Assessment of Tillage Erosion Rates on Steepland Oxisols in the Humid Tropics Using Granite Rocks

B. B. Thapa*, D. K. Cassel, and D. P. Garrity

ABSTRACT

Soil translocation by animal-powered tillage may lead to land degradation in small scale steepland agriculture in the humid tropics. This study evaluated tillage-induced soil translocation on an Oxisol with 25 and 36% slopes in Claveria, Philippines. The three tillage systems were contour moldboard plowing (CMP), moldboard plowing up and downslope (UMP), and contour ridge tillage (CRT). Rocks 3 to 4 cm in "diameter" used as soil movement detection units (SMDU) were placed at 10-cm intervals in a narrow 5-cm-deep trench near the upper boundary of each plot, the position of each rock recorded, and the trench backfilled. Five tillage operations used to produce one corn (*Zea mays* L.) crop were performed during a one month period: two moldboard plowing operations for land preparation (except for CRT), one moldboard plowing for corn planting, and two inter-culture (inter-row cultivation) operations. After these operations, over 95% of the SMDU were recovered manually, their exact locations recorded, and their movement used to estimate soil transport due to tillage. Mean annual soil flux for the 25% slope was 365 and 306 kg m^{-1} yr^{-1} for UMP and CMP, respectively. For the 36% slope, comparable values were 481 and 478 kg m^{-1} yr^{-1}. Estimated tillage erosion rates for the 25% slope were 456 and 382 Mg ha^{-1} yr^{-1} for UMP and CMP, respectively, and increased to 601 and 598 Mg ha^{-1} yr^{-1}, respectively, for the 36% slope. The mean displacement distance, mean annual soil flux, and mean annual tillage-induced soil loss for both slopes were reduced by approximately 70% on both slopes using CRT compared to CMP and UMP. The present rapid rate of land degradation by moldboard plowing could be dramatically reduced with the adoption of ridge tillage.

INTRODUCTION

Moldboard plowing in intensive mechanized farming systems erodes topsoil and reduces the productive potential of soil resource (Veseth, 1986). This process also occurs under small scale farming systems in the humid tropics where animal-powered moldboard plowing is performed (Garrity, 1996). In alley cropping, topsoil generally moves downslope from the upper part of the alley and accumulates in the lower portions of alley. As a result, terraces develop between adjacent vegetative barrier strips within a few years (Agus et al., 1997). One consequence of this soil movement is that crop productivity decreases in the upper portion of the alley and increases in the lower portion of the alley (Thapa, 1997).

B.B. Thapa*, Department of Crop Science, NCSU, Raleigh, NC 27695 –7620; D.K. Cassel, Department of Soil Science, NCSU, Raleigh, NC 27695 –7619; D.P. Garrity, Southeast Asian Regional Research Programme, ICRAF, P. O. Box 161, Bogor 16001, Indonesia.

Published in Soil Science Society of North Carolina Proceedings, Volume XLI (1998).

The rate of soil movement on farmed upland soils under various tillage and soil management practices in the humid tropics is unknown as is the rate of land degradation. Many tilled upland soils in the region, however, have slopes of 30% or even higher. Ridge tillage may provide an option to reduce downhill soil translocation and reduce the rate of land degradation on intensively tilled, steepland soils in the humid tropics (Thapa et al., 1998a, b). The objective of this study was to quantify, using small granite rocks as soil movement tracers, soil displacement and tillage-induced soil erosion for three animal-powered tillage systems on highly erodible steepland soils in the humid tropics.

MATERIALS AND METHODS

Site Description

The study was conducted on hillsides ranging from 20 to 45% slope at Claveria, Philippines (8°38'N, 124°55'E). The soil is a very fine, kaolinitic, isohyperthermic, Lithic Hapludox (Soil Survey Staff, 1992) of volcanic origin. Bulk density of the surface 20-cm layer is near 1.0 Mg m^{-3}. Greater details on the site, soil properties, and weather characteristics are reported by Thapa (1997).

The experiment was conducted in 1996 in two fallow alleys where black mulberry (*Morus nigra*) hedgerows had previously grown (Fig. 1). Alley 1 had an average slope of 25%, but ranged from 20 to 30%. Mean slope in alley 2 was 36% and ranged from 30 to 45%. Each tillage erosion plot was 7-m-wide by 8-m-long (downslope). Slope across the contour for all plots was less than 1%.

Tillage Systems

Three replications of three tillage systems were evaluated in 1996 on each of the two alleys. The tillage systems were contour moldboard plowing (CMP), moldboard plowing up and downslope (UMP), and contour ridge tillage (CRT). Because of time and labor constraints, and to minimize the effects of rainfall, soil creep and faunal activity on soil movement, all tillage operations for the corn crop that normally would be spread over a 60-day period were compressed into a 30-day period (March 20 to April 20). The nominal depth of tillage operations was 20 cm. Daily rainfall during this period was < 10 mm thus minimizing the opportunity for water-induced soil movement.

Tillage operations for the CMP and CRT systems were done on the contour. A single ox-pulled, single bottom moldboard plow was used and soil was displaced downslope. For the CRT system, no tillage occurred after placement of the soil movement detection units (discussed below) until corn planting on 10 April. Corn planting for all three tillage systems was simulated by making shallow furrows for seeds using the moldboard plow. The moldboard plow was used on 15 and 20 April to simulate inter-row cultivation operations to suppress weeds in the CMP and UMP systems. These operations moved soil from the inter-row to the corn row to create a raised bed; soil was moved downslope on one side of the row and upslope on the other side. During cultivation of the CRT system, 20-cm-high ridges spaced 60 cm apart, the distance between adjacent corn rows, were constructed on the contour using an ox-pulled ridger, i. e., a doubleblade moldboard plow which moved soil to both sides as it was pulled in the inter-row.

Soil Movement Detection Units

Prior to tillage, soil movement detection units (SMDU) to estimate soil translocation by tillage were installed in all eighteen erosion plots. Fifty-one rough surfaced granite rocks (nominal diameter 3 to 4 cm) were painted white and identified with consecutive numbers 1 through 51 or 52 through 102, and buried in each plot at locations shown in Fig. 2. Within each plot, a 5-m-long trench (5-cm deep and 5-cm wide) was hand dug, 51 consecutively numbered rocks placed in the trench at 10 cm intervals, and the trench backfilled. The original location of each SMDU was referenced to bamboo stakes installed on the plot border. Placing SMDU numbered 52 through 102 in a plot adjacent to plots with SMDU numbered 1 through 51 allowed us to determine if SMDU were transported to an adjacent plot.

Manual excavation of SMDU began 25 April 1996 after all tillage operations for one corn crop had been completed. The coordinates for each numbered rock recovered was recorded. The actual displacement distance based on row and column displacement measurements was calculated using the Pythagorean theorem. The lateral, downslope, and actual displacement data for each plot were analyzed using the univariate procedure (SAS Institute Inc., 1988). Analysis of variance of the univariate procedure statistics was performed using the generalized linear model GLM procedure (SAS Institute Inc., 1988).

Soil flux (kg m^{-1} $crop^{-1}$) in this experiment is defined as the mass of soil that moves from a specified location in the field in response to the summation of an unit length of one pass of all tillage operations required to grow one corn crop. The soil flux (Q_s) was computed as:

$$Q_s = MD \times TD \times BD \qquad [1]$$

where MD = displacement distance (m yr^{-1}), TD = tillage depth (0.2 m), and BD = bulk density (1×10^3 kg m^{-3}).

Mean annual tillage erosion rate (TER) (Mg ha^{-1} yr^{-1}) was calculated by dividing the annual soil flux (Q_s) value by the plot or downslope length (L) and converting the value to a ha basis. Q_s can be replaced by regression equations relating tillage erosion rate to percent slope. Mean annual TER for a given tillage practice or system refers to the mean annual soil flux that occurs due to tilling an unit land area having a given slope and given downslope length or contour interval.

RESULTS AND DISCUSSION

Displacement of Soil Movement Detection Units

The percent recovery of SMDU was 95% or greater for every plot and was unaffected by tillage system or percent slope. This high recovery percentage results from the use of large-diameter SMDUs and excavation of the entire plot area. Tillage and slope significantly affected actual displacement distance (P= 0 .01) (Thapa, 1997). The variable "Q3" is defined as the distance from their original location beyond which 25% of the SMDUs were displaced. The slope x tillage interaction was significant for the mean and Q3 distances. The actual mean displacement distance for UMP increased from 101 cm at 25% slope to 134 cm at 36% slope; for CMP, the increase was from 85 cm at 25% slope to 133 cm at 36% slope (Fig. 3A). On both slopes, the mean and Q3 displacement distances were lowest for the CRT system. The actual Q3 displacement distance was generally much smaller for CRT than for CMP and UMP (Fig. 3B). These results indicate that net soil movement on steep slopes was downhill regardless of whether plowing was up and down the slope or along the contour.

Soil Flux and Tillage Erosion Rate

Our assumption in the following discussion is that SMDU, soil clods, and soil particles move by tillage at identical rates. The slope and tillage main effects for the mean and Q3 parameters for soil flux and tillage erosion rate were highly significant (P =0.001) (ANOVA not shown). The mean soil flux (Fig. 3C) and the tillage erosion rate (Fig. 3D) increased with percent slope for all three tillage systems. For the UMP system, the mean soil flux was 423 kg m^{-1} yr^{-1} and the mean tillage erosion rate was 529 Mg ha^{-1} yr^{-1}. The use of ridge tillage on the contour (CRT) reduced these amounts about 70%.

Soil Flux Models and Nomograms

Mean annual soil flux increased with percent slope, the rate of increase being greater for CMP and UMP than for CRT (Fig. 4). The significant r^2 values of 0.57 indicate that 57% or more of the soil flux is related to soil steepness. The data clearly show that contour ridge tillage reduces the rate of tillage erosion on steep slopes.

Turkelboom et al. (1997) and Poesen et al. (1997) developed nomograms to estimate annual soil loss from a particular field for different tillage systems. In this study, we utilized linear relationships between mean annual soil flux and percent slope in the development of the soil loss nomogram equations shown in Fig. 5. The nomograms define soil loss as a function of percent slope (s) and contour interval or downslope length (L). Based on our experimental results, we found that mean annual soil loss is different for each tillage system and is dependent on downslope plot or field length. For a field with a long downslope length, soil is displaced downhill but most of the soil remains in the field. On the other hand, if the field is narrow and oriented so that the downslope length is short, a high proportion of the displaced soil moves across the lower border of the field and is lost. For example, for a narrow field with a slope of 25% and a 5-m-long slope (Fig. 5A), the estimated mean annual soil loss for UMP is 800 Mg ha^{-1} yr^{-1} for UMP and 600 Mg ha^{-1} yr^{-1} for CMP. Less than 200 Mg ha^{-1} yr^{-1} mean annual soil loss is estimated for similar conditions for the CRT system. For a steeper slope (40%, Fig. 5B), no difference in soil loss was observed between the CMP and UMP systems.

CONCLUSION

We were successful in measuring soil displacement, soil flux, and tillage erosion rates using 3- to 4-cm-diameter stones as soil movement detection units. Mean actual displacement distance of SMDU affected by 20-cm-deep tillage operations ranged from 24 cm at 25% slope in the CRT system to 134 cm at 36% slope in the UMP system. Mean annual soil flux ranged from 85 Mg m^{-1} yr^{-1} at 25% slope in the CRT to 381 kg m^{-1} yr^{-1} at 36% slope in the UMP system.

Similarly, the mean annual tillage-induced soil loss ranged from 106 to 601 Mg ha^{-1} yr^{-1} in the UMP system. Mean displacement distance, annual soil flux, and tillage-induced soil loss were reduced by approximately 70% using the CRT system compared to CMP and UMP systems. Soil flux was linearly correlated with percent slopes in all tillage systems.

REFERENCES

Agus, F., D.K. Cassel, and D.P. Garrity. 1997. Soil-water and soil physical properties under contour hedgerow systems on sloping Oxisols. Soil Tillage Res. 40:185-199.

Garrity, D.P. 1996. Tree-soil-crop interactions on slopes. p. 229-318. In C.K. Ong and P. Huxley (ed.) Tree-Crop Interactions, A Physiological Approach. Commonwealth Agricultural Bureau Intern., Walingford, UK.

Poesen, J., B. van Wesemael, G. Govers, J. Martinez-Fernandez, P. Desmet, K. Vandaele, T. Quine, and G. Degraer. 1997. Patterns of rock fragment cover generated by tillage erosion. Geomorphology 18: 183-197.

SAS Institute Inc.1988. SAS/ STAT Users' Guide, Release 6.03. SAS Institute Inc., Cary, NC.

Soil Survey Staff. 1992. Keys to soil taxonomy, 5th Edition. SMSS Technical Monograph. no. 19. Blacksburg, Virginia, Pocahontas Press Inc.

Thapa, B.B. 1997. Contour ridge tillage and natural grass barrier strip effects on soil erosion, soil fertility, and corn production on sloping Oxisols in the humid tropics. Ph. D. Dissertation (Soil Science). North Carolina State University, Raleigh, North Carolina, USA. p. 13-46.

Thapa, B.B., D. K. Cassel, and D.P. Garrity. 1998a. Assessment of tillage erosion rates on steepland Oxisols in the humid tropics using granite rocks. *In* G. Govers (Ed.) Proceeding of the International Symposium on Soil Translocation and Tillage Erosion held in Toronto, Canada, July 24-25, 1997. Soil and Tillage Res. Spec. Publ. (In press.)

Thapa B.B., D.K. Cassel, and D.P. Garrity. 1998b. Ridge tillage and contour natural grass barrier strips reduce tillage erosion. *In* G. Govers (Ed.) Proceeding of the International Symposium on Soil Translocation and Tillage Erosion held in Toronto, Canada, July 24-25, 1997. Soil and Tillage Res. Spec. Publ. (In press.)

Turkelboom, F., J. Poesen, I. Ohler, K. Van Keer, S. Ongprasert, and K. Vlassak. 1997. Assessment of tillage erosion rates on steep slopes in northern Thailand. Catena 199:1-16.

Veseth, R. 1986. Tillage erosion - changing landscapes and productivity. *In* R. Veseth and D. Wysocki (Ed.) STEEP Extension Conservation Farming Update, Fall 1986. University of Idaho, Moscow, ID 2-7.

Fig. 1. Schematic cross section from top to bottom of an experiment plot showing different slopes.

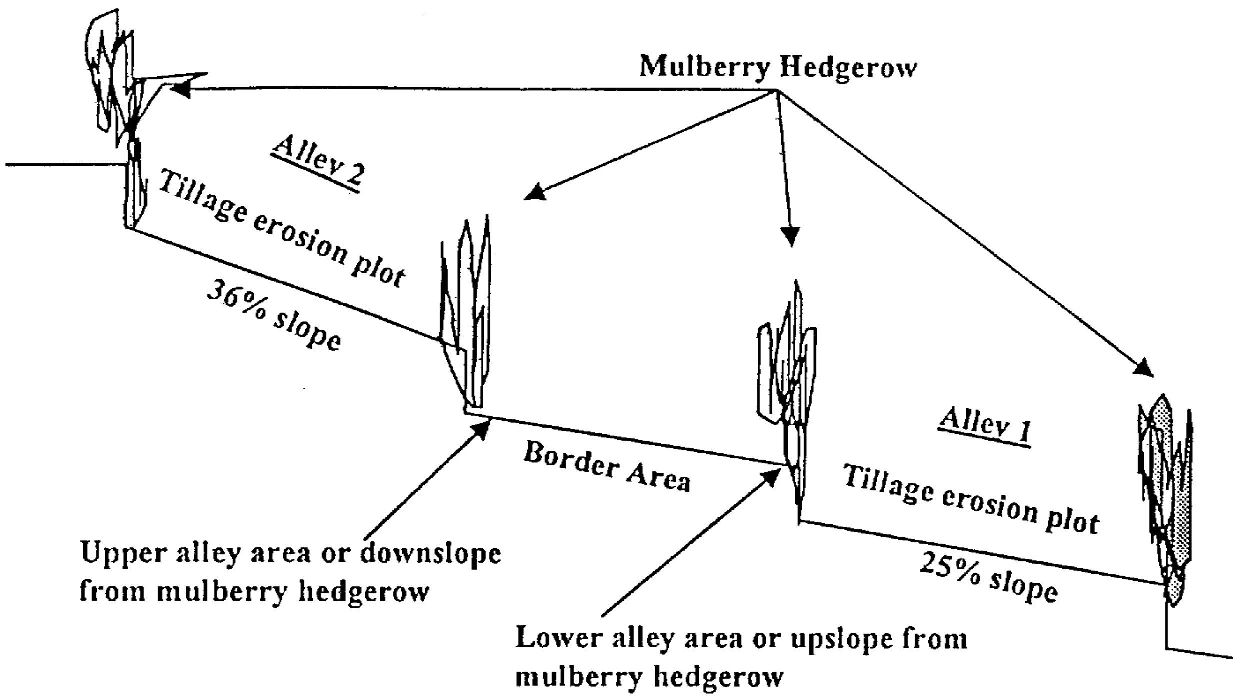

Fig. 2. Plot layout and schematic showing placement of soil movement detection units (SMDU). Fifty-one SMDU were inserted per plot. Plot dimensions not drawn to scale.

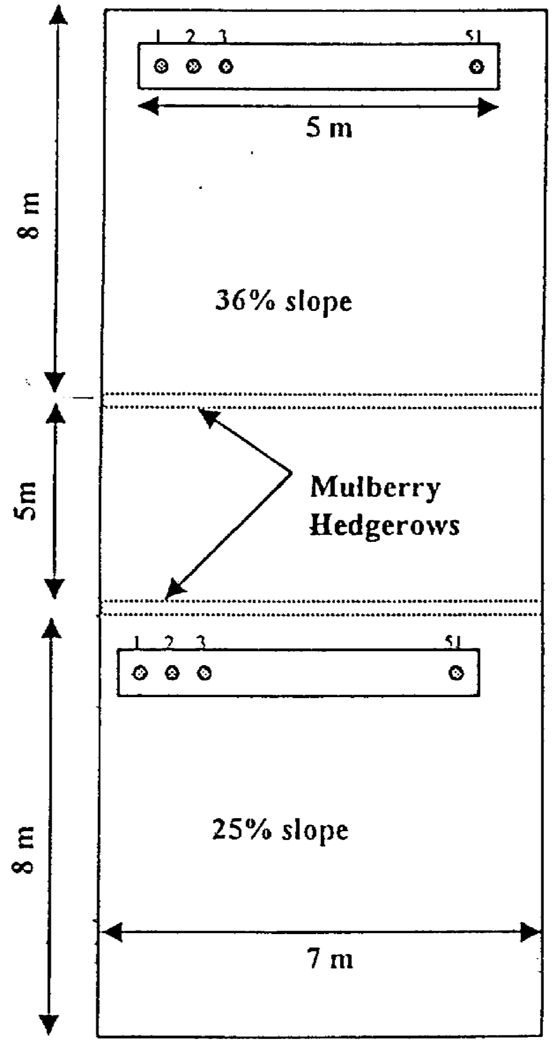

Fig. 3. Mean and Q3 actual displacement distance of SMDU (A, B) and estimated mean soil flux (C) and tillage erosion rate (D) for three tillage systems at two slopes after simulated tillage for one corn crop. CMP = contour moldboard plowing; CRT = contour ridge tillage; UMP = moldboard plowing up and downslope. Tillage means followed by common letters above the Average bars are not significantly different at the P = 0.05 probability level; vertical bars indicate the standard error.

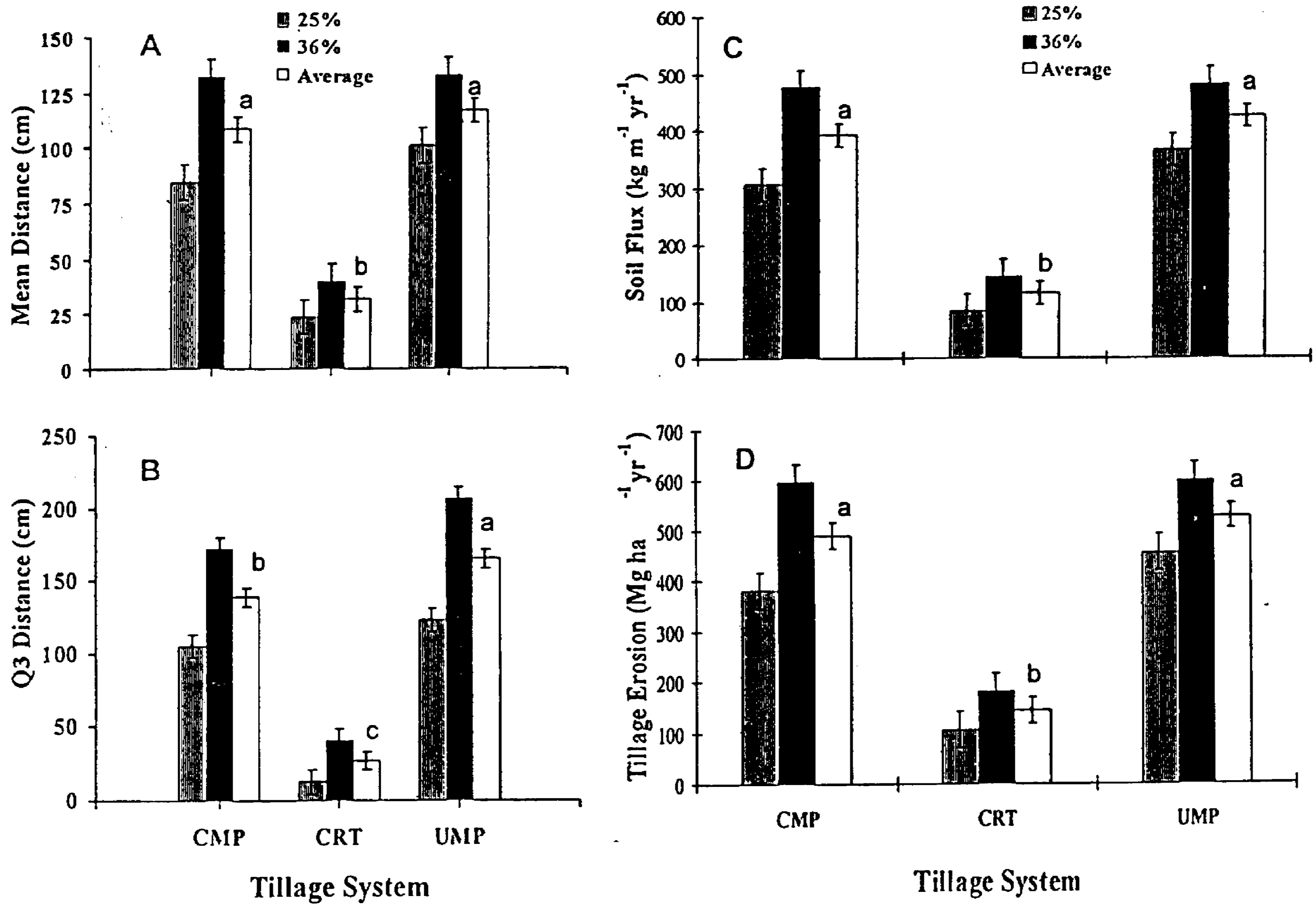

Fig. 4. Relationship between soil flux, based on mean and Q3 displacement distances, and percent slope for three tillage systems at Claveria, Philippines. The symbols *, ** and *** indicate significance at the P = 0.05, 0.01 and 0.001 probability levels, respectively.

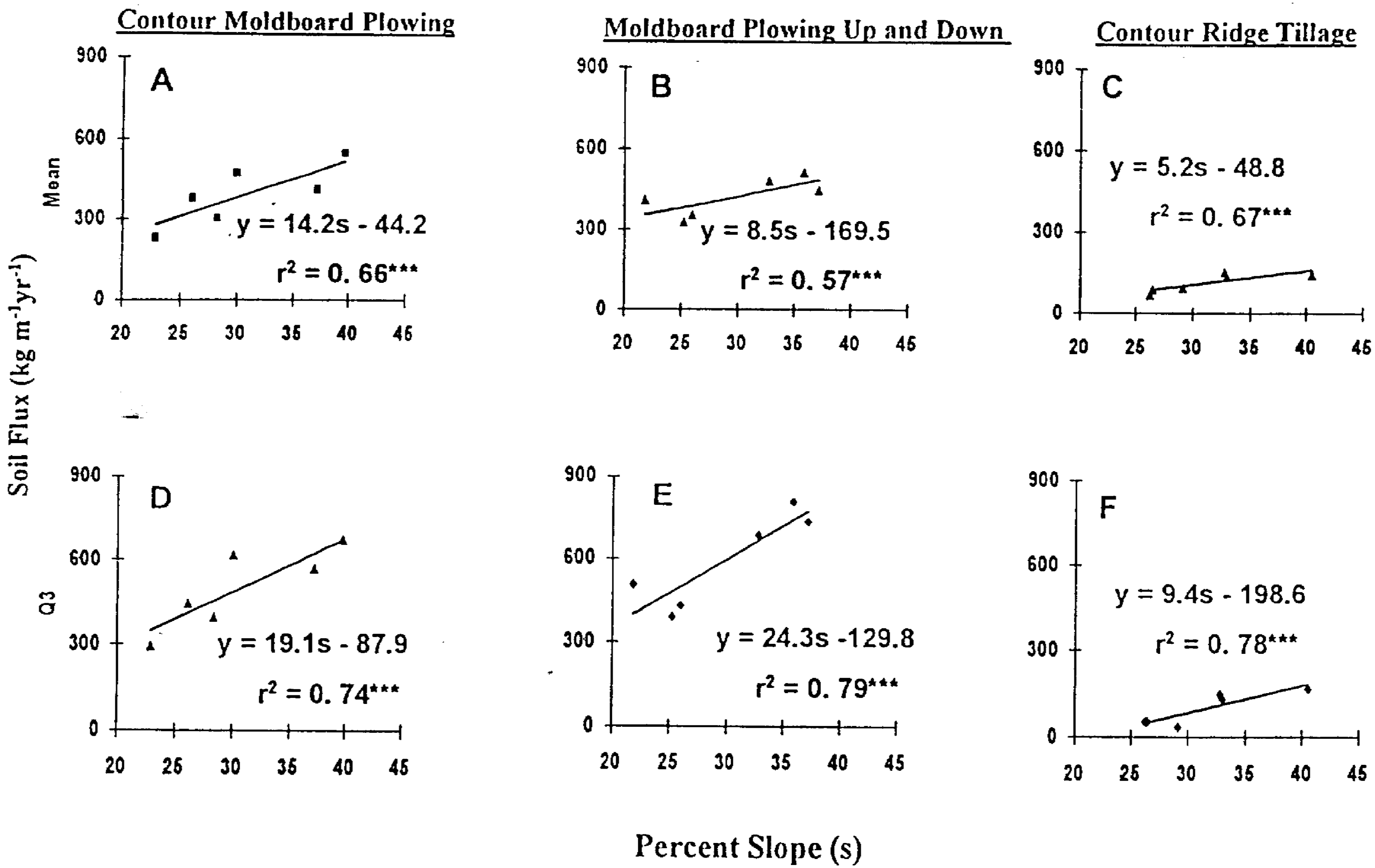

Fig. 5. Nomograms to determine mean annual tillage erosion rate (TER) for three tillage systems as a function of percent slope and contour interval distance or plot length at Claveria, Philippines. CMP = contour moldboard plowing, UMP moldboard plowing up and downslope, and CRT = contour ridge tillage, s is percent slope and L is slope length or contour interval distance (m). Nomogram equations given in A also used for B.