Bench terracing in the Kerinci uplands of Sumatra, Indonesia

By Stephen F. Siebert and Jill M. Belsky

ABSTRACT: Bench terracing's effect on erosion, soil characteristics, crop yields, and cropping area and socioeconomic factors that affect farmers views and use of bench terraces were evaluated in the Kerinci uplands of Sumatra, Indonesia. Bench terraces reduced soil loss 70% ($P<0.05$) on enclosed runoff plots in comparison to unterraced fields under the same cropping pattern. Erosion under bench terraces was not significantly different from two grass bund treatments that are less labor- and capital-intensive. Furthermore, bench terraces resulted in a 50% reduction in peanut yields ($p<0.01$) at the base of terrace risers in comparison to middle bench sites, a 13-31% loss in cropping area, and the exposure of chemcially and physically undesirable subsoils. High-income farmers were two and a half times more likely than middle- or low-income farmers to construct bench terraces. However, neither high farm income nor government subsidies insured long-term terrace maintenance. Terraces are not widely maintained, even among high-income farmers, because they conflict with existing agroforestry-based land use practices that are less labor-demanding. In contrast, agronomic methods of soil conservation, particularly grass bunds, are used widely by low-income farmers without payment of subsidies.

SOIL erosion is widely recognized as one of the most serious environmental problems confronting developing countries in the tropics. On-farm soil degradation and reduced crop yields, downstream disturbance of hydrological regimes, and increased rural proverty have been linked to increased rates of soil erosion (*1, 4*).

During the last decade, development agencies, such as the World Bank and the U.S. Agency for International Development, as well as host country governments, have financed hundreds of soil conservation projects in an attempt to control soil degradation and develop more productive and sustainable land management practices. Bench terraces are a widely used soil conservation technique in this effort (*2, 11*)

There are several types of bench terraces, including level bench, outward sloping, reverse slope, step, and irrigation terraces (*11*). Irrigation terraces, as the name implies, are used for irrigated crops, particularly rice (*Oryza sativa* L.). Outstanding examples of irrigation terraces can be seen in the Philippines and other centers of early civilization (*8*). The other types of terraces are used under rainfed conditions, and it is these latter types that are encouraged in upland soil conservation projects (*18*).

Soil scientists have made recommendations about how and under what circumstances bench terraces should be constructed. Hudson (*11*) and Sheng (*17*) contend that hand-built terraces are suitable for slopes up to 47%. Elsewhere Sheng (*18*) noted that the depth of the topsoil should not be less than half of the height of the riser to insure sufficient topsoil on the bench. Lal (*14*) found that bench terraces are effective on slopes up to 47%, but concluded that their high cost renders them unjustified for low-value subsistence crops. Hurni (*12*) concluded that terraces probably are the best means of soil conservation, provided site-specific agroecological and socioeconomic conditions are considered. In contrast, Temple (*20*) reported that bench terraces are unsuited to farming conditions in a mountainous area of Tanzania because their construction exposes infertile subsoils, requires too much labor, and results in soil saturation and landslides.

Potential constraints to the use of bench terraces rarely have been quantified and often are overlooked when advocating and administering soil and water conservation programs. Throughout tropical uplands, bench terraces have been built on a variety of slopes and soil types. In Indonesia, for example, the government subsidizes bench terrace construction on land with slopes up to 50%, regardless of soil type (*6*). Similarly, bench terraces are promoted to farmers without regard to their current land use or socioeconomic status.

Bench terraces can reduce water runoff and soil erosion in many instances (*9, 22, 23*). However, there is surprisingly little empirical data from tropical uplands that document (a) soil sediment losses under bench terraces relative to other less capital- and labor-intensive soil conservation measures, (b) the effect of bench terrace construction on soil productivity and crop yield, and (c) the benefits and disadvantages of bench terracing as perceived by the farmers who are expected to build and use the technology.

Study and methods

We conducted our research in the highland valley of Kerinci, Sumatra, Indonesia. Irrigated rice is dominant in the valley; cinnamon [*Cinnamomum burmanni* (Ness) Blume], coffee (*Coffea canephora* Peirre ex Froehner), and other cash crops are grown on hills above the valley. Most farmers in Kerinci cultivate both an irrigated rice field and one or more hillside farms.

Soil erosion is widespread in Kerinci. In 1976 the Indonesian government initiated a soil conservation program known as "Penghijauan" (Regreening) in an attempt to reduce upland degradation. The Penghijauan program subsidizes the use of soil conservation practices, including bench terraces and grass contour bunds, chemical fertilizers, and cultivation of high-value crops on "model" farms. Since the early 1980s, the program has concentrated exclusively on the introduction of bench terraces (*6*).

Soils in Kerinci are complex red-yellow podzolics (isohyperthermic Tropohumults) overlying sedimentary parent materials. Annual rainfall is about 1,945 mm (72inches),

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which falls primarily between September and May (*16*).

We conducted our research from August 1987 to May 1988 in two villages: Sungai Ning, an area characterized by severe soil degradation, low household incomes, and annual-focussed cropping patterns, and Koto Lebuh Tinggi, an area with relatively little soil erosion, high household incomes, and annual/perennial rotational (agroforestry) cropping systems.

We measured soil losses associated with various land use practices in Sungai Ning using enclosed runoff plots. Each runoff plot, 1.5 m x 10 m (5 x 33 feet), was bordered by 0.5-cm (0.2-inch) thick plywood strips that were imbedded 25 cm (10 inches) into the soil. A galvanized metal flume and collecting tanks at the base of each plot collected eroded sediment and water runoff (*4, 21*). The study employed a randomized complete block with three replications. We established the blocks on slopes of 33%, 35%, and 38% and cultivated two locally important crops, peanuts (*Arachis hypogaea* L.) (October - January) and corn (*Zea mays* L.) (January - May). We collected eroded sediments and water runoff following every rainfall (only sediment losses are reported here).

We studied five land use practices:

1. Control - existing agricultural practices, that is, peanuts planted at 25 x 25-cm (10 x 10-inch) spacing, corn planted two seeds per hole at 75 x 100-cm (30 x 40-inch) spacing, and no soil conservation measures employed.

2. Control - existing agricultural practices with increased planting density and nitrogen-phosphorus-potassium (NPK) fertilizer application, that is, peanuts planted at same spacing as in the control in conjunction with 100 kg/ha (89 pounds/acre) triple-super phosphate (TSP) and 50 kg/ha (45 pounds/acre) potassium chloride (KCl) applied at the time of planting and corn planted one seed per hole at 25 x 75-cm (10 x 30-inch) spacing and fertilized with 100 kg/ha urea, 100 TSP, and 50 kg/ha KCl applied at the time of planting, and an additional 100 kg/ha urea applied 4 and 8 weeks after planting.

3. Level bench terraces - design based on Penghijauan program recommendations, that is, three terraces per 10-m (32-foot) plot, risers 75 cm tall and planted to *Setaria* spp. grass at 30-cm intervals.

4. Grass contour bunds - three bunds per plot, each 15 cm (6 inches) tall and planted to double rows of *Setaria* at 30-cm spacing.

5. Grass and *Gliricidia* - a N-fixing leguminous tree for use as a mulch, each at 30-cm intervals. Mulch cover was maintained at about 50% ground cover throughout the cultivation period following an initial application rate of 0.5 kg/m² (5,000 kg/ha, 4,460 pounds/acre).

Table 1. Sediment losses on runoff plots as influenced by soil conservation measures, Kerinci, Sumatra.

Conservation Measure	Soil Loss (t/ha) September-May	Soil Loss (t/ha) November-May
Control, none	3.81a*	3.51a
Control, fertilizer	1.59b	1.33b
Bench terraces	1.13bc	0.68bc
Grass bunds	0.81bc	0.40c
Grass + *Gliricidia* bunds & mulch	0.53c	0.34c

*Values followed by different letters are significantly different ($p<0.05$) using protected LSD analysis.

The grass and grass plus *Gliricidia* bund treatments were developed following conversations with local farmers and a review of the literature (*13, 14, 19*). These two techniques require little capital or labor to establish and maintain relative to bench terraces. Furthermore, grass bunds continue to be built and maintained by some local farmers without payment of subsidies following their introduction by the Penghijauan program in the late 1970s.

We evaluated the effect of bench terrace construction on yield by recording mean weight of peanuts and total above ground biomass from nine plants collected at the base of risers (an area of subsoil exposure during terrace construction) and at middle bench sites (an area of little or no subsoil incorporation) on the runoff plots.

We measured the effect of bench terrace construction on soil chemical and physical properties by collecting five soil samples from the base of terrace risers and from middle bench sites in the runoff plots. The soil samples were then pooled and analyzed for pH, cation exchange capacity, calcium (Ca), magnesium (Mg), K, available P, N, carbon, aluminum (Al), and hydrogen ion (H+) concentrations as well as percent sand, silt, and clay fractions at the Soil Testing Laboratory, Sukarami Research Institute for Food Crops, in Padang, Sumatra.

We measured the loss of cropping area resulting from the establishment of soil conservation measures for peanut and corn crops on the runoff plots and on adjacent farms. Results are expressed as a percentage of total cropping area available when soil conservation measures are not used.

We investigated socioeconomic factors that underlie farmers' views and use of bench terracing through participant observation, farmer interviews, and a random survey of 25% of all households in the two villages. A subsample (25%) of upland fields were field-checked to validate farmers' descriptions of cropping prac and conservation strategies and to eval the status of their bench terraces.

We analyzed eroded sediment losse summing the data for the cropping y conducting a log transformation (varia were proportional to treatment means), employing protected least-significa difference analyses to test for significan ferences and to compare treatment me We used analysis of variance to tes significant differences in peanut yields total aboveground biomass productio

Results and discussion

Agronomic performance. Use of conservation measures resulted in a si cant reduction ($p<0.05$) in soil ero compared to cultivation without cons tion measures (Table 1). Use of bench races reduced soil losses about 70% pared to the control, while grass bund grass and *Gliricidia* bunds with m lowered mean soil losses 79% and respectively. Soil erosion rates under b terraces were not significantly diff from the control-fertilizer treatmen from the two grass bund measures, after allowing 6 weeks for soil settlin the establishment of *Setaria* on te risers.

Soil erosion rates under bench ter could decline in future years. Howev significant improvement in bench te performance on farms is unlikely be of the widespread failure by farme adhere to terrace design specifications properly maintain terrace risers. poorly maintained, soil erosion rat bench terraces may be comparable even exceed farming without use o conservation measures (*2*). For exa poorly maintained bench terraces inc erosion on 4% of the farms in a soi servation project in Java, Indonesia

The soil erosion rates observed i study were low relative to other s from the tropics (*9, 13, 17, 19*). Sever tors may account for this. First, emp field studies have revealed that Tropoh soils, such as those in Kerinci, ha herently low erodibility relative to tropical soil families due to the stru stability provided by oxidic constituen Second, Kerinci receives substantial precipitation and has a lower rainfall sity index than many other are Southeast Asia (*16*), and the area is n ject to highly erosive typhoon rains. rainfall erosivity is relatively low as

The effect of bench terrace constr on soil productivity and crop yield r limitations to their use on sites with s topsoils that overlie chemically and/o ically limiting subsoils. For example, mean peanut production at the base of terrace risers was only half of that observed at mid-terrace sites ($p<0.01$) (Table 2).

There are a number of potential soil-related constraints to the use of bench terraces in Kerinci (Table 3). Soil pH and concentrations of Ca, Mg, K, and available P were lower at the base of terrace risers than at mid-bench sites, while Al and H+ concentrations and percent clay content were higher. These conditions are all unfavorable to crop growth. Local farmers recognize this problem and report that cassava (*Manihot esculenta* Crantz), which is tolerant of acid, relatively infertile soils, is the only crop suited to sites where subsoil has been exposed. However, the low value of cassava makes it unlikely that farmers would terrace cassava land unless subsidized to do so.

The extent of subsoil exposure and mixing during bench terrace construction and its effect on crop yield will vary from one site to another depending on such factors as topsoil depth, slope steepness (i.e., depth and frequency of terraces constructed), method of terrace construction, and susceptibilty of the crop to adverse chemical and physical characteristics. Under conditions such as in Kerinci—20-50% slopes with shallow topsoils and undesirable subsoils—at least 20% of the total cropping area is likely to be affected by subsoil incorporation during terrace construction and, thus, subject to reduced crop yields. Subsoil incorporation could be reduced by saving topsoil during terrace construction and redistributing it over the bench or by constructing terraces uphill and spreading topsoil from above. However, both of these techniques require additional labor.

Use of soil conservation measures often reduces the area available for crop production. Of the three measures evaluated, bench terraces resulted in the greatest loss of cropping area, up to 32% (Table 4). From the farmer's perspective, any loss of cropping area must be compensated for by a corresponding increase in crop yield and/or the production of some other valuable product. We observed no crop yield responses to conservation farming methods in this study, and the only commodity produced by these conservation methods was *Setaria* grass for use as livestock fodder.

Socioeconomic considerations. While enclosed runoff plots, on-farm studies, and analyses of soil samples provide insight into the relative performance and impacts of various conservation measures, the ultimate test is the farmer's appraisal. What do Kerinci farmers think and do about soil conservation, and what is their rationale for using or not using bench terraces?

All of the farmers interviewed were aware of bench terraces and the Penghijauan program efforts to encourage their use. Of the farm households surveyed, 24% had constructed bench terraces without government subsidies, although 20% of these did so because they were promised payments. Households with relatively high incomes were about two and a half times more likely to construct bench terraces than those with low incomes (Table 5).

Farmers who have never built bench terraces reported that the labor required for construction and maintenance (or capital required to hire labor) was the major constraint. Farmers also reported that the use of terraces typically resulted in (a) topsoil loss and an initial reduction in crop yields, (b) competition between crops and grasses planted on the risers, (c) a 25-35% loss of cropping area, and (d) the use of fertilizer that is costly and considered dangerous to crops by inexperienced users.

Table 2. Effect of bench terrace construction on peanut yield and total aboveground biomass, Kerinci, Sumatra.

	Mean Yield (kg/ha)*	
Terrace Location	*Nut Yield*	*Aboveground Biomass*
Base of risers	4,112	10,736
Mid-bench sites	8,160	16,160
Differences	$p<0.01$	$p<0.01$

*N=9.

Table 3. Effect of bench terraces on selected soil characteristics, Kerinci, Sumatra.

	Location	
Characteristic	*Base of Risers*	*Mid-bench*
pH	5.4	5.8
CEC (meq)	26.2	25.0
Mg (meq)	4.3	7.7
Ca (meq)	3.6	10.4
K (meq)	0.9	2.2
Available P (ppm)	0.3	4.4
N (%)	0.14	0.32
C (%)	1.46	4.45
Al (meq)	14.1	0.6
H^+ (meq)	7.6	0.5
Soil texture (%)		
Sand	18.0	46.7
Silt	32.8	33.3
Clay	49.2	20.0

Table 4. Reduction in cropping area due to the use of soil conservation measures, Kerinci, Sumatra.

Conservation Measure	*Reduction in Area (%)* Peanuts	Corn
Control-none	0	0
Bench terraces	32	13
Grass bunds	17	5
Grass + *Gliricidia* bunds	10	5

Table 5. Relationships between unsubsidized bench terrace construction and farm household income, Kerinci, Sumatra.

	*Household Income Strata (%)**		
Terrace	*Low*	*Middle*	*High*
Never built terraces	83	85	56
Built terraces	17	15	44

*Chi square significance $p<0.05$; N=62.

Survey results and field checks revealed that only 63% of subsidized terrace users and 47% of unsubsidized terrace users maintain their terraces. Farmers do not maintain terraces, even after the initial capital and labor have been provided, primarily because of conflicts with labor allocation priorities and other land use practices. For example, high-income hillside farmers typically use rotational agroforestry practices on their hillside farms. During the first year, these farmers plant annual crops, such as beans (*Phaseolis* spp.), intercropped with cinnamon or coffee. Annual cultivation is not possible with this system after the third year due to shading, and the labor required in cinnamon and coffee cultivation is very low, only 1 or 2 days per year (excluding harvest). Consequently, farmers have no desire to return more frequently to their fields to maintain terraces. Furthermore, farmers believe that tree crops provide sufficient protection against soil erosion.

Of those farmers who use and maintain terraces, less than half have adequately protected terrace risers. Farmers purposefully leave risers bare because they report that (a) *Setaria* grass is not always available for planting; (b) elephant grass (*Pennisetum purpureum*), another recommended species, dessicates the soil on terrace benches; (c) grass can interfere with crop growth; and (d) without livestock and thus fodder needs, they have no reason to grow grass.

Twenty-seven percent of the households surveyed use grass bunds. Importantly, 85% of these farmers are in the low- or middle-income strata. Moreover, 80% of this group cultivate primarily annuals, which are more susceptible to erosion than perennial crops, on their hillside farms. Kerinci farmers recognize the risk of erosion but conclude that "when the government pays, we build bench terraces, but when the farmer pays, we build grass bunds" (farmer in Sungai Ning, personal communication).

Conclusions

Soil conservation is not a new concept to farmers in Sumatra. In fact, Dutch colonial authorities mandated the construction of terraces and the use of cover crops as early as 1874 (*7*). Farmers in Kerinci were instructed by local village leaders to build terraces on newly opened swiddens in the early

1900s. However, many farmers refrained from using terraces then, just as they do now, because of their high labor demands and conflict with alternate land uses (*15*).

Despite government promotion and subsidies, bench terraces are not widely used in Kerinci. While use of bench terraces is greatest among high-income farmers, neither high income nor government subsidies insure long-term terrace maintenance and use. As Chapman concluded, "If the constraints were not so severe [i.e., in rainfed fields], we would no doubt find terracing more widespread in Southeast Asia" (*3*).

The erosion control value and farmer preference for grass bunds and agroforestry systems underscore the importance of agronomic soil conservation measures in Kerinci. Our study supports the view that "conservation farming today needs improved farming methods that only include mechanical protection works as a last resort" (*10*).

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