International Research Journal of Agricultural Science and Soil Science (ISSN: 2251-0044) Vol. 2(7) pp. 267-275, July 2012
Available online http://www.interesjournals.org/IRJAS

Full Length Research Paper

Rainfall simulation to evaluate erosion and hillslope runoff in two agricultural management systems in central Mexico

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Abstract

Lake Patzcuaro extinction is being caused by the prevalent hillslope agricultural system. Conservation tillage is an alternative to reduce erosion and runoff in hillslope agriculture. The aim of this work is to demonstrate that conservation tillage reduces runoff and soil losses, as well as identify erodability and infiltration parameters under rainfall simulation. Simulation was carried out in Patzcuaro lake watershed. Rainfall simulation was performed in two runoff plots, conservation tillage (CT) and conventional tillage (TT) under dry and wet soil conditions. Rill (Kr), interill erosionability (Ki), shear (τ) and critic shear stress (τ_c), and hydraulic conductivity (Ks) were computed for the two treatments. Results indicated that erosion parameters are directly related to erosion susceptibility, TT was higher susceptibility (Ki= 1,262,608 kg s m^{-4}; Kr= 0.08 sm^{-1}; τ_c=1.3 Pa) than CT (Ki= 2,552 kg s m^{-4}; Kr= 0.0002 sm^{-1}; τ_c=2.1 Pa). Hydraulic conductivity was higher in CT Ks=82.8 (dry), and Ks=64.4 mm/h (wet), than TT 48.6 (dry) and 55.2 mm/h (wet).

Keywords: Watershed management, no tillage, rainfed maize, infiltration, erosion parameters.

INTRODUCTION

Soil erosion is widely recognized as a major threat to agriculture production, particularly in less developed countries, where it not only degrades the land and reduces food production but also harms the economy by reducing income and increasing poverty.In fact soil erosion is the firs step to land degradation that eventually can lead to collapse of societies (Fisher, 2005). Approximately 80% of the world's agricultural land presents moderate levels of erosion (Jara et al., 2009). It can also have serious offsite effect. Intense rainfalls and soil detachment from hillslope lands could cause human casualties and economic injuries (Sánchez et al, 2011). The potential for soil erosion and runoff water losses are highly dependent of rainfall intensity and slope gradient (Boer and Puigdefabregas, 2005). This problem also damages Mexican field due to practicing steep slope rainfed agriculture (McAuliffe et al., 2001). Mexico loses one million hectares per year of forests affecting hydrological cicle and natural resources (Oropeza et al., 2002). Climatic change caused for deforestation has increased 0.4 °C of mean temperature and rainfall intensity in Central México (Tapia et al, 2011). Some endorreic Mexican lakes have disappeared like Chalco, Zumpango, Cuitzeo, etc. and others like Xochimilco, Zirahuen, Chapala and Patzcuaro are constantly losing water surface due to soil particles ingressions on the water. The prevalent rainfed agriculture management involves intense soil movement in maize production system, and the topographic conditions enhance sediment outlets to the bottom of the endorreic watershed: the lake. However, local knowledge on land management has demonstrated

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that soil erosion and fertility depletion can be handled and agriculture could remain sustainable over centuries (Barrera-Bassols and Zinck, 2003).

Farmers of the Patzcuaro watershed are used to till practices, since the colonial era (Fischer et al., 2003). These practices along the hillslope soils promote runoff and sediment yields rates up to 3.5 ton/ha per year (Bravo et al., 2005b). Most rainfed agricultural lands (35,000 ha), sown with maize receive intensive rain events of 82 mm hour^{--1} or upper when most of the maize field still has less than 70% of cover ground (Tiscareno et al., 2004). This rainfall intensity causes soil detachment and runoff increases off-site impacts, and these particles may eventually get the lake. Suspended or settled soil particles are causing lake eutrophication and serious problems for aquatic life where some species are unique (white fish Chirostoma estor, Jordan, and achoque Ambystoma dumerilii Jordan) (Orbe-Mendoza et al., 2002). The transportation of minerals and organic matter by surface flow becomes easier with deforestation. This flow increases nutrient inputs to the lake, promoting a massive bloom of diatoms (A. Granulata and Stephanodiscus sp.). Ingressions of 0.48 mg/l of phosphorous have been measured by Bradbury, (2000), causing the eutophication of the lake.

Interrill (Di) and rill detachment (Dr), are related to how susceptible are the soils to erosion (Romero et al., 2007). Conservation tillage is a practice that increases water infiltration (Dimanche and Hoogmoed 2002), whereas continuous soil tillage reduces saturated hydraulic conductivity (Poulenard et al., 2001). Soils minerolgy and texture may influence infiltration rates and soil losses (Wakindiki and BenHur, 2001). The top residue soil cover in conservation tillage increases soil organic matter which generates better soil structure and aggregate stability (Salinas-García et al., 2002). Soils of Patzcuaro watershed are weakly structured and easily disaggregated by water. Rainfall simulation research in rangelands of Patzcuaro watershed was made to obtain Ki and Kr parameters (Bravo et al 2005a, Bravo et al 2006), but the agricultural lands are the most important surfaces susceptible to erosion (Tapia-Vargas et al., 2001), and the hydraulic conductivity of this soils has not been described in alterantive soil managements. The aim of this work is to demonstrate that conservation tillage reduces runoff and soil losses, as well as identify erodability and infiltration parameters of each tillage method under rainfall simulation.

MATERIALS AND METHODS

The experimental site was at Ajuno, located in the lake of Patzcuaro watershed. This Experimental Station belongs to the National Forestry Livestock and Agricultural Investigations Institute of Mexico (INIFAP), placed at km 17.5 of the toll highway Patzcuaro-Uruapan. The climate is CW_2 which means tempered subhumid with a rainfall season from June to October. Annual mean precipitation is 990 mm with usually dry and cold winter. Soils are mainly derived from volcanic ashes at most Patzcuaro watershed. The soil of the Experimental Station is Hydric Hapludand (Alcalá et al., 2001)

Rainfall simulation

In the experimental sites rain simulation was performed on the two treatments, conservation tillage (CT) and traditional tillage (TT). It was utilized the variable intensity rainfall simulator operated with a solenoid (Miller, 1987). The rainfall simulator (Figure 1), works with a 110 VAC that activates an engine with an arrow, which in each cycle activates and deactivates the electrical switchers of the solenoid valves, that in the close-open fast cycle regulates the spray water flux from the nozzles constructed within the solenoid, producing an intermittent form of rainfall to the preconstructed 1*1 m and 1*3 m plots. Residue and litlle stones were removed outside the plots, grass and other little plants were clipped just above of the soil. Water to simulator is supplied by an electrical water pump, 0.75HP, 110 VAC, with a volume of 0.0007 m^3 s^{-1}. Water energy is controlled by a valve conected to a manometer, which is usually set at 0.29 MPa; flux intensity generally is controlled by the engine speed or the water energy (Miller, 1987).

The simulation was performed on dry and wet soil (after 24 hours) with two replications in different places of the same treatment. Initial conditions were similar to both treatments although in CT the volumetric soil water was 30% higher. Previously, simulator was calibrated to apply rainfall intensity from 95 to 120 mm/hr, for the two-contrastant treatments, was measured with pluviometers during 85 minutes. This rain intensity is the maximum reported rain intensity in the Patzcuaro watershed (Tiscareno et al., 2004). Database was obtained from the evaluated variables: Runoff (l and mm), and soil losses (g) on samples taken every 5 minutes of simulation, but peak runoff discharge (l min^{-1}) and time to runoff (s) was registered one time in the two replications. Soils losses were weighted to obtain the output of sediments rate (g s^{-1}).

Rill detachment

On previously wet soil, an increasing flow from 5 to 35 l min^{-1} was applied on the upper limit of each tillage treatment in the simulation plot just as was explained by Villar et al., 1999. Each flow was individually applied until a steady flow was reached, which was invariable accomplished between 6 to 8 minutes of application. When the steady flow was reached, a 1.0 liter water sample was taken; measuring the time of filling and

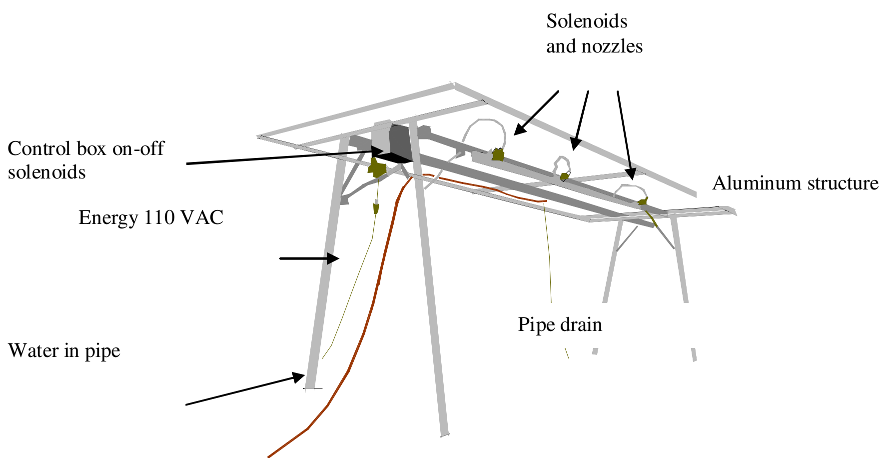

Figure 1. Rainfall simulator solenoid operated utilized in experimental plots

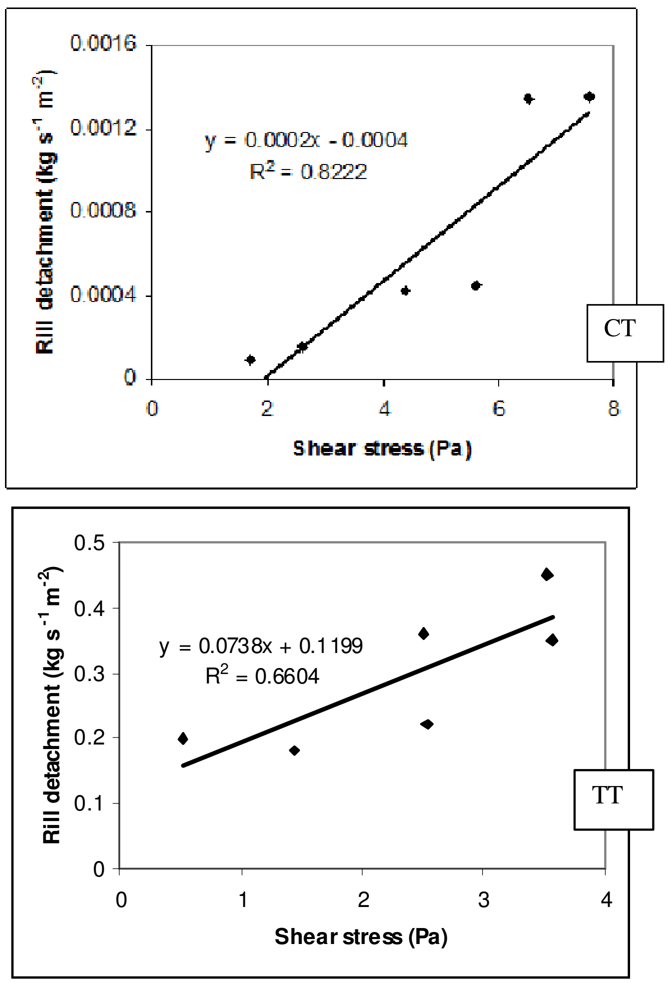

Figure 1. Rill detachment coefficient (*Kr*), in two soil management treatments of Patzcuaro watershed.

evaluating the sediments produced in the flow; at the same time the flow width, depth and speed was taken. With this information the hydraulic radius of the flow for each flux was determined with the section area and wet perimeter relationship. For all flow levels, the pair of shear stress data (τ) and the discharge of sediments where adjusted by linear regression using the following expression:

$$Dr = \tau_c + Kr\,\tau \quad (1)$$

Where:

Dr = Rill Detachment (kg s^{-1} m^{-2})

τ = shear stress (Pa), obtained with the expression for uniform flow (Haan et al., 1994) the shear stress is due for:

$$\tau = Rh * S \quad (2)$$

Where:

Rh = rill hydraulic ratio (m)

S = rill slope (ad.)

τ_c = critic shear stress (Pa)

Kr = rill detachment (s m^{-1})

According to Elliot et al., (1989), the slope of the regression is the value of the rill detachment coefficient (Kr), while the critic shear stress (τ_c) is the quotient of the regression constant and the slope ($\tau_c = -a/b$).

Interill detachment (Di)

The effect of constant rainfall simulation on the considered tillage treatments was evaluated for each sampling time, to obtain the interill detachment coefficient (Ki) with the expression:

$$Di = \frac{Ki}{I^2 S_f} \qquad \text{(kg s m}^{-4}\text{)} \qquad (3)$$

Where:

D_i = interill detachment rate (kg s^{-1} m^{-2})

I = rainfall intensity (m s^{-1})

S_f = slope factor (ec. 18)

The ratio of interill detachment coefficient (Ki) was obtained during rainfall simulation, directly from the runoff by sampling at equal times (5 minutes), measuring the filling time of the sampling container and computing the intensity of the rainfall period. Graphics for each treatment were obtained to calculate Kr and to compute the Di value as well as the values of the different variables (τ,τ_c, Dr). Tillage effects on each treatment were compared with the magnitudes reported by Elliot et al., (1989) for some simulations sites in U.S.A. and Mexico (Villar, 1999).

Infiltration model adjustment

Data of the runoff and rainfall ratio of the simulation events were processed to calculate the Hillel (1980), model parameters which present, under no saturated conditions, the following form:

$$I = a\sqrt{t} + bt \quad (4)$$

I = accumulated infiltration (mm h^{-1})

t = acumulated time (h)

a y b= regresion coefficients

Under saturated conditions the model becomes to:

$$I = a + b\,t \quad (5)$$

Infiltration rate is obtained from

$$\frac{dI}{dt} = \frac{b}{\sqrt{t}} + a \quad (6)$$

when t tends to infinite the limit of accumulated infiltration (4) and infiltration rate (6), is :

$$\lim \frac{dI}{dt} = \lim_{t\to\infty}\left[\frac{b}{\sqrt{t}} + a\right] = a \quad (7)$$

where a is the steady state infiltration or saturated hydraulic conductivity. Notice that this expression is the same as the limit of the infiltration rate. The derivation of the saturated infiltration equation (5), yields:

$$\frac{dI}{dt} = \lim_{t\to\infty}\left[\frac{bt + a}{dt}\right] = b \quad (8)$$

Where b is a steady state of hydraulic conductivity when $t \to \infty$.

The steady state hydraulic conductivity in both soil management treatments can be compared to detect significative differences, the statistic t parameter is:

$$t = \frac{a_1 - a_2}{\sqrt{Sp\left[\frac{1}{SS_1}\right] + \left[\frac{1}{SS_2}\right]}} \quad (9)$$

with:

$$Sp = \frac{MSE_1 - MSE_2}{2} \quad (10)$$

Where:

a_1 and a_2 = regression parameters for CT and TT equations respectively.

SS_1 and SS_2= square sum for regression model

MSE_1 y MSE_2 = mean square error equations with n-2 + n-2 degrees of freedom

RESULTS AND DISCUSSION

Rainfall Simulation Results

Hidrological variables of rainfall simulation on both soil management treatments are presented in Table 1. The differences are evident: TT yielded more runoff and soil erosion than CT. A big difference is observed in soil losses with 18,800 g m^{-2} in TT versus 410 g m^{-2} in CT. The worst effect occurs under wet soil where both runoff and soil losses are 100% higher than dry soil. These results verify previous works that found major soil erosion susceptibility of this andisols under wet soil conditions (Tiscareno et al.,

Table 1. Evaluated hydrological variables of two soils till managements in the Patzcuaro watershed.

Treatment	Soil loss ($g\ m^{-2}$)	Sediment concentration ($g\ l^{-1}$)	Peak runoff Discharge ($l\ min^{-1}$)	Time to runoff (s)
Dry simulation				
Traditional till	18,820 (±2424)	347 (±99.1)	2.32 (±0.4)	731 (±53.5)
Conservation till	410 (±154)	2 (±0.78)	0.74 (±0.05)	485 (±69)
Wet simulation				
Traditional till	35,491 (±6415)	333 (±95.5)	1.74 (±0.11)	310 (±25.5)
Conservation till	441 (±113)	7 (1.5)	0.76 (±0.06)	393 (±22)

Notice: Numbers among parentheses are standard error

Table 2. Rainfall simulation results in two soil management treatments.

Treatment	Interill detachment ($g\ s^{-1}m^{-4}$)	Rainfall ($mm\ h^{-1}$)	Total runoff (mm)
Dry			
Traditional till (TT)	3.61 (±0.26)	111.6 (±6.2)	69.9 (±6.4)
Conservation till (CT)	0.01 (±0.005)	119.4 (±6.0))	25.9 (±7.5)
Wet			
Traditional till (TT)	7.0 (±1.05)	101.2 (±7.7)	100.1 (±11.8)
Conservation till (CT)	0.1 (±0.05)	124.1 (±6.5)	60.3 (±6.0)

Notice: Numbers among parentheses are standard error

2004). Sediment concentration and peak runoff discharge were also higher in TT than CT in both soil conditions. Sediment concentration is low in CT with only 2 g l^{-1} while in TT is plentiful with 347 g l^{-1} these results reflect that streams outgoing from these agricultural lands could improve its quality by implementing CT as was shown by Kogelman et al., (2006). It is remarkable that time to runoff was higher in dry soil condition in TT than in CT. This could be caused by lower soil humidity content in TT than in CT.

The measured soil loss from TT was significantly and linearly correlated with storm runoff. The relationships under dry and wet soil respectively, were expressed by:

Soil loss = 30.4 (runoff)** + 5.95 r^2= 0.61

Soil loss = 35.1 (runoff)** + 86.3 r^2= 0.67

The response of sediment concentration respect the discharge rate in TT soil management under dry and wet soil simulation was:

Sediment conc. = 24.9 (discharge)* + 5. 13 r^2= 0.38

Sediment conc. = 81.3 (runoff)** –65.9 r^2= 0.94

The same relationship was obtained for CT treatment, on dry and wet conditions:

Sediment conc. = -0.46 (discharge) + 0.27 r^2= 0.15

Sediment conc. = 1.45 (runoff)* – 0.37 r^2= 0.38

(*) and (**) regression coefficient is significant p≤ 0.05 and p≤ 0.01, respectively.

The expressions reflect the difference of each treatment to reduce soil losses and runoff, and clarify the problem of soil loss, intensified when soil is wet. Values of regression coefficient in TT are larger in wet soil (a=86.3; b=35.1) than in dry soil (a=5.9; b=30.4), just this quantification should alert about problem seriousness. Although not well correlated in CT, the correlated low values of regression coefficients indicate that soil losses are reduced on both wet and dry soil.

Nowadays, climatic change has provoked intense rainfalls until 250 mm in 24 hours on July (Tapia et al., 2011). Furthermore, first precipitations on June moisten the soil fastly. Subsequent rainfalls on July enhance soil erodability because soil is wet and rainfall has great kinetic energy, more than 1000 MJ mm ha^{-1} h^{-1}. This energy is dissipated by soil detachment due to the fact that crop cover is still less than 30% (Tiscareno et al., 2004). This effect is causing huge sediments output from hillslope agricultural lands.

Interill detachment (Di)

The results of rainfall simulation are presented in Table 2. The difference between the two soil management systems is clear with respect to interill detachment rate (Di) and runoff (Q), CT yielded 0.01 g s^{-1} m^{-4} and 25.9 mm while TT yielded 3.61 g s^{-1} m^{-4} and 69.9 mm, of Di and Q, respectivlely. Jimenez et al., (2006), suggest that

Table 3. *Ki* and Kr parameter values for the two tillage treatments in Patzcuaro watershed.

Parameter	Soil till management treatment		Soil from USA[1]	Soil from Chiapas[2]	Rangeland Patzcuaro
	Conservation till	Traditional till			
Dry Condition					
Ki (kg. s m^{-4})	2,552.0	1,262,608.0	1,170,000.00	2,901,000.00	407,216
Kr (s m^{-1})	0.0002	0.080	0.0031	0.0043	0.0022
τ_c (Pa)	2.1	-1.3	0.24	2.7	3.5
Wet Condition					
Ki (kg. s m^{-4})	19,271	3,113,579.0			979,650

Source: [1]Norton y Brown (1992). [2] Villar *et al.,* (1999).). [3]Bravo *et al*, (2005a)

undisturbed Andisols are considered to be highly stable and resistant to water erosion, CT promotes undisturbed soil but TT implies soil movement that facilitates soil detachment. This performance explains that CT had lower erosion rate under continuous rainfall, when compared to a continuously tilled soil. Undisturbed soil in this region improves its stability which holds more water and helps to reduce the runoff and the transport of detached sediments, contrary to TT. Also, Q is enhanced in TT under dry simulation while CT had lower value, meaning that 63% of the applied water was infiltrated into the soil. Hence, is clear that CT is able to increase water infiltration and to reducing Q from hillslope lands.

Soil movement caused by TT elevates soils susceptibility to rill erosion. Norton and Brown (1992) demonstrated that as the time passes, younger tillage produced higher detachment among rills than the old tillage. This may explain what is occurring in the productive units of the watershed, where the continous movement of the soil with TT promotes soil vulnerability to rill erosion, which is the first detachment factor leaving the soil susceptible to be removed if the flow among rills has enough capacity to transport it out of the plots.

This problem happens in these disturbed soils like the ones in the hillslopes at the Patzcuro watershed, which can be seen in the rainfall simulation results (Table 2). This soil is highly sensible to interill detachment with 3.61 g s^{-1} m^{-4} (dry) and 7.0 g s^{-1} m^{-}4 (wet), so sediments detached will be available to be transported out of the plot by the rill flow. The difference between the dry and wet rainfall simulation was quite noticeable. In absolute terms CT treatment shows how the soil reaches detachment stability with 0.01 g s^{-1} m^{-4} (dry) and 0.1 g s^{-1} m^{-4} (wet). It was expected that when the soil is wet it should present a lower erosion rate, as was demonstrated by Simmanton et al., (1988) and Meyer and Harmon (1992) who found a higher transport of sediments in dry rainfall simulation conditions (94.8 Mg ha^{-1}), than in wet simulation (33.3 Mg ha^{-1}). In Andisol soils of Patzcuaro, it was found that the detachment was higher in wet soil with high maginitude of Di, meaning more harmfull in the steady wet condition of the rainfall season.

Rill detachment (Dr)

Values for the Ki and Kr parameters are shown in Table 3. Rill erosionability information from soils of similar texture from USA(Laflen et al., 1991, Norton and Brown 1992), Chiapas (Villar et al., 1999 and Pátzcauro (Bravo et al., 2006) are presented, the found values are by its magnitude, consistent with here evaluated (1170 x $10^{\cdot3}$ kg. s m^{-4} and 939 x $10^{\cdot3}$ kg. s m^{-4} in USA sandy soils, 2,901 x $10^{\cdot3}$ kg. s m^{-4} in Chiapas and 407.2 x $10^{\cdot3}$ kg. s m^{-4} in Patzcuaro rangelands, against 1,293 x $10^{\cdot3}$ kg. s m^{-4} here observed). Meanwhile, the parameter values differ considerably in CT with just 2.5 x 10^{3} kg. s m^{-4}. Under wet simulation CT increased to 19.2 x 10^{3} kg. s m^{-4} and TT increased to 3,113 x 10^{3} kg. s m^{-4}. Soils under this condition lacks protection to reduce raindrops impact which produce high Ki values only comparable to the higher ones found by different authors in the most erodible soils of the USA (Elliot et al., 1989, Norton and Brown, 1992).

Linear adjustment for the rill detachment data, (Dr) obtained from increasing flow simulation plots for the TT and CT, are presented in table 3. As it could be appreciated there is a contrasting behavior between the rill detachment obtained with CT and TT in huge proportions. While in the CT Dr Rates are of the order of 0 to 1.5 g. m^{-2} s^{-1}, in TT rates start in more than 100 to 500 g. m^{-2} s^{-1}. This clearly shows the superiority of CT in reducing the rill erosion and lowering the production of sediments than the TT. These effects were obtained in equal inflow conditions, indicating that soil protection by conservation till is very important to reduce erosion, and rill and interill detachment.

This unequal response is also partly due to the less required critic shear stress (τ_c) to produce high rates of detachment in TT. Differences between treatments may be detected through the difference in the required values to produce rill erosion shown in both x axe of the Figure 1.

Although both soils belong to the same site, it seems like the CT soil is more mature and consolidated as was corroborated by Norton and Brown (1992), when they evaluated the erosion differences in two soil types. This

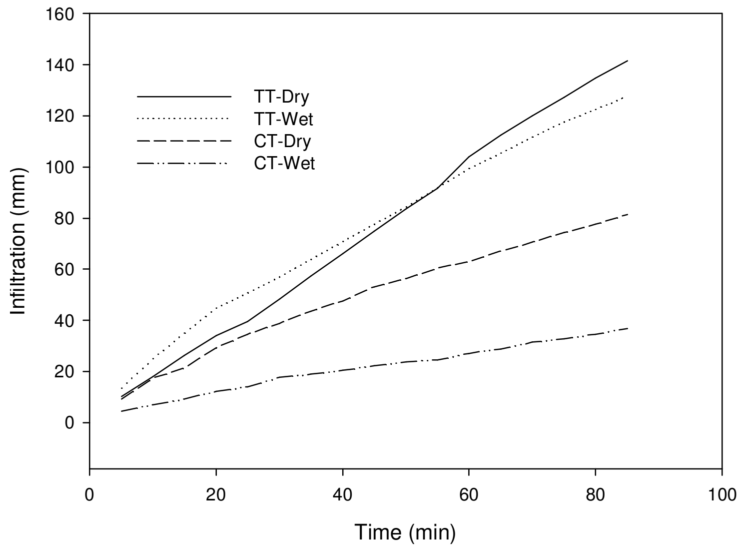

Figure 2. Accumulated infiltration (I), in dry and wet soil in two soil managements, traditional till (TT) and conservation till (CT), of Patzcuaro watershed.

may indicate that CT conferees better soil properties, according to the Dr obtained values, make it to behave like more evolved and consolidated soil.

The obtained parameter values of Kr in dry and wet sandy soils are higher in TT than those registered in CT. The Kr parameter is the slope of the equation between Dr and shear strees data and its magnitude reflected in CT (2.0×10^{-4} s m^{-1}) a consolidated soil condition instead the value of TT (830 x 10-4 s m^{-1}), that is a soil susceptible to erosion, agree with Bravo et al., (2006), whose evaluated Kr (0.5 x 10-4 s m^{-1}), for soil rangeland defined as consolidated soil. This results suggest that in hillslope soils of Patzcuaro watershed, should not be tilled and the farmers should utilize the application of CT practice with vegetal and clipping weeds residues, to improve soil consolidation.

Referring to the critical shear stress in rills (t_c), the measured CT= 2.1 Pa and TT= -1.3 Pa is clearly contrasting. Soil in TT had so low stability that value of critic shear stress to initiate detachment is negative. The necessary energy to detach particles is too low in TT. Although, when comparing the values of the two treatments, this characteristics pointed out that a bigger energy was required in CT to initiate sediment detachment than the energy required in TT to begin the same phenomena (Figure 1). Both CT and TT are lower in both treatments to those reported in Chiapas (2.7 Pa) and Bravo et al (2006) (3.5 Pa). This means that less effort is required to detach soil particles.

Infiltration model adjustment

Hillel model infiltration curve (I) for the rainfall simulation in Ajuno for both treatments (CT and TT) is drawn in Figure 2. At the beginning of the simulation (first five minutes), infiltration rates are high for both treatments; however CT has the capability to maintain high infiltration rates, while TT quickly diminished the soil infiltration capacity. This phenomenon is directly related with the runoff of both treatments. This means that if one treatment provides bigger infiltration rate, which is the case of CT, runoff will be limited and maintained low. Also, typically erosion increases with decreasing infiltration (Jiménez et al 2006). As it was expected, steady state infiltration was obtained at 0.58 hours of simulation, but under wet condition this situation was reached earlier, at 0.48 hours in both treatments (Figure 2).

CT treatment increases substantially the infiltration rate, from the beginning of the precipitation and maintains a high rate during all the simulation time. On these data it can be observed that conventional tillage (TT) does not maintain the high infiltration rates shown at the beginning of the precipitation, and this promotes runoff and sediment transportation by the flow and a detachment of higher particles occurs. CT treatment maintains high infiltration rates, reduces runoff and the effects on erosion are inverse to those of TT. This increasing of infiltration rates shown in CT was also registered by Zhang et al., (2007), who found that CT increases infiltration rates due surface

Table 4. Hidraulic conductivity (K_s) statistic comparison in two system management soils under rainfall simulation

Treatment	K_s	SS	EMS	t_c
Dry				
Traditional till (TT)	48.6	6316.2	0.79	2,011.8**
Conservation till (CT)	82.8	9484.5	1.36	
Wet				
Traditional till (TT)	22.2	1,170.9	0.24	1,050**
Conservation till (CT)	64.4	13,949.1	2.92	

SS: regression square sum, EMS: error mean square, t_c : t computed $p\leq$ 0.01 (*), $p\leq$ 0.05 (**), respectively.

soil porosity is enhanced.

In this analysis the importance of the hydraulic conductivity magnitude (K_s) is directly related to the treatment capacity to admit a bigger precipitation rate and it can be infiltrated faster into the soil profile. CT presents a higher K than the TT, indicating that it can support higher precipitation rates due to its infiltration capacity, which reduces runoff (Table 4).

Differences found in the K_s values during rainfall simulation may be directly attributed to soil management treatment. As it is argued by Jasso (1997), the soil consolidation may be altered by the tillage method. In this study case CT has improved the soil structure and consequently has increased its infiltration capacity. This improvement could be made through the development of greater porosity in the top soil zone of CT which promotes an increase in infiltration rates (Rhoton et al., 2002).

Dry and wet simulation allowed knowing K_s differences for the two-soil management methods. This evaluation indicates the superiority of non tillage management to produce higher K_s values in both dry and wet conditions. CT behaves like an authentic sponge that can absorb higher precipitation rates and maintains a high disproportion with respect to TT, which is higher more than 100% in dry condition and more than 200% in wet condition. This differential is what allows CT to show a uniform behavior, maintaining higher infiltration rates throughout the storm, while TT rapidly reduces K_s which is reflected in lower infiltration rates and an early start of runoff.

Infiltration rate analysis also permited detecting differences between treatments. Table 4 shows the better performance of CT treatment by allowing water flow trough the soil with 82.8 mm/hr under dry condition and 64.4 mm/h under wet condition, compared with those obtained by TT with only 48.6 mm/h and 22.9 mm/h in respectively under dry and wet conditions.

Statistic analyses to Ks values detected highly significant differences between both treatments. Hydraulic conductivity registered in CT is different from that obtained in TT under dry (t_c= 2,011.8), and wet (t_c=1050.1) conditions. In both cases CT was significantly different of TT ($p\leq$ 0.01). This indicates that CT acquires better soil structure and adequate soil aggregation to improve soil infiltration capacity.

CONCLUSIONS

Rainfall simulation showed that traditional tillage produced more runoff than conservation tillage. Hence interill detachment is higher in TT than in CT. Also, all the erodability parameters like erodability coefficient and erosionability coeffcien are higher in TT than in CT. Meanwhile, hydraulic conductivity parameter was 290% higher in CT than TT. This allowed making comparisons among the evaluated parameters magnitudes as well as knowing what causes the conventional treatment to be susceptible to produce high rates of runoff and sediment.

The application of the erosionability parameters quantified in this work can be used to represent hydrological events in the Patzcuaro watershed hillslope agriculture. This represents certain advantages with respect to the empirical parameters in representing the hydrological process that occurs in the soil management treatments. With the application of the erosion parameters farmers and technicians may obtain a significant advantage in the comparison of the soil erosion process. Conventional tilled hillslope agriculture land is the main source of sediments that are diminishing the Patzcuaro lake water storage capacity. Fortunately, the amount of sediment left by the production unites may be located, forecasted and reduced with conservation tillage. However, this study requires further research to better document the alternative soil management with the use of complementary hydrological files for future truly modeling.

ACKNOWLEDGEMENT

The authors are grateful to the Consejo Nacional de Ciencia y Tecnología- México, which supported this research project. Also, Dr. Oussama Mounzer for his assistance. To Teresa and Mariana (In memoriam).

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