica-de-la-produccion-agricola (Recuperado: abril 2021).

SIAP (Sistema de Información Agroalimentaria y Pesquera). 2020. Estadísticas de la producción Agrícola 2020. Secretaría de Agricultura y Desarrollo Rural. México. http://infosiap.siap.gob.mx:8080/agricola_siap_gobmx/ResumenProducto.do (Recuperado: abril 2021).

Turrent-Fernández A, Cortés-Flores JI, Espinosa-Calderón A, Hernández-Romero E, Camas-Gómez R, Torres-Zambrano JP, Zambada Martínez A. 2017. MasAgro o MIAF ¿Cuál es la opción para modernizar sustentablemente la agricultura tradicional de México? Revista Mexicana de Ciencias Agrícolas 8 (5): 1169–1185. https://doi.org/10.29312/remexca.v8i5.116

Velázquez GJJ, Salinas GJR, Potter KN, Gallardo VM, Caballero HF, Díaz MP. 2002. Cantidad, cobertura y descomposición de residuos de maíz sobre el suelo. Terra Latinoamericana 20 (2): 171–182.

Vettorello CI, Clemente JP, Esmoriz GF, Díaz CC, Cotorás DA, Molina L, Cotés L. 2017. Prácticas de conservación para la reducción de inundaciones. AUGM DOMUS 5: 37–52.