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Functional relationships of Soil Organic Carbon loss and water erosion in arid watersheds of Central North of Mexico

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***Abstract*— Land degradation is a severe problem that has been reported in most soils of the world; the loss of Soil Organic Carbon (SOC) is a serious risk that threatens the good quality of soil. In Mexico the 25.4% of total land degradation is caused due to soil erosion by water which implies loss of SOC. This research was developed in the municipality of Santo Domingoin the state of Durango, Mexico;the objective was to find a functional relationship between SOC and soil erosion and runoff that can be used for further modelling purposes.To accomplish this objective, we established a crop of maize and we evaluated sixteen experimental units in the field.In each of them,rainfall simulationswere performedunder both wet and dryAntecedent Soil Moisture Conditions (AMC). The results have shown that the relationships among variables are explained ($r^2 \geq 0.90$)by linear and exponential models. Specifically the relationship among runoff and SOC is explained in 98% by a logistic model. This model fits better the behavior of SOC loss process depending upon runoff since that intuitively the phenomenon follows a growth model.**

***Keywords*—modelling, rainfall simulation, soil degradation, maize.**

I. INTRODUCTION

The cost of soil erosion is about US$ 400 million up to US $44 billion annually in different countries around the world. Those costs are the result of erosion on and off site, for example, in agriculture the tillage practices cause the breakdown of soil structure and finally the loss of Organic Matter (OM)and Soil Organic Carbon (SOC), which is an important indicator of soil health [1], [2].

The erosion damage is mainly depending of the characteristics of the extreme rainfall and the consequences occurred in the field. The most important effect is the loss of nutrients and soil. There are reports of up to 0.4-0.5 m deep sediment mobilized, causing an important loss of N (Nitrogen), P (Phosphorus) and OM [3]. Some reports suggest that Soil Organic Carbon (SOC) loss is affected by erosion processes because of a linear relationship between SOC loss and erosion intensity (soil loss) found in different soil types, with high correlation coefficients [4]. The macroaggregates are separate and distributed into microaggregates by raindrop impact, and release organic carbon (OC) at the same time. In addition, SOC is transported by runoff in both dissolved organic carbon (DOC) and big or heavy particles deposited in micro-depression during the migration lane [5]. The SOC loss increased with an increase in erosion intensity, which is a function of the amount of soil loss

People have tried to model erosion but their results are imperfect or site specific, that interfere with proper soil conservation strategies in arid lands. Those necessary actions are required to protect the soil integrity and fertility. Intensive agriculture is increasing as population the same as food demand and those practices are generating an important soil loss [6].Therefore, soil fertility is getting loss as a consequence of erosion process.

Land degradation in Mexico is about 1.3 millions of km^2, which represents 70% of whole territory; the most important component of land degradation is soil erosion by water with 25.4%. This country as part of United Nations Convention to Combat Desertification (UNCCD) since 1994 has contributed to strong the promotion of strategies to mitigate land degradation such several laws stablished about the theme [7].

According to the background written in last paragraphs, we establishedas the objective of current research to find a functional relationship between SOC and soil erosion andrunoff that can be used for furthermodelling purposes.

II. Materials and methods

A. Study Site

The selection of the study site was made by a typology of soil conservation practices as well as a characterization of soil texture, organic matter and slope in agricultural lands. An experimental plot was established with seasonal crop of maize in the locality of Santo Domingo at 25° 49' 41.94" north latitude and 104° 26' 18.97” west longitude, under an arid climate (BWhw, BSohw). The annual average temperature is 18°C, with a range of 14 to 22°C and approximately 200 to 400 mm ofrainfall per year. The soil type is Leptosol. The sowing took place on September 11 and 12, also it was replanted on September 26, 2015, toobtain a density of 68000 plants per hectare.

The dimensions of every experimental unit were three meters wide and five meters long. In each experimental unit was isolated a surface of one by three meters with smooth galvanized sheets, in the lower part of each plot a metal structure was placed to concentrate the superficial drains. The soil loss was inducted by rainfall simulations carried out with Miller simulator [8] that is showed in Figure 1. The rainfall simulation was performed from November 11 to 16, 2015, under twoAntecedent Soil Moisture Conditions (AMC),wet (8% to 10% of moisture)and dry (0.9% to 4% of moisture).

Fig. 1. Rainfall simulator.

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B. Rainfall simulation and sediment sampling

The simulator worked with a portable power plant of 5500 watts, which generates an energy of 110 VAC, the water was applied to the runoff plots by a spray nozzle of 360°, the pressure was controlled with the use of 3 manometers each one controlling the flow of each sprinkler. The simulator worked in an average intensity of 94.80 mm/h.

The rainfall simulation was developed at each experimental unit, with a duration of 35 minutes, sediment samples were collected in1L plastic containers, every 5 minutes; the sediment samples were filtered to obtain only the soil particles, once dry, the organic carbon content was determined by an elemental analysis with LECO instrument.

C. Statistical analysis

The variables of study were Soil Organic Carbon (SOC), soil loss and runoff; these data were analyzed statistically by a correlation analysis and the selection of a fitting model using the Table Curve 2D trial version 5.0 software.

III. RESULTS AND DISCUSSION

Selected models are shown in Table I, the first two rows show SOC as dependent variable of runoff and soil loss and in third row the soil loss is considered as dependent variable; in addition, the relation between data is illustrated in Figures 2 to 4. The sigmoid curve equation (1) describes SOC behavior both wet and dry conditions, then the equation (4) refers to the soil loss under wet condition only. Equation (2) is a linear fitting for SOC as dependent variable of soil loss in wet condition; the same variables but under dry condition are represented by equation (3), that is a power regression model. The exponential equation (5) describes soil loss behavior during runoff under dry soil condition.

TABLE I: PROPOSEDFUNCTIONS FOR MODELLING SOIL ORGANIC CARBON AND SOIL LOSS.

Variables	Model	AMC	Parameters a	b	c	d	r^2
x = Runoff y=SOC	$y = \frac{a+b}{1+exp\left(-\frac{x-c}{d}\right)}$ (1)	Wet Dry	1.534 1.489	26.869 267.159	98.764 104.895	4.892 8.075	0.98 0.88
x = Soilloss y = SOC	$y = a + bx$ (2)	Wet	0.031	0.023			0.98
	$y = a + bx^{0.5}$ (3)	Dry	-1.845	0.570			0.94
x = Runoff y = Soil loss	$y = \frac{a+b}{1+exp\left(-\frac{x-c}{d}\right)}$ (4)	Wet	71.436	986.3	96.984	3.954	0.98
	$y = a + bx + cexp^x$ (5)	Dry	-1.238	1.943	1.095e-31		0.90

AMC= Antecedent Soil Moisture Condition; SOC= Soil Organic Carbon.

The sigmoid function has an "S" shape and three sections: first, a slow growth rates at the bottom, second, a sharply rising line and third, it starts a horizontal asymptote. As seen on Figures 2 and 4 both SOC and soil loss increase slowly at the beginning, then, the data have a rapid change toward the top, finally, the points seem to lie down especially under wet antecedent soil moisture conditions. The behavior is not evident in dry conditions probably due to that in dry conditions, the soil is still prone to continuing releasing SOC.

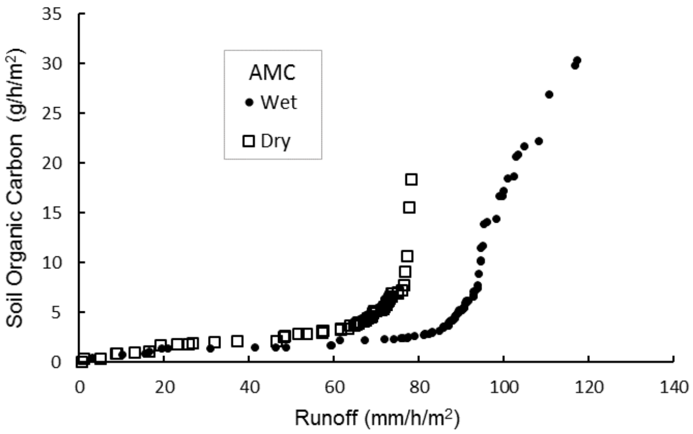

Fig. 2. Scatter diagram of relation between Soil Organic Carbon and Runoff during rainfall simulation.

The fitting linear equation in second row of Table I shows that SOC increases 0.023 g/h/cm^2 for 1 g/h/cm^2 of soil loss under wet AMC. On the other hand, we selected a power regression for modelling the same variables but under dry AMC because it describes a slightly curved linewhich make statistical sense.

Exponential equationrepresents the relation between variables under dry AMC in figure 3 seems to be the best fitting because the points continue to rise; however, it could be that more observedpointswillcause the fall of the curve.

This results may compare to those of simulated rainfall experiments under bare soil that were conducted in China [4] aiming to study the characteristics of SOC loss caused by water erosion; the researchers found significant linear correlations between SOC loss and soil loss. Also, in other study [9], the investigators established a potential curve correlation of the type $y = \alpha x^{\beta}$, where "x" is the runoff rate and "y" the erosion rate under both conventionally-farmed soil and organically-farmed soil.

Finally, it is important to mention that the data can be fitted to other equations for example high order polynomial models however we did not take account them since one important criteria of selection is to minimize the number of predictor variables according to Occam's razor principle, which states that the simplest is to be preferred [10]; also, as a model becomes more complex the residual values are reduced, which causes better adjustments, but they show the behavior of the observed data rather than the real population [11].

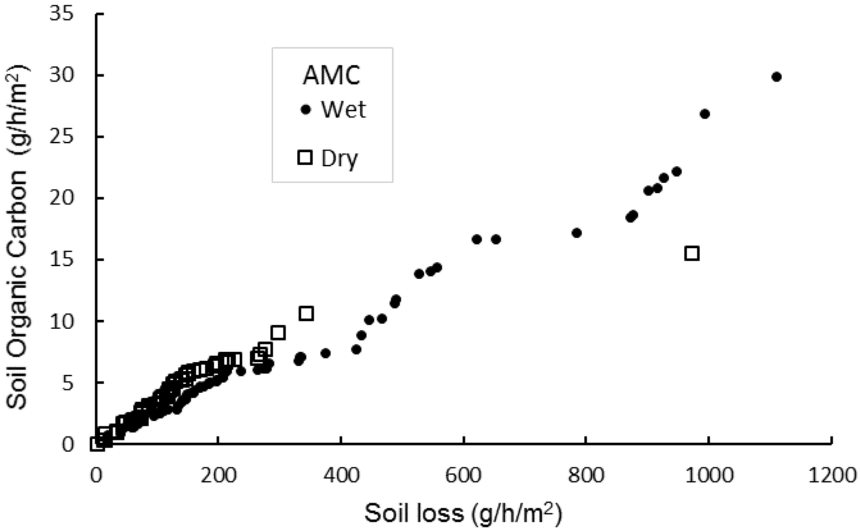

Fig. 3. Scatter diagram of relation between Soil Organic Carbon and Soil loss during rainfall simulation.

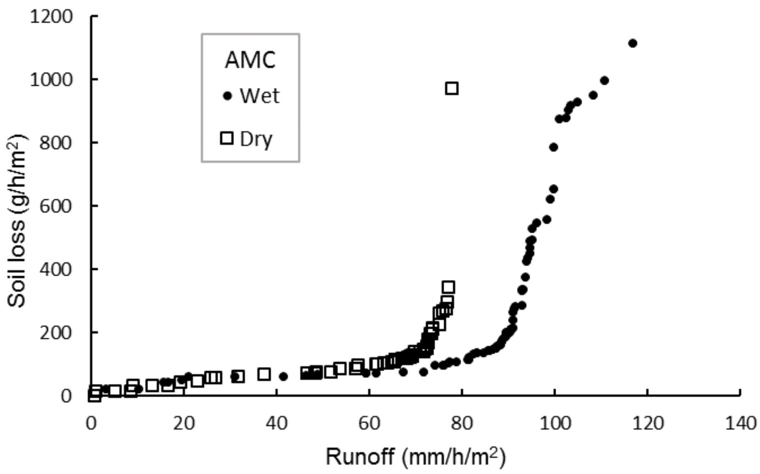

Fig. 4. Scatter diagram of relation between Soil Organic Carbon and runoff during rainfall simulation.

IV. CONCLUSION

Scientific studies aiming to parameterizing simulation models of Soil Organic Carbon (SOC) loss during runoff events must be conducted under controlled conditions. In this way, rainfall simulators provide a useful tool, which can modify the antecedent soil moisture, rainfall intensity, also on laboratory conditions, it is possible to control the land slope and soil cover. In current research, we simulated rainfall occurrence in agricultural land of an arid watershed and we took periodical samples to study the relationship between SOC loss, soil loss and runoff.

Results have shown the correlation among variables when using linear and exponential models. A logistic model explains in 98% the dependence between runoff and SOC; this type of model is intuitive since any phenomenon of growth follows this type of behavior where it initiate slowly then a rapid growth is achieved and finally the trend arrives to a plateau where it stabilizes despite the increasing of runoff.

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