

## **Tillage-Induced Erosion in the Humid Tropics: Rates, Effects on Soil Properties, and Approaches to Reduce It**

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### **ABSTRACT**

Large amounts of soil are eroded annually from tilled, hilly upland soils in the humid tropics. Two experiments were conducted on Oxisols in the Philippines to estimate the tillage-induced soil displacement or translocation, soil flux, and soil erosion associated with several animal-powered tillage systems. For both experiments, soil movement was estimated using tracers, 12-mm steel nuts in one case, and small granite rocks in the second, which were buried 5 cm deep in the soil. Experiment 1 involved up to 20 tillage operations associated with growing four corn crops on soil with 16 to 22% slope over a 2-year period. Tillage systems were contour moldboard plowing (CMP), contour ridge tillage (CRT), and contour moldboard plowing in combination with contour grass barrier strips (GCMP). Experiment 2 was a 1-month-long field simulation that evaluated soil translocation at slopes of 25 and 36% for three tillage systems: CMP, CRT, and moldboard plowing up and downslope (UMP). The tracers were excavated at the termination of each study and soil translocation calculated, assuming that soil material in the Ap horizon moved at the same rate as the tracers. The CRT and GCMP treatments had the lowest translocation rates. The grass barriers in treatment GCMP enhanced the formation of terraces between adjacent contour grass strips due to soil moving from higher to lower elevation within a given alley. For Experiment 1, the mean calculated downslope soil fluxes were 163, 53, and 65 kg m<sup>-1</sup> yr<sup>-1</sup> for CMP, CRT, and GCMP, respectively. For experiment 2, the mean calculated downslope soil fluxes for 25% slope were 132, 36, and 180 kg m<sup>-1</sup> yr<sup>-1</sup> for CMP, CRT, and UMP, respectively. Movement of soil downslope redistributed the applied P and Ca in the alleys of GCMP enriching the soil at the lowest elevation. We conclude that high rates of soil transport arise due to tillage practices in these hilly upland soils in the humid tropics.

### **INTRODUCTION**

Sustaining crop production on intensively farmed land in the humid tropical uplands is a great challenge. Subsistence agriculture is practiced throughout much of this area and it is necessary for a farmer to produce two or even three crops per year. Water-induced soil erosion has been identified as a problem leading to soil degradation in these areas and many

organizations have spent millions of dollars attempting to reduce it to an acceptable level. One of the approaches to controlling erosion has been to till the soil on the contour rather than tilling it up and downslope. While this approach helps, its adoption by subsistence farmers is limited. Planting and maintaining contour rows or bands of trees, shrubs or grasses to intercept water runoff and suspended soil material is another approach to retain soil on sloping fields (Paningbatan et al., 1995; Agus et al., 1997). This *alley cropping* approach has dramatically reduced water-induced soil erosion, but the practice, especially on P-limited acid soils, nearly always reduces crop yields compared to fields without the strips of trees or shrubs (Sanchez, 1995).

Tillage-induced soil erosion (tillage erosion) has only recently been considered to be a factor contributing to the degradation of soils (Lewis and Nyamulinda, 1996). Although tillage erosion was recognized in the early 1940's (Mech and Free, 1942), only within the past decade has the process been identified as a significant process in altering geomorphic features on the landscape. In general, tillage causes a net downslope movement of soil material. There is a net loss of soil material from convex positions on the landscape and often a net gain of soil material at concave positions lower on the landscape. The redistribution of soil on the landscape can give rise to changes in soil physical, chemical and biological properties. These changes in soil properties, in turn, can alter the productivity of the soil resulting in highly variable yields within a given field. When soil material crosses the lower boundary of a field, whether by tillage erosion or water-induced erosion or a combination of the two processes, it represents a loss of the soil resource from that particular field.

The objective of this paper is to summarize the results of two tillage erosion experiments conducted on the Philippine uplands in the humid tropics. The objective of each experiment was to estimate the rates of soil translocation, soil flux, and tillage erosion for several animal-powered tillage systems. In addition, the changes in P and Ca distribution in the Ap horizon were assessed.

### **MATERIALS AND METHODS**

Two experiments were conducted in Claveria municipality, Misamis Oriental, Philippines (8°38'N, 124°55'E) from 1994 to 1996. Mean annual rainfall is about 1900 mm. Months receiving the most rainfall are June, July and August. Pan evaporation exceeds rainfall from January

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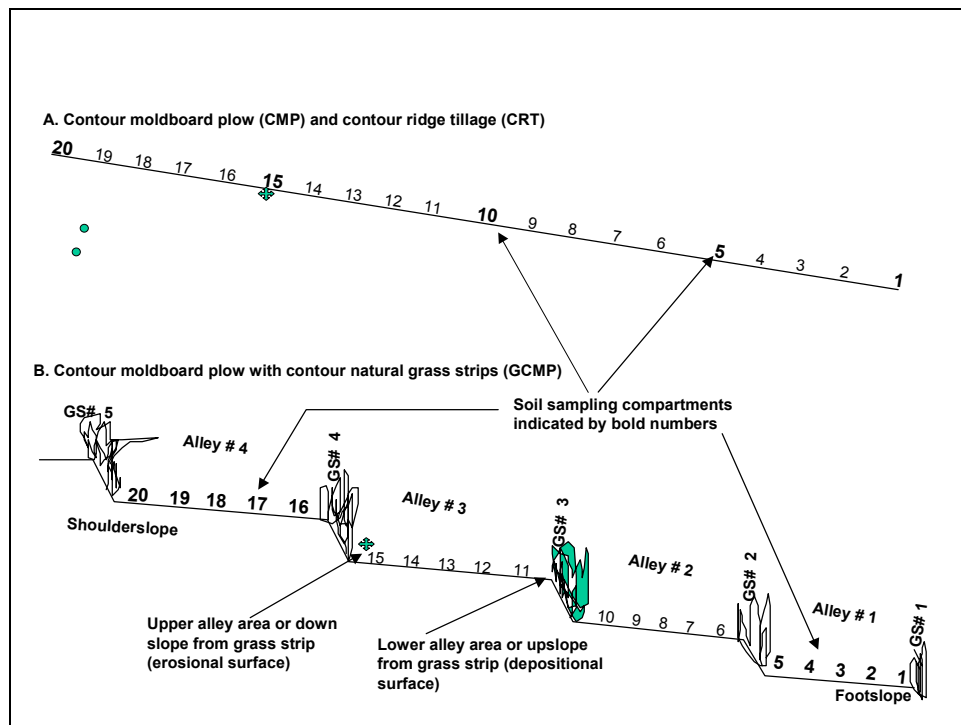


Figure 1. Schematic diagram for transect across (A) treatments CMP, CRT, and (B) treatment GCMP. The reference point marked by the cross arrow near compartment 15 represents the center of the 0.90 x 0.95 m microplot area in which the metal tracers were installed.

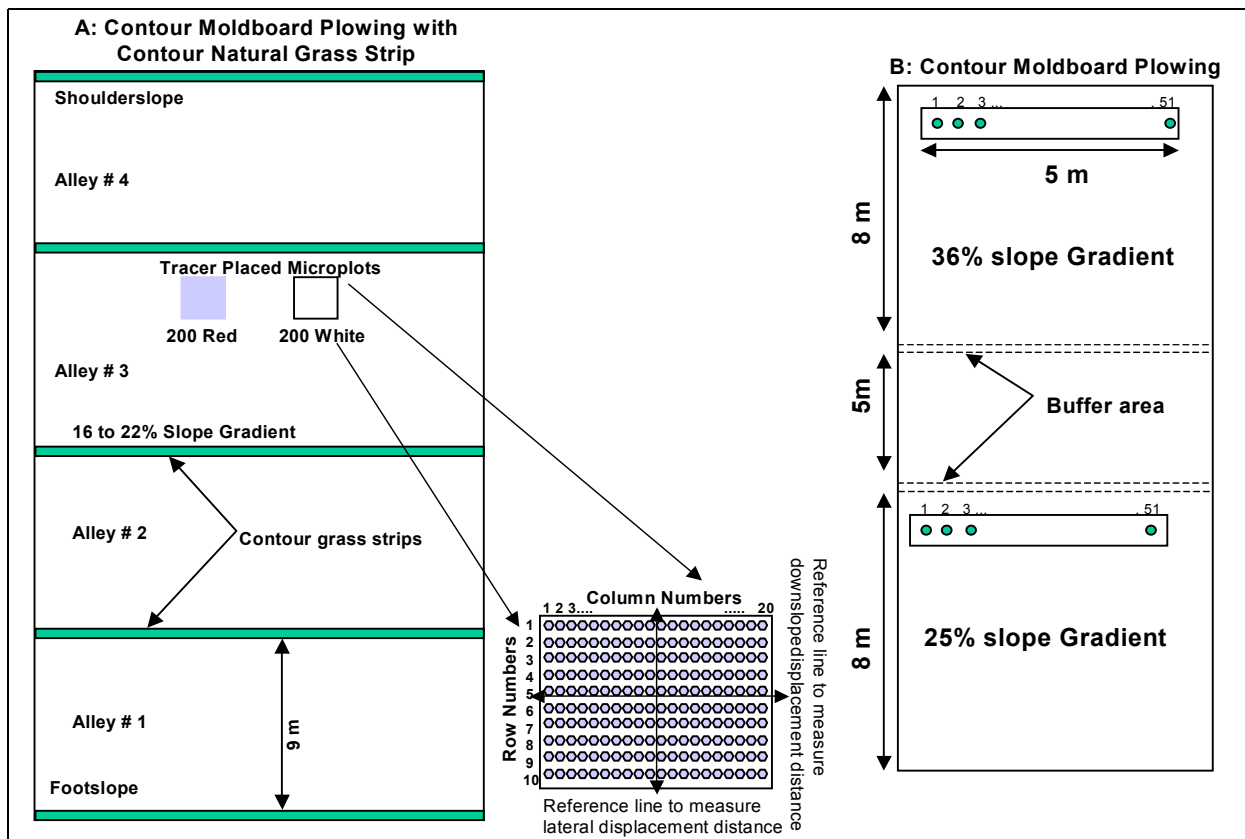


Figure 2. Schematic diagram showing placement of soil movement tracers in (A) treatment GCMP in experiment 1 and (B) CMP in experiment 2.

through May. The first grain crop in the upland area is planted in May when the monsoons begin. The second grain crop is planted as soon as the first crop is harvested. Soils at the site are of volcanic origin and are very fine, kaolinitic, isohyperthermic, Lithic or Rhodic Hapludoxes. Clay content exceeds 72% throughout the profile and carbon content of the Ap horizon is approximately  $1.6 \text{ g kg}^{-1}$  (Thapa et al., 2000).

**Experiment 1** This experiment was designed to estimate the rate that soil material moves due to various tillage systems and to evaluate changes in soil chemical properties as a result of soil translocation. It began in 1994 on a site that was established in 1992 to evaluate the effects of several soil management systems on tillage and water-induced soil erosion and crop yield (Thapa, 1997). In the present study, the soil management systems which incorporated the tillage systems of interest are: [1] contour moldboard plowing (CMP), [2] contour ridge tillage (CRT), and contour barriers formed by natural grass strips plus contour moldboard plowing (GCMP). Each tillage system was replicated three times on plots 8 m wide and 38 m long. The continuity of the open field CMP treatment (Fig 1A) was disrupted by contour natural grass barrier strips for treatment GCMP (Fig. 1B), for which five contour natural grass strips spaced about 9 m apart formed four alleys. The slope gradients where the tracers were buried ranged from 16 to 22% and the surface soil bulk density was  $730 \text{ kg m}^{-3}$ . A single ox performed all tillage operations. The CMP and GCMP treatments had five tillage operations performed for each of the four corn crops grown from August 1994 to Jan. 1996; these included four tillage operations by a narrow moldboard plow (Thapa, 1997) and one harrowing. The moldboard plow was used to plow to make furrows and cover the seed during planting, and to cultivate the soil. For CRT, no initial plowing or harrowing was done, but planting and the first ridging involved use of the moldboard plow. The second ridging operation was done by a locally fabricated ridger. Moldboard plowing to break the soil before planting for the CMP treatment turned soil downslope, following the common practice in the region. Nominal depth of tillage operations was 0.20 m. Each corn crop received inorganic fertilizer applications of N, P, and K at rates of 80, 30, and  $30 \text{ kg ha}^{-1}$ , respectively. Lime at the rate of  $3 \text{ Mg ha}^{-1}$  was applied to all plots only in 1992.

Prior to beginning the tillage operations for the second crop in 1994, soil movement tracers (12-mm hexagonal steel nuts painted white or red) were placed 0.05 m deep in the soil in the geometrical arrangement shown in Fig. 2A. For example, for GCMP, 200 red tracers were placed on a grid on the left-hand side of the plot and 200 white tracers were placed in an identical grid at the upper right-hand side of one of the alleys between the grass strips. The tracers were manually excavated in 1996 after all tillage operations for producing the four successive corn crops had been completed. Manual recovery of the tracers involved systematic removal of  $0.10 \text{ m} \times 0.10 \text{ m} \times 0.20\text{-m}$ - deep blocks of soil and forcing all soil material through a sieve. The coordinates of each soil block containing a given colored metal tracer were recorded relative to the references shown in Fig. 2A. The lateral and upslope-downslope

translocation distance for each tracer was computed using the center of the original tracer placement area as the origin. The actual distance of each tracer translocation was calculated using the Pythagorean theorem.

Following harvest of the corn crop in 1996, three subsamples of soil per compartment from the 0.20-m-deep Ap horizon were collected for each plot from compartments 1, 5, 10, 15, and 20 for treatments CMP and CRT and from compartments 1 to 5 and 16 to 20 for GCMP (Fig. 1). The subsamples within each plot for each compartment were composited. These samples, along with samples collected at the same locations using the same sampling procedure in 1992, before the plots were installed, were extracted using the Mehlich-1 procedure (Mehlich, 1953) and analyzed for extractable P and exchangeable Ca.

**Experiment 2** This experiment was conducted in 1996 and was designed to evaluate the effect of percent slope on tillage translocation rates for three alternative tillage systems for producing corn on steep land soils. The following three tillage systems, replicated three times on two slopes, were evaluated: contour moldboard plowing (CMP), contour ridge tillage (CRT), and moldboard plowing up and downslope (UMP). Each plot was split with respect to soil slope; the 8-m-long by 7-m-wide subplot at the lower elevation had a mean slope of 25% whereas the mean slope of the upper subplot was 36%. The surface soil bulk density was  $900 \text{ kg m}^{-3}$ . Corn was not planted, but all tillage operations required to produce a corn crop were performed during a 1-month-long period. In practice, these operations would occur over a 2-month period. All tillage operations and equipment used for CMP and CRT were similar to experiment 1. The UMP was similar to CMP except that plowing occurred up and downslope.

Fifty-one soil movement tracers were placed in each of the 18 subplots prior to beginning the tillage operations (Fig. 2B). Tracers were small granite rocks having a nominal diameter of 0.03 to 0.04 m. Each rock was painted white and identified with a number so that, upon excavation at the end of the study, the exact distance of tracer movement could be determined. The tracers were buried at the 0.05-m depth at 0.10-m intervals on a 5-m-long transect near the upper boundary of each subplot. Upon completion of the last tillage operation, the tracers were systematically excavated and the coordinates of each tracer recorded.

The soil tillage translocation coefficient,  $Q_s$ , as defined below is related to the soil flux originally defined by Govers et al. (1994).  $Q_s$  is defined as the mass of soil crossing an imaginary plane perpendicular to the soil surface in response to all tillage operations required to grow two corn crops in one year. The plane runs along the contour and is one meter long and extends 0.20 m below the soil surface, i. e., the depth of tillage. For both experiments, the soil flux was calculated by

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

where MD is the mean measured downslope distance of tracer displacement on an annual basis, TD is tillage depth (0.20 m), and BD is bulk density.

In a previous paper, Thapa et al. (1999a) derived an equation to estimate tillage erosion (TE) for these plots as

$$TE = Q_s / L \quad [2]$$

where L is the field or plot length in the downslope direction or distance between contour grass barriers.

Individual plot data was analyzed using descriptive statistics and PROC GLM procedure (Thapa et al., 1999a, b).

## RESULTS AND DISCUSSION

A comparison of parameters associated with the tracers for the two experimental approaches is shown in Table 1. Of particular importance is the time required to recover the tracers. It required 3300 technician-hours to recover 85% of the 12-mm steel nut tracers installed in experiment 1, whereas only 80 hours were needed to recover 99% of the granite rock tracers in experiment 2. However, we consider both recovery rates to be excellent. The position of each recovered metal tracer for the three tillage treatments on the 16% slope (experiment 1) is shown in Fig. 3. Greater downslope displacement was observed for CMP compared to CRT and GCMP. For CMP, two tracers moved more than 7 m downslope from their original placement. Less downslope tracer movement occurred for CRT because the ridges, constructed when the first corn crop was planted, remained in place for all crops thereafter. For GCMP, the tracers were displaced downhill, but not much further than for CRT because the contour grass barriers arrested downhill tracer movement. Considerable lateral tracer displacement occurred for all treatments because all cultivation operations were performed on the contour.

The frequency distributions for the distance the metal tracers moved downslope are shown in Figure 4. For 16% slope, the tracers in CMP moved as far as 7 m downslope (Fig. 4A). However, at the same slope, less than 10% of the tracers moved further than 2 m downslope for CRT; less than 15% of the tracers for GCMP moved as far as 2 m. When slope increased from 16 to 22% (Fig. 4B), the downslope displacement distance increased for all treatments.

The solid colored bars in Fig. 5A show significantly greater mean downslope displacement distance for CMP, being over two times greater than for the other two treatments. Likewise, the downslope annual soil flux, calculated using equation [1], is more than two times greater for CMP (Fig. 5B). Inherent in these calculations is the

assumption that the soil in the Ap horizon moves only due to tillage and at the same rate as the tracers. Finally, the magnitude of annual downslope tillage erosion, computed using equation [2] is more than two times greater for CMP (43 Mg ha<sup>-1</sup>) than for CRT and GCMP (Fig. 5C). This result clearly shows that a higher rate of soil translocation occurs to grow grain crops under CMP management compared with CRT and GCMP. Mean corn grain yields for the 2-year period for CMP, CRT, and GCMP were 6.1, 5.9, and 6.7 Mg ha<sup>-1</sup>, respectively. At present it appears that the corn grain yield is not significantly different between CMP and CRT, but the ratio of the weight of soil transported downslope to the weight of corn grain produced is 7.1, 2.4, and 2.6 for CMP, CRT, and GCMP, respectively. The ratio for CMP means 7.1 Mg ha<sup>-1</sup> soil was being displaced to grow 1 Mg ha<sup>-1</sup> corn grain yield. Over time as more soil is displaced, the corn grain yield likely will decline, and the ratio for CMP is expected to become larger. For the CRT, the ratio is expected to remain small.

The white bars in Fig. 5A represent the *actual* or *total* distance that the tracers moved, i. e., the resultant of the lateral and the downslope distances. For CRT and GCMP, the lateral displacement distance exceeded the downslope distance. This can also be observed in Fig. 3.

The mean downslope displacement distance of the granite tracers for the simulated tillage for one corn crop in experiment 2 is shown in Fig. 6A. The tracers were displaced significantly further downslope for CMP and UMP compared to CRT. Little difference in distance of downslope tracer movement occurred for CMP and UMP. All contour moldboard plowing operations displaced soil in the downward direction. For UMP, moldboard plowing displaced tracers and soil in the downslope direction when the soil was plowed downslope, but displaced some tracers and soil upward when plowed in the upslope direction. However, the net displacement for UMP was downslope. The mean soil fluxes and mean tillage erosion rates (Figs. 6B,C), adjusted to an annual basis, i. e., for two crops, were results for a given treatment are greater than those reported on Fig. 5. This result occurs primarily because the slopes are steeper and the slope lengths are shorter.

The soil phosphorus concentration in the 0.20-m-deep Ap horizon in 1996 before the metal soil tracers in experiment 1 were excavated and in 1992 when the soil management plots were established are shown in

**Table 1. Parameters associated with the soil movement tracers for the two experiments.**

Parameters	Experiment # 1	Experiment # 2
Duration of experiment	2 years	1 month
Soil movement tracers	12-mm- dia hex metal nuts	3- to 4-cm-dia granite stones
Exact initial location know	No	Yes
Tillage systems	CMP, CRT, GCMP	CMP, CRT, UMP
Crops	4 corn crops	None, simulated
Range in slope gradient	16 to 22%	25 to 36%
Ease of tracer recovery	Very difficult	Very easy
Tracer recovery time	3300 man day hours	80 man day hours
Tracer recovery percentage	85%	99%

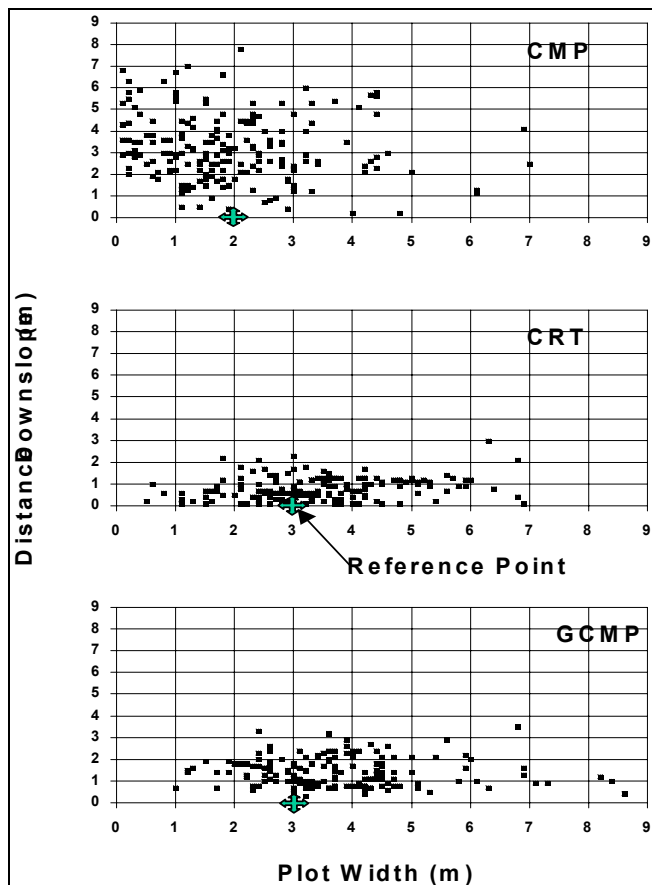


Figure 3. Distribution of retrieved red colored soil movement tracers for three tillage systems on 16% slope after cultivating the land for four corn crops over a 2-year period.

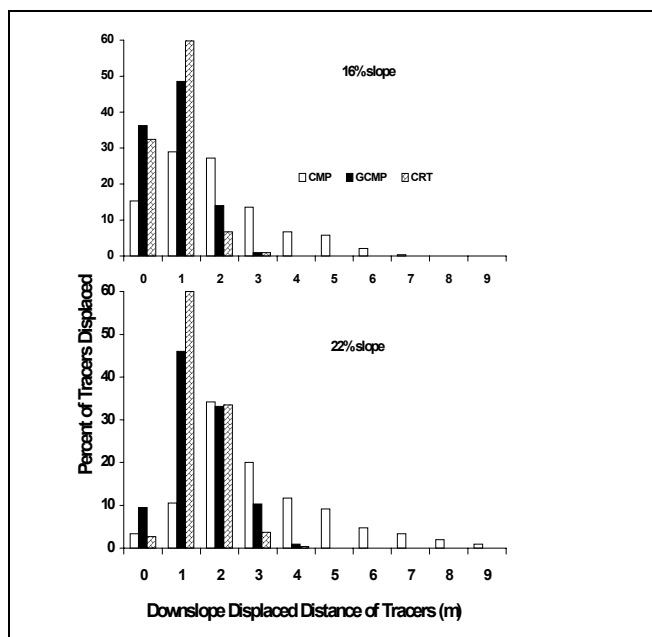


Figure 4: Frequency distribution of the downslope distance tracers moved for three tillage systems on 16 and 22% slopes.

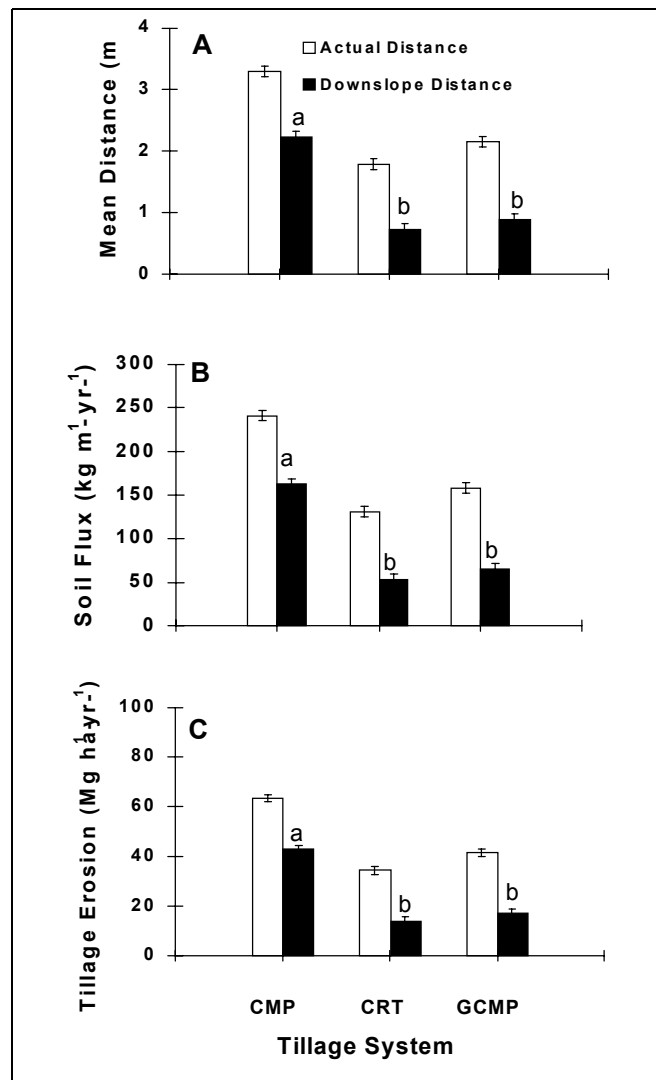


Figure 5. Mean downslope and actual displacement distances of steel tracers (A), soil flux (B), and tillage erosion (C) for three tillage systems. (CMP = contour moldboard plow, CRT = contour ridge tillage, GCMP = contour moldboard plow with contour grass strip). Downslope tillage system means with common letters above the bars are not significantly different at the  $p = 0.05$  level. Vertical lines at the top of each bar indicate the standard error.

Figs. 7A, B, and C. In 1992 there was a small P concentration gradient across the CMP treatment, but not across the CRT treatment or across the alleys of the GCMP treatment. By 1996, the P concentration gradient for GCMP appears to be increasing due to translocation of the P-rich soil from the upper part of the alley to the lower part of the alley. The compartment values for GCMP are averages of two alleys in that treatment. Gradient in extractable Ca existed for all treatments in 1992 (Figs. 7D, E, F). In 1996 slightly steeper gradients developed in CMP and CRT but the gradient increased 4-fold for GCMP indicating that Ca is gradually increasing at the lower elevation within each alley due to transport of Ca-rich soil downslope by tillage erosion. These gradients will continue to increase as more soil is transported downslope as time progresses.

## SUMMARY AND CONCLUSIONS

Tillage-induced soil erosion is significant and contributes to the soil degradation process occurring in much of the hilly upland areas of the humid tropics. In the present case, even though the tillage equipment used for farming is small and a single animal pulls it, the collective tillage operations to grow two crops in one year caused soil to be transported 1 to 2 meters downslope. Even when manual tillage is used, as reported by Turkelboom et al. (1997), soil translocation and tillage erosion occur. In our animal-powered contour tillage system this contribution was estimated to be as much as 7.1 Mg ha<sup>-1</sup> of soil to produce 1 Mg ha<sup>-1</sup> of corn grain. The contour ridge tillage system displaced soil at the lower rate of 2.4 Mg ha<sup>-1</sup> to grow 1 Mg ha<sup>-1</sup> of corn grain. The ridge tillage system reduces the downward transport of soil on sloping field, but weed control for this system under a humid tropical environment is challenging. Further study in relation to this problem is needed.

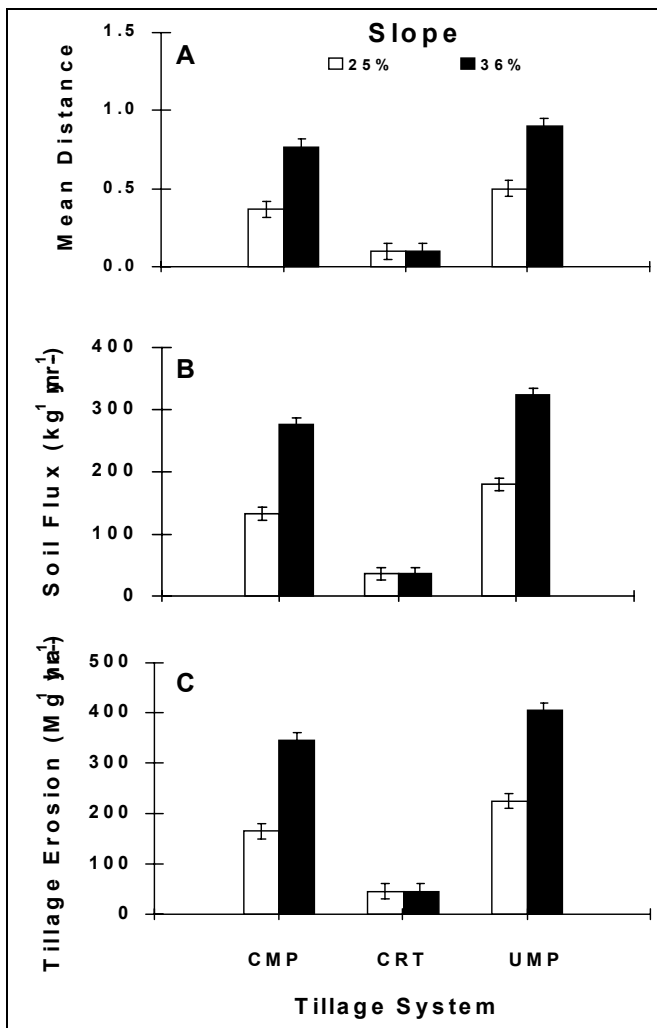


Figure 6. Mean downslope displacement distance of granite tracers after simulated tillage for one corn crop (A), soil flux (B), and tillage erosion (C) for three tillage systems for two slopes.

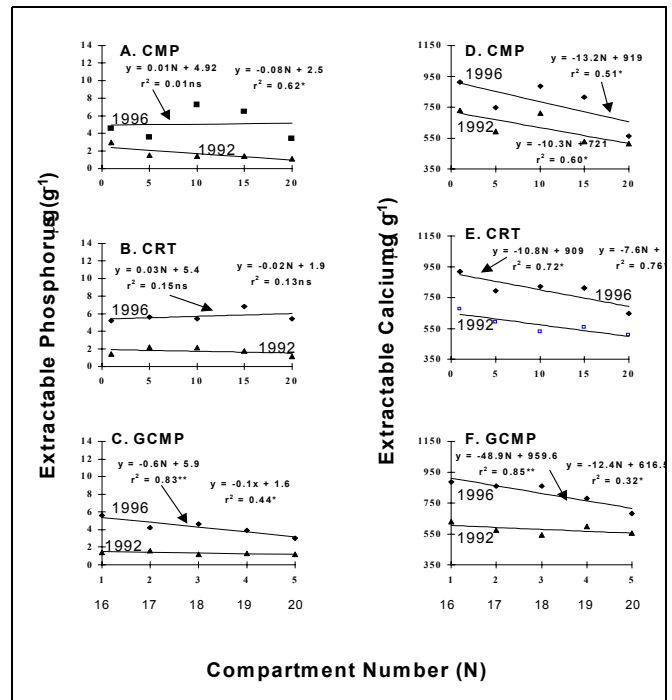


Figure 7. Extractable P and exchangeable Ca concentrations versus compartment in 1992 and 1996 for the contour moldboard plow, contour ridge tillage, and contour moldboard plow with contour grass strip treatments.

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