Ridge tillage and contour natural grass barrier strips reduce tillage erosion

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Abstract

Large amounts of soil are eroded annually from tilled, hilly upland soils in the humid tropics. Awareness has been increasing that much of this erosion may be due to tillage operations rather than water-induced soil movement. This field study estimated soil translocation and tillage erosion for four tillage systems on Oxisols with slope gradients of 16–22% at Claveria, Misamis Oriental, Philippines. Soil movement was estimated using ‘soil movement tracers’ (SMT) which consisted of painted 12-mm hexagonal steel nuts. The SMT were buried in three replicate plots of the following tillage treatments: (1) contour moldboard plowing in the open field (MP-open); (2) contour ridge tillage in the open field (RT-open); (3) contour moldboard plowing plus contour natural grass barrier strips (MP-strip); and (4) contour natural grass barrier strips plus ridge tillage (RT-strip). Two hundred SMT were placed at the 5-cm depth at 5-cm spacings on 10 rows and 20 columns in two microplots within each plot. The microplots were oriented with the boundaries running downslope and along the contour of each 8-m-wide × 38-m-long (downslope) tillage plot. After tilling the land for four successive corn (Zea mays L.) crops (20 tillage operations), the SMT were manually excavated and their positions recorded. Recovery of SMT ranged from 82% to 85%. Displacement of SMT was directly related to slope length, percent slope, and tillage method. Mean displacement distance of SMT during the four corn growing seasons was 3.3 m for MP-open, 1.8 m for RT-open, 1.5 m for the RT-strip, and 2.2 m for MP-strip. Based on tillage operations associated with two corn crops per year, mean annual soil flux was estimated to be 241, 131, 158 and 112 kg m⁻¹ for MP-open, RT-open MP-strip, and RT-strip, respectively. Compared to the mean annual soil loss for MP-open of 63 Mg ha⁻¹, soil loss was reduced by 30%, 45%, and 53% for the MP-strip, RT-open, and RT-strip systems, respectively. Both ridge tillage and natural grass barrier strips reduced soil displacement, soil translocation flux, and tillage erosion rates. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Over the last few decades, many researchers have studied rainfall and runoff water as agents for soil detachment and transport to lower positions on the landscape. This research led to the development and refinement of empirical models such as USLE (Wischmeier and Smith, 1958, 1978), RUSLE (Renard et al., 1991), and process-based models such as GUEST (Rose and Freebairn, 1985; Rose, 1988), WEPP (Foster et al., 1989; Nearing et al., 1989), EUROSEM (Morgan et al., 1990), and MEDALUS (Kirkby et al., 1993). Even though these models use climatic data, the condition of the soil surface and its variability...
create uncertainties in the soil loss estimates. The various soil erosion models have not considered the effects of tillage on soil erosion.

Tillage is a dynamic process that alters the nature of the soil surface, detaches and displaces soil aggregates and clods, and moves or translocates soil to lower elevations (Powell and Herndon, 1987). This translocation of soil to lower elevations (tillage erosion) has not been considered to be a major factor contributing to the overall soil erosion process even though Mech and Free (1942) reported tillage-induced downslope soil movement over five decades ago. The new challenge is to model soil erosion by considering water, tillage, soil creep, wind, and fauna-induced soil transport. In most situations, however, water and tillage-induced soil erosion dominate all other forces of soil erosion.

Animal-pulled tillage implements and human-powered hoes (Turkelboom et al., 1997; Lewis and Nyanmulinda, 1996) are common in present-day farming systems in the humid tropics. For many soils on convex slopes, tillage erosion may be responsible for a significant reduction of topsoil depth and exposure of subsoil (Veseth, 1986). Current knowledge of tillage erosion is limited, and most of the information was developed for tillage operations using large tractor-pulled tillage implements and farm machinery on gently sloping land in North America and Europe (Lindstrom et al., 1990, 1992; Lobb et al., 1995; Govers et al., 1994).

On sloping land in the humid tropics, reduction of net downhill soil movement due to animal or human-powered tillage implements is essential to sustain crop production. This is true even for contour alley cropping systems where a reduction in tillage erosion would reduce the rate of soil scouring in the upper part of an alley. Alley cropping is a system for which annual crops are grown in the area or ‘alleys’ between rows of perennial legume shrubs or trees. This practice emerged in the early 1970s as a conservation farming technique on acid, steepland Oxisols and Ultisols in the humid tropics (Benge, 1987; Kang et al., 1990; Nair et al., 1995). Contour strips of legume shrubs or trees on sloping land proved to be an effective barrier to water-induced soil erosion (O’Sullivan, 1985; Lal, 1987; Young, 1989; Agus, 1993). In the Philippines, Thapa (1991) found that a 1-m-wide contour strip of the legume shrub, Desmanthus virgatus, in 12-m-long plots on a 14–19% slope reduced water-induced soil loss from 200 to <10 Mg ha\(^{-1}\) year\(^{-1}\) for land tilled up and downslope.

On moderately sloping and steep lands, many tillage operations up and downslope still occur, but plowing across the slope is gaining in popularity worldwide. Ridge tillage is a conservation tillage practice in which ridges are reformed atop the planted row by cultivation, and the ensuing row crop is planted into ridges formed the previous growing season. The soil ridges are left from year to year. Crop residue is left on the soil surface between adjacent ridges and weeds are controlled with herbicides, interrow cultivation, or a combination of the two. As the crop grows, soil from between the ridges is thrown up on the ridges to maintain them. Thapa (1997) evaluated ridge tillage for the first time on sloping uplands in the humid tropics and reported significantly higher corn grain yield for ridge tillage systems at reduced operating cost compared to moldboard plow tillage systems.

The use of contour grass barrier strips is an alternative for the perennial shrubs or trees in some alley cropping systems (Thapa, 1997). Contour ridge tillage in combination with contour natural grass barrier strips is a simple, practical and effective alternative conservation method for intensively tilled sloping uplands in the humid tropics. Information on the effects of various tillage systems on tillage-induced soil erosion will provide useful information to further evaluate their efficacy. The objectives of this study were to evaluate the effects of four tillage systems on tillage-induced soil translocation downslope (tillage erosion) and compare the effectiveness of contour ridge tillage and natural grass barrier strips in reducing tillage erosion for corn production on highly erodible steepland soils in the humid tropics.

2. Materials and methods

2.1. Site description

The study began in July 1994 and was superimposed on ongoing experimental plots established in 1992 at Claveria municipality, Misamis Oriental, the Philippines (8°38’N, 124°55’E). The experiment was located on hillsides ranging from 16% to 22% slope gradients at ca. 500 m above mean sea level. The soil
is a very fine, kaolinitic, isohyperthemic, Lithic Hapludox (Soil Survey Staff, 1992) of volcanic origin (Table 1). Bulk density was <1.0 Mg m\(^{-3}\) throughout the soil horizons. Pan evaporation in this region typically exceeds rainfall from January through May and rainfall exceeds pan evaporation from June through December. Monthly rainfall and pan evaporation for 1994 and 1995 are presented in Fig. 1. Total rainfall in 1994 and 1995 was 2020 and 1901 mm, respectively.

### Table 1

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Clay (%)</th>
<th>Bulk density (Mg m(^{-3}))</th>
<th>Base saturation (%)</th>
<th>CEC (cmol(^+) kg(^{-1}))</th>
<th>Exchangeable aluminum (cmol(^+) kg(^{-1}))</th>
<th>Soil pH in H(_2)O (1 : 1)</th>
<th>Total N (g kg(^{-1}))</th>
<th>Bray P (mg kg(^{-1}))</th>
<th>Organic C (g kg(^{-1}))</th>
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<tr>
<td>0–15</td>
<td>78</td>
<td>0.73</td>
<td>33</td>
<td>9.1</td>
<td>1.0</td>
<td>4.1</td>
<td>2.0</td>
<td>5.7</td>
<td>16.0</td>
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<td>15–37</td>
<td>85</td>
<td>0.85</td>
<td>21</td>
<td>8.2</td>
<td>1.6</td>
<td>3.7</td>
<td>1.0</td>
<td>2.0</td>
<td>9.0</td>
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<tr>
<td>37–77</td>
<td>88</td>
<td>0.94</td>
<td>21</td>
<td>8.0</td>
<td>2.1</td>
<td>4.1</td>
<td>1.0</td>
<td>2.3</td>
<td>5.0</td>
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</tbody>
</table>

2.2. Tillage and cultural practices

The four tillage systems, each consisting of a combination of one tillage method and one field condition, were: (1) contour moldboard plowing in the open field, the control (MP-open); (2) contour soil barriers formed by ridge tillage in the open field (RT-open); (3) contour barriers formed by natural grass strips plus moldboard plowing (MP-strip); and (4) contour barriers formed by a combination of ridge tillage and natural grass strips (RT-strip). The 8-m-wide \(\times\) 38-m-long plots were arranged in a randomized complete block design with the four tillage systems replicated three times. The continuity of the slope length (Fig. 2(A)) was disrupted by contour natural grass barrier strips in the MP-strip and RT-strip systems (Fig. 2(B)). Five contour natural grass strips formed four alleyways in each MP-strip and RT-strip experimental plot. Five 50-cm-wide unplowed contour natural grass strips were established at intervals based on a 1.5 m vertical drop in elevation. Because these narrow strips were not tilled, natural grasses were soon established. The grass strip was dominated by bahia (\(Paspalum notatum\)), guinea (\(Panicum maximum\)), and Rottboellia (\(Rottboellia cochinchinensis\)) grasses. Alley width in plots with grass barrier strips was 9–10 m depending on slope. By September 1995, distinct terraces had formed between adjacent grass strips.

Tillage operations to a depth of 20 cm were performed alternately along the contour for all four

![Rainfall vs Pan Evaporation](image-url)

*Fig. 1. Monthly rainfall and pan evaporation at Claveria, Misamis Oriental, Philippines (IRRI, 1994 to IRRI, 1995).*
systems. For the MP-open system, a single animal (ox)-pulled, single bottom moldboard plow and harrow (in separate operations) were used to prepare the land prior to corn seeding. In accordance with local custom the moldboard plow direction was such to displace soil downslope. The moldboard plow was also used to create 15-cm-wide furrows at seeding and for two ‘hilling up’ operations of the MP-open plots. Hilling operations, performed primarily to control weeds and incorporate side-dressed fertilizers, moved soil both upslope and downslope.

The RT-open system was managed analogous to the MP-open system for planting and the first hilling operations. During the second hilling operation, 20-cm-high ridges spaced 60 cm apart (distance between adjacent corn rows) were constructed on the contour using an ox-pulled, locally-fabricated ridger. The ridger was a double-blade moldboard plow, which displaced soil both uphill and downhill from the furrow to both corn rows. Once formed initially in 1992, the ridges were maintained permanently in the same position for all four crops. The MP-strip system was identical to the MP-open system except that natural grass strips in the former were left in place permanently after they became established. The RT-strip system was managed using the combination of practices described for the RT-open and MP-strip systems.

Corn (Pioneer 3274) was planted within one or two weeks following harrowing (Table 2). The corn was hand seeded 2-cm deep and 25-cm apart in each furrow and covered by foot. Plant population was \( \approx 67,000 \) plants ha\(^{-1}\). Nitrogen, P and K fertilizers were applied at rates of 80, 30, and 30 kg ha\(^{-1}\) on elemental bases, respectively. Hand weeding by machete in all four systems was performed 40 days after corn emergence. For RT-open and RT-strip, an additional hand weeding was necessary two weeks before crop harvest. The dates and types of implements used for the cultural operations for the four tillage systems from August 1994 to October 1996 are given in Table 2.
2.3. Soil movement tracers

Prior to inserting soil movement tracers (SMT), the soil surface elevation was measured at 240 points in each plot and the average percent slope of each plot was computed. The SMT were installed on July 1994 at the shoulder slope position in the 8-m-wide 38-m-long erosion plots (Fig. 3). The cross slope was minimal. The SMT were metal 12-mm hexagonal steel nuts painted with a red or white anti-rust coating. The SMT were buried in two 90-95-cm demarcated microplots. Each microplot was divided into cells of 10 rows down the hill by 20 columns along the contour. One SMT was placed at the 5 cm depth at the nodes of the grid by pressing an index finger into the soil. Red SMT were placed in the left-hand microplot and white SMT were placed in the right-hand microplot of each plot. The location of all buried tracers was recorded.

2.4. Excavation of tracers and distance measurement

The SMT were excavated in May 1996 after all cultural operations and harvests for four successive corn crops were completed. The SMT were recovered by manually excavating the entire 8-m-wide × 11-m-long plot section. Labor to excavate the tracers for 12 erosion plots required the equivalent of 538 eight-hour days. Each plot was excavated by systematically removing 10 cm × 10 cm × 20-cm deep soil blocks. The excavation began 0.5 m uphill from row 1 of the buried SMT. A 20-cm-high metal framework was pushed into the soil and a metal soil dividing strip was pushed into the soil to cut the soil 20-cm deep. Then the soil was cut using a locally fabricated 10-cm-wide × 20-cm-long knife and removed in 10 cm × 10 cm × 20 cm deep blocks. Each soil block was crushed manually and forced through a screen with 10-mm openings. Upslope–downslope and horizontal coordinates for the recovered SMT were recorded relative to the references shown in Fig. 3. Using the center of the original 90- × 95-cm tracer placement area as the origin, the horizontal and upslope–downslope displacement distance for each SMT was computed by counting rows and columns. The actual distance, which is the total distance of each SMT translocation was calculated using the Pythagorean theorem.

2.5. Statistical analysis and nomogram development

The horizontal, downslope, and actual displacement distances of all recovered tracers for each erosion plot were analyzed using the SAS univariate procedure.
Analysis of variance was performed using the generalized linear model (GLM) procedure (SAS Institute Inc., 1988). Treatment means were compared by Duncan’s multiple range test. The mean and Q3 displacement distances were regressed on percent slope for contour moldboard plowing and ridge tillage.

Nomogram development for each tillage system involved measurement of the displaced distance of SMT (discussed above), determination of soil flux, and computation of tillage erosion rates. The soil flux \( k \) was computed as:

\[
k = MD \times TD \times BD
\]

where MD is the mean actual displaced distance (m year\(^{-1}\)), TD the tillage depth of 0.2 m, and BD is soil bulk density (kg m\(^{-3}\)). Eq. (1) estimates the soil flux caused by tillage operations based on either the actual or total displacement distance of SMT assuming that runoff water, wind, faunal activity, and soil creep were minimal during the two-year period. Later, in Fig. 8(A) and (C), we will see that MD can be expressed in terms of slope gradient using a regression equation. This soil flux computation is similar to those of Turkelboom et al. (1997) and Govers et al. (1994), except that our unit of soil flux, kg m\(^{-1}\), represents the total soil flux for all tillage operations on an annual rather than a per tillage event basis. Soil flux (kg m\(^{-1}\) year\(^{-1}\)) in our case 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 performed annually to

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Fig. 3. Schematic of area where soil movement tracers were inserted in open field (MP-open, RT-open) and contour natural grass strip (MP-strip, RT-strip) plots. Two hundred red and 200 white 12-mm hexagonal painted stainless-steel nuts were inserted in each plot. Plot dimensions not to scale.
grow crops. Mean annual soil loss due to a given tillage practice refers to the mean annual soil flux that occurs due to tilling an unit land area with a given slope length or contour interval. Mean annual tillage erosion rate (TER) (Mg ha\(^{-1}\) year\(^{-1}\)) was calculated by dividing the soil flux value by the plot or slope length (L) (downslope for MP-open and RT-open, and alley width or contour interval distance for the MP-strip and RT-strip systems) and converting the value to a per ha basis as follows:

\[
TER = \frac{MD(cm) \times TD(cm) \times BD(kg/m^3)}{L(m)} \times \left(\frac{1 m}{100 cm}\right)^2 \times \frac{1 Mg}{10^3 kg} \times \frac{1}{2} \times \frac{10^4 m^2}{ha} (2)
\]

where TD is 20 cm and 1/2 represents the conversion of data collected over a two-year period to a one-year period. Simplifying, the nomogram becomes

\[
TER = \frac{[(19.2 \times S - 72.8)TD \times BD]}{20 \times L} (3)
\]

for contour moldboard plowing and

\[
TER = \frac{[(8.8 \times S - 5.7)TD \times BD]}{20 \times L} (4)
\]

for contour ridge tillage. The function in parentheses in Eqs. (3) and (4) replaces MD and was derived by regressing mean displacement distance on percent slope (S) (presented later in Fig. 8(A) and (C)). Likewise MD in Eq. (2) can be replaced by regression equations (presented later in Fig. 8(B) and (D)) to estimate soil erosion rates based on the Q3 distance of SMT movement.

3. Results and discussions

3.1. Tracer recovery and movement

Percent recovery of the 400 SMT buried per plot was 82–85% and was not affected by tillage system (Table 3). However, tillage system did affect the percent of SMT displaced downslope (p < 0.0001). Only 54% of the SMT recovered in the RT-strip system were displaced downslope, but for the other systems, >80% of recovered SMT were displaced downslope.

In reality, each SMT likely was displaced from its original location. Since each SMT was not numbered, and therefore could not be assigned an exact original location, it was necessary to measure displacement distance using the center of the SMT microplot as a reference (Fig. 3). Consequently, a few SMT for the ridge tillage system were recovered in a location having an upslope–downslope component identical to the original row in which it was placed, but moved laterally from the original column in which it was placed. In this situation, calculation of SMT displacement distance relying only on row counts (downslope), such as reported by Turkelboom et al. (1997), would ignore lateral soil movement and, thus, underestimate actual SMT displacement. Measurement of downslope displacement distance by Turkelboom et al. (1997) was appropriate because hand digging on a 60% slope is systematically done by hoeing down hill. Our situation is different in that animal-powered, contour plowing can create both lateral and upslope–downslope soil movement. Plotting of x and y coordinates of each recovered SMT in our study, in reference to the original position, allows comparison of both upslope–downslope and horizontal displacement of SMT for the different tillage systems.

The displaced position of each recovered SMT after growing four corn crops, in reference to the center of the 90- x 95-cm microplots is shown in Fig. 4 for the four tillage systems. The greater spread of tracers downslope for the MP-open compared to the RT-open system was expected because the soil in the ridges in the latter tend to reduce the rate of downward movement. Likewise, downhill tracer movement was greater for the MP-strip than for RT-strip system.
Fig. 4. Displacement of SMT for four tillage systems on 16% slope after cultivating the land for four corn crops. Total number of recovered SMTs out of 200 for each color are given in parentheses. The reference point marked by the large dot represents the center of the 90 × 95 cm area of SMT installed microplot. One row = 10 cm, one column = 10 cm.
Fig. 5. Displacement of red SMT for four tillage systems on 19% and 22% slopes after cultivating the land for four corn crops. Total number of recovered SMTs out of 200 for each treatment are given in parentheses. The reference point marked by the large dot represents the center of the 90 × 95 cm area of SMT installed microplot. One row = 10 cm, one column = 10 cm.
For each tillage method, SMT movement was less under grass strips (MP- and RT-strip) compared to the open field. Tracers for MP-open and MP-strip moved further downslope than those for RT-open and RT-strip. An increase in percent slope exacerbates downhill movement of SMT for the MP systems (Fig. 5). Slope steepness had less effect on tracer movement for the RT systems.

The reference point for calculation of downslope movement of tracers is between rows 5 and 6 (Fig. 3). This coincides with row zero in Figs. 4 and 5. The reference line in the microplot used to calculate horizontal tracer movement is between columns 10 and 11 (Fig. 3). When we first began to excavate the SMT, we excavated the border area between tillage plots in addition to the entire plot area because we did not know how far the tracers would move horizontally.

After excavation of three plots (RT-open, MP-strip, and RT-strip in Fig. 4), we discovered that few tracers moved into the border area, and we discontinued excavation of the border area.

The relative frequencies of actual SMT displacement distance for the four tillage systems and three slopes are presented in Fig. 6. Incorporation of ridge tillage into a tillage system reduces actual SMT movement. Most SMT under the grass strip systems moved <6 m from the original position, whereas some of the SMT under open field systems moved 8 m or more. Observation of relative frequency data in Fig. 6(A, C, and E) shows that the greatest actual displaced distance for the open system increased with percent slope. The open system has no barriers to restrict downslope SMT transport as exists for the grass strip systems.

![Fig. 6. Relative frequency distribution of actual displaced tracers for four tillage systems at three slopes.](image-url)
Lindstrom et al. (1990) reported a strong correlation between tillage-induced soil movement and percent slope. Other factors reported to affect tillage-induced soil movement include slope length (Turkelboom et al., 1997), speed of tillage operation, size of tillage implement, and direction of tillage (Lobb et al., 1995). Factors such as tilling fallow land during high weed incidence, or first plowing for seed bed preparation, might contribute to the dispersion of SMT in the MP systems. Roots and large clods accumulating in front of the moldboard plow often cause soil to be dragged along with the plow. In addition, when turning a moldboard plow at the end of a row, a plowman applies extra force to free the plow of any accumulated soil so as to lighten the plow before lifting it from the furrow. Lifting the plow takes less physical effort when the plow is turned downhill.

3.2. Displacement distance of tracers

Various statistical parameters based on actual displacement distance for the four tillage systems at 16%, 19%, and 22% slope gradients are shown in Table 4. Mean displacement distance increased with percent slope for each tillage system, but the rate of increase in displacement distance with respect to slope was higher for the MP systems compared to the RT systems. The highest standard deviation occurred for MP-open, which had the greatest tracer dispersion. The standard deviation of displacement distance is useful as an indicator of random dispersion of tracers due to different tillage systems. Standard deviation for each treatment is expected to be smallest in the first year of tillage and to increase as the number of tillage operations increases.

The analysis of variance for mean, Q3, and maximum actual and downslope displacement distances are shown in Table 5. Highly significant differences in these statistical parameters as affected by tillage system were observed. In Fig. 7 we see that the greatest mean and maximum actual displacement distances occurred for MP-open.

The observed difference in mean SMT displacement distance between MP-open and MP-strip was due to the contour natural grass barrier strips. The grass strips reduced the amount of soil moving down-

<table>
<thead>
<tr>
<th>Tillage system&lt;sup&gt;a&lt;/sup&gt;</th>
<th>n&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Mean&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Maximum&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Q3&lt;sup&gt;d&lt;/sup&gt;</th>
<th>SD&lt;sup&gt;e&lt;/sup&gt; (cm&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>p &lt; W&lt;sup&gt;f&lt;/sup&gt;</th>
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<tr>
<td>16% Slope</td>
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<tr>
<td>MP-open</td>
<td>341</td>
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<td>780</td>
<td>361</td>
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</table>

<sup>a</sup> MP = contour moldboard plowing; RT = contour ridge tillage.
<sup>b</sup> Number of tracers recovered out of 400 SMT buried per plot.
<sup>c</sup> The distance beyond which 25% of the tracers were displaced.
<sup>d</sup> Standard deviation.
<sup>e</sup> Probability test in univariate procedure which is similar to ‘T’ in ANOVA.
slope and gradually reduced the percent slope in the alley between adjacent grass strips. Failure to observe differences in mean SMT displacement distance between RT-open and RT-strip was due to the large reduction in SMT movement under ridge tillage alone. Both ridge tillage systems reduced SMT displacement distance compared to the MP systems.

### 3.3. Models for displacement distance of tracers

Linear regression models relating the mean and Q3 parameters for actual SMT displacement distance as a function of percent slope for two tillage systems are presented in Fig. 8. The high $r^2$ value for moldboard plowing in Fig. 8(A) indicates that soil displacement is highly related to percent slope. The slope of the curves for contour moldboard plowing (Fig. 8(A) and (B)) was two- to three-fold higher compared to the slopes of contour ridge tillage (Fig. 8(C) and (D)). The low $r^2$ value and gentle slope for the ridge tillage curves indicate that soil movement for this practice is not as closely related to percent slope as for moldboard plowing.

### 3.4. Soil flux and tillage erosion rates

Estimation of soil flux and tillage erosion rates was based on actual displacement distance of tracers assuming that the tracers and soil material move at the same rate. The mean and Q3 for soil flux and tillage erosion rate were highest for MP-open and lowest for RT-strip (Table 6). Annual soil flux and tillage erosion rate were greater for the MP-open

![Image](image-url)
compared to the MP-strip, but no differences in soil flux and erosion rates were observed between RT-open and RT-strip. The relation of soil flux to tillage operations performed on an annual basis are compatible with water erosion rates reported in a companion study (Thapa, 1997). The soundness of using Q3 to estimate

Table 6
Annual soil flux and tillage erosion rates for four tillage systems at Claveria, Philippines

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Annual soil flux rate</th>
<th>Annual tillage erosion rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Kg m$^{-1}$ year$^{-1}$</td>
<td>Q3 $^{b}$</td>
</tr>
<tr>
<td>MP-open</td>
<td>241$^{a}c$</td>
<td>304 a</td>
</tr>
<tr>
<td>RT-open</td>
<td>131 c</td>
<td>161 c</td>
</tr>
<tr>
<td>MP-strip</td>
<td>158 b</td>
<td>195 b</td>
</tr>
<tr>
<td>RT-strip</td>
<td>112 c</td>
<td>141 c</td>
</tr>
<tr>
<td>Standard error</td>
<td>±6.6</td>
<td>±6.9</td>
</tr>
</tbody>
</table>

Source          df  Mean squares from ANOVA

| Blocks         | 2       | 2301.6 | 2975.5 | 159.5 | 205.4 |
| Treatments$^{d}$ | 3       | 9714.5 | 15760.2 | 672.9 | 1091.6 |
| Residuals      | 6       | 130.1  | 141.0  | 9.0   | 9.7   |
| CV %           |         | 7.1    | 5.6    | 7.1   | 5.9   |

$^{a}$MP = contour moldboard plowing; RT = contour ridge tillage.
$^{b}$Q3 soil flux and erosion rate are computed based on the distance beyond which 25% of the tracers were displaced.
$^{c}$Means in a given column followed by common letters are not significantly different at the $p = 0.05$ level.
$^{d}$Significant at the $p = 0.0001$ for all soil flux and tillage erosion variables.
soil flux and tillage erosion rates as proposed by Thapa et al. (1999) needs further investigation but the concept appears to be valid.

The 63.4 Mg ha\(^{-1}\) year\(^{-1}\) of tillage erosion in the MP-open system is very high and much soil eventually will be lost from the field if soil continues to move downslope unimpeded. Installation of contour grass strip barriers reduced the annual tillage erosion rate by one-third. The higher tillage erosion rate in MP-strip (42 Mg ha\(^{-1}\) year\(^{-1}\)) compared to RT-strip (30 Mg ha\(^{-1}\) year\(^{-1}\)) indicates a more rapid rate of terrace formation for MP-strip. Soil moved from the upper alley area in the MP-strip system accumulates on the upslope side of contour grass strips and forms a terrace more quickly. This process accelerates topsoil loss in the upper alleyway, which may cause serious soil fertility degradation in the zone just below the contour grass strip. Thus, from the field or mass balance point of view, redistributed soil is not lost from the field because the soil material remains on the terrace. However, from a nutrient management point of view, breaking the continuum of slope length with contour grass strips creates zones of land with scoured and nutrient-poor surface soil, and a zone in the lower alleyway with accumulation of a nutrient rich and deeper topsoil (Govers et al., 1994; Poesen, 1995; Garrity, 1996; Turkelboom et al., 1997). We estimate that as much as 40% of the cropped alleys might eventually be degraded physically, chemically, or biologically if the alleys are moldboard plowed frequently. In this study, 42 Mg ha\(^{-1}\) year\(^{-1}\) of soil in the MP-strip system moved downhill from the upper alley, leaving an exposed acidic subsoil with high Al saturation. Although the reduced yields in the upper alleyways may be compensated partially or wholly by increased yields in the lower alleyways, and the soil fertility of the upper alleyways may recover gradually over a number of years, careful management of these spatially variable areas within an individual alley must be provided to avoid short- and long-term negative effects on crop production.

3.5. Nomogram for tillage erosion rates

Nomograms to determine soil losses for contour moldboard plowing and ridge tillage as a function of percent slope and plot length (distance between adjacent contour grass strips or length of open plot) are shown in Fig. 9. Regression equations relating displacement distance to percent slope (Fig. 8(A) and (B)) were used for the MD term in Eq. (1). Soil redistribution to lower alleyways under moldboard plowing can be as high as 500 Mg ha\(^{-1}\) year\(^{-1}\) if a farmer cultivates land with a slope of 20% and a grass strip contour interval or plot length of 5 m. About 53% of this soil movement can be reduced by adopting ridge tillage.

4. Conclusions

Intensive moldboard plowing, where practiced, is a primary factor of land degradation in humid tropical uplands because the more fertile topsoil is physically
displaced downhill exposing less fertile, acidic subsoil. Soil degradation by moldboard plowing and its long-term consequences on soil physical, chemical, biological, and hydrological properties has been omitted from alley cropping research and soil erosion modeling. This omission may help explain the failure of alley cropping to meet farmers’ expectations to have higher crop production. The present challenge is to model soil erosion by considering all soil transport agents—tillage, water, wind, soil creep, macro-fauna and human activities. In this study, we assumed negligible rates of soil erosion by wind, soil creep, and faunal activity. This limitation should be taken into consideration when extrapolating our results to other field conditions.

Reduction of tillage erosion is indispensable to maintain soil fertility and sustain crop production on sloping lands in the humid tropics, especially under contour hedgerow alley cropping systems. Contour ridge tillage in conjunction with natural grass barrier strips gradually reduces the degree of slope, breaks the continuum of downhill slope length, and reduces the amount of soil removed from the field.

5. List of symbols

SMT soil movement tracers—devices, natural or manmade, placed in the soil to assess the mass transport of soil
MP moldboard plow
RT ridge tillage
$k_s$ soil flux, i.e. the mass of soil that moves through a vertical cross-section of the plough layer of unit width due to the combined effects of all tillage passes performed annually to grow crops
MD displaced distance—the distance a SMT is displaced in one year
TD tillage depth
BD bulk density
TER mean soil loss due to contour moldboard plowing on ridge tillage contour (Mg ha$^{-1}$ year$^{-1}$)
Q3 the distance beyond which 25% of all recovered SMT moved
Q1 the distance beyond which 75% of all recovered SMT moved

References


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.


