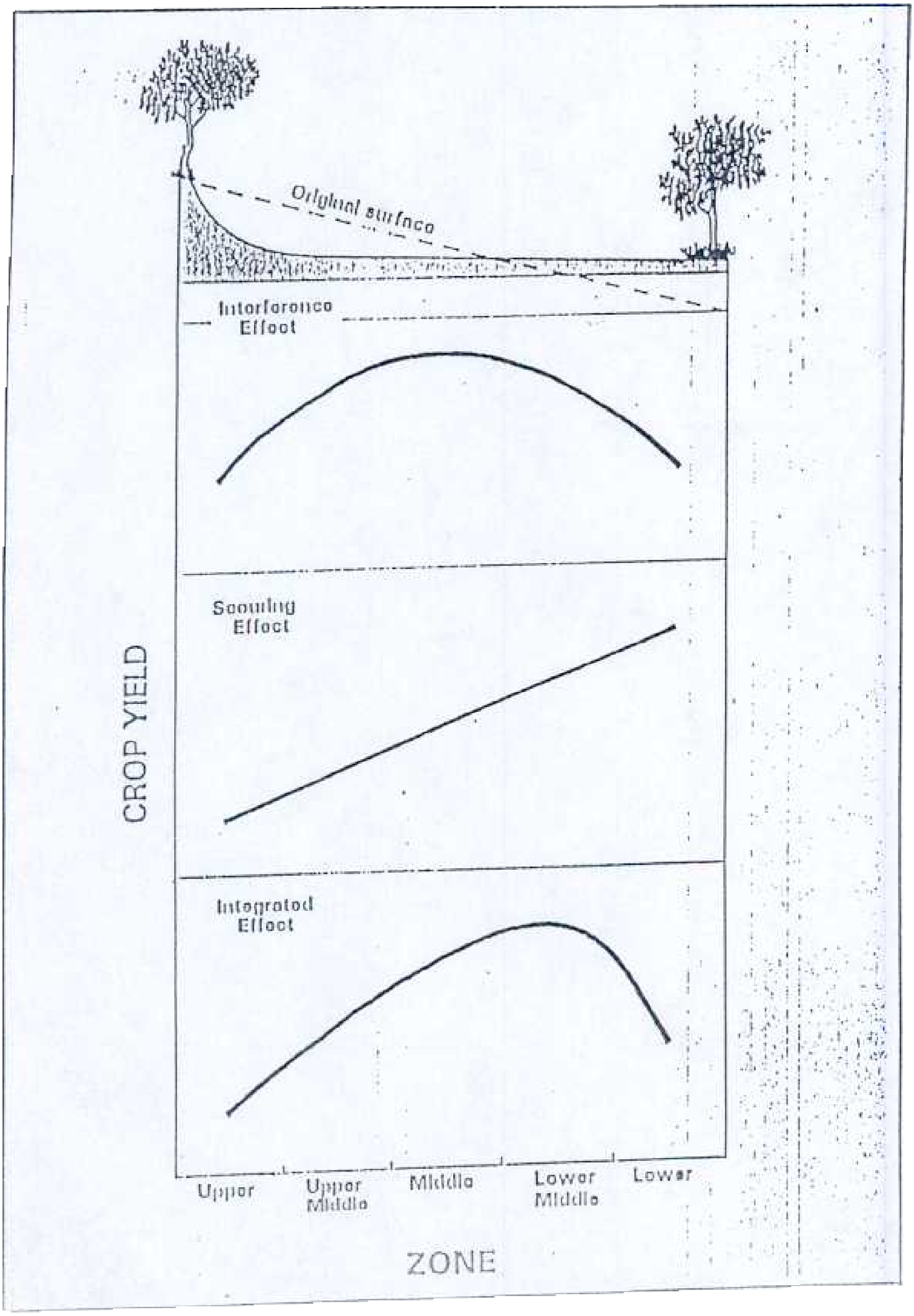
Figure 2. How the scouring effect of tillage, and the interference effect of hedgerows on crops, creates crop yield variability across alleyways in contour hedgerow systems on slopes.



A Ridge tillage system for animal-draft farming. As we searched for practical ways to farm hedgerow systems to avoid scouring by preventing the movement of soil downslope by tillage, examined exposed to the principles of permanent-ridge tillage as practiced in the United States. One of the pioneers of this tillage system, Wes Buchele of Iowa State University (Buchele, 1956), worked with us in the adaptation of ridge tillage to animal power systems. There are several different types of crop production systems on ridges in the tropics (Lal, 1990). Many of these are traditional farmer-developed practices used in South and Central America (Coe, 1964; Parsons and Denevan, 1967; Armillas, 1971), the Congo basin and West Africa (Jurion and Henry, 1969; Okigbo and Greenland, 1976), and in Southeast Asia. These systems may be defined as ridge tillage since they are share the characteristic that the topsoil is scraped and concentrated in a defined region to deliberately raise the seedbed above the natural terrain (Lal, 1990). But the ridges are not maintained permanently in an untilled condition. To date we have been unable to find a single published reference in the humid tropics on ridge-tillage with the ridges permanently maintained, as is practiced by ridge-till farmers in North America.

The principle of the permanent-ridge tillage system is to maintain alternate strips of untitled and tilled land in a row-cropped field: An untilled strip (the ridge) where the crop is planted in the same exact row position in each successive season; and an inter-row area where cultivation is practiced weed control and hilling-up is done. As adapted to animal-powered systems the sequence of operations is as follows:

1) Make a shallow furrow through the stubble of the previous crop and plant in the same row,

2) Cultivate the crop with the moldboard plow in the standard way that maize farmers use in the Philippines (usually an off-barring operation at about 14 days after emergence, and hilling-up at about 28 days after emergence.) This creates the ridges.

3) After harvest there is no plowing or harrowing operations before planting the next crop. Return to step 1 and plant in shallow furrows through the stubble of the previous crop. If there is considerable weed growth on the ridges, band-spray a broad-spectrum systemic herbicide (usually glyphosate is preferred) on the ridges to eliminate early weed competition. Inter-row cultivation controls weeds in the inter-row area, and hilling-up buries weed growth on the ridges.

The ridge-till field looks little different than a conventional row-crop field. The ridges are but slightly more pronounced than those in conventional hilled-up maize. They tend to slump down during and between crops. At planting the ridges may be only slightly elevated above the base level of the inter-row furrows.

What are the hypothesized advantages of such a system? First, many studies in the US have shown that the permanent ridge system dramatically reduces soil loss. The ridges may act as a partial barrier to the surface flow of water, but their major distinction is that they act as a zone of greater infiltration. The no-tillage area tends to accumulate organic matter and macropores due to soil biological activity and root channes. Since primary and secondary tillage operations are not practiced for land preparation between crops, the land is less subject to erosion in the off-season. Second, Labor and expense in land preparation is eliminated. Pre-plant weed control is accomplished by judicious use of a herbicide.

We recently completed a four-year study of permanent-ridge till systems on two farmers fields in Claveria, Philippines (Thapa *et al*, 1996). The soils were very fine kaolinitic clays classified as Lithic and Rhodic Hupludox, with strongly acidic surface soils (pH of 4.1-4.4), organic carbon contents of 1.6%. The conventional cropping system in this area is two crops of maize per year. Most cropland has slopes in the range of 10 to 60 percent. Annual rainfall is about 2000 mm. Farmers plow and harrow twice to prepare the land for each crop using a single draft-animal and moldboard plow. Planting is done by hand in furrows made with the plowpoint. Seeds, usually single-cross hybrids, are dibbled in the furrow and covered by foot. Inter-row cultivation is also done with the same moldboard plow. We used the same local equipment for the permanent-ridge till system.

In conventional maize production farmers generally plant on the contour, more or less. We compared the conventional system with ridge tillage, and with natural vegetative strips (NVS) laid out at an 8 m distance from each other, a difference of 1.5 meters in vertical drop. The fourth treatment was a combination of ridge tillage in the alleyways between natural vegetative strips. Hybrid maize was produced in all treatments in rows spaced 60 cm apart.

The slopes of the on-farm experiments were 14% at Patrocenio village and 20% in Anei. The annual soil loss was 85.5 tons/hectare on bare, uncropped soil, 7.2 t/ha in Patrocinio, and 23.4 t/ha in Anei. Ridge tillage reduced soil loss by 49% in Patrocinio, and 58% in Anei (Table 1). Natural vegetative strips reduced soil loss even more: 97% in Patrocinio and 90% in Anei. When the two conservation tillage systems were combined, soil loss was 0.3 t/ha in Anei, 1.1 t/ha in Patrocinio. Clearly, both systems were effective measures to dramatically reduce erosion. When combined they proved exceedingly effective.

We compared the Infiltration rates in the four treatments. The permanent ridges in the ridge-till treatments had infiltration rates of 49 cm/hr, 30% higher than in the rows of the conventional treatment. Infiltration rates were also high for the zone just above the natural grass strips (59 cm/hr). The high infiltration rates reduced runoff from row-to-row in the ridge till system, and reduced runoff through the grass barriers in the NVS. Kiepe (1995) demonstrated that infiltration rates in the vicinity of contour hedgerows is the major factor explaining the exceptional ability of contour hedgerows systems to reduce runoff and off-field soil losses.

Mean grain yields of six crops over the three-year period were the same for the conventional system and ridge-till (3.9 t/ha and 3.8 t/ha, difference nonsignificant). The grass strips occupied 12.6% of the field area. This resulted in grain yields that were about 10% lower than those for the conventional system or the ridge-till system alone (Table 2). Thus, ridge tillage maintained maize yields, although it drastically reducing the amount of labor invested tillage and weed control. It was not as effective as NVS in erosion control, but did not cost the farmer any penalty in crop yield compared to conventional maize production.

Did permanent-ridge tillage reduce downslope soil scouring from the upper alleyways to the lower alleyways? This was the issue that first prompted our interest in adapting this unique tillage system to animal-powered farming systems. Our measurements on tillage-induced soil movement within the treatments are not yet completely analyzed, so a definitive answer is awaited. However, preliminary examination of the data suggests that ridge tillage did indeed dramatically slow down the downslope movement of soil across the alleys ways. This would slow the rate at which topsoil is removed on the upper alleyways and deposited above the grass strip downslope. The practice, therefore, appears to hold strong promise. It could be the most effective way to manage contour hedgerow systems on land with quite shallow soils. One important extrapolation domain may be for the limestone-based soils of the central Visayan

Table 1. Water- and tillage-induced soil erosion as affected by management system in Claveria, Misamis Oriental, Philippines. (Source: Thapa, Cassel, Garrity and Mercado. 1996)

Soil Mgt. Systems	1993	1994	1995	Mean
	Ane-i site (soil loss ton/ha)			
Contour Plowing	26.7	26.1	17.1	23.4a
Ridge Tillage (RT)	9.9	12.5	7.1	9.8 b
Natural Grass Strip (NGS)	2.2	1.8	2.5	2.2c
RT plus NGS	1.2	1.0	1.2	1.1c
Bare	0.0	75.2	95.7	85.5
CV% = 39.9				
	Patrocinio site (soil loss ton/ha)			
Contour Plowing	6.0	10.0	5.7	7.2a
Ridge Tillage (RT)	3.3	5.1	2.7	3.7b
Natural Grass Strip (NGS)	0.3	0.3	0.1	0.2c
RT plus NGS	0.4	0.3	0.1	0.3c
CV% = 75.9				

Table 2. Corn grain yield as affected by soil management system in Claveria, Misamis Oriental, Philippines.
(Source: Thapa, Cassel, Garrity and Mercado. 1996)

Soil Mgt. Systems	1993 Crop season		1994 Crop season		1995 Crop season		Mean*
	1st	2nd	1st	2nd	1st	2nd	
	Patrocinio site (Grain Yield ton/ha)						
Contour Plowing	5.6	3.8	5.0	2.8	3.4	3.7	4.1
Ridge Tillage (RT)	5.4	3.7	5.2	3.0	3.3	4.5	4.2
Natural Grass Strip (NGS)	4.9	3.6	5.6	2.7	3.0	3.4	3.7
RT plus NGS	5.2	3.4	4.4	2.8	3.1	4.1	3.8
Standard deviation = 0.9 - 1.0							
	Ane-i site (Grain Yield, ton/ha)						
Contour Plowing	4.4	3.0	4.4	2.1	2.8	4.0	3.8
Ridge Tillage (RT)	5.5	2.8	4.5	1.6	2.8	4.0	3.5
Natural Grass Strip (NGS)	4.4	2.7	3.8	1.9	2.6	3.6	3.4
RT plus NGS	4.0	2.6	3.8	1.4	2.5	4.1	3.1
Standard deviation = 0.9 - 1.1							
CV% = 75.9							

islands, where the topsoil is often only 20-30 cm deep over limestone rock. Under these conditions the scouring effect can be devastating to long-term crop production if hedgerows are installed.

Weed control is the key challenge in converting to a permanent-ridge till system. In superimposed trials we tested various methods of weed management that compared the use of glyphosate with non-herbicide alternatives. In this humid tropical environment there is profound potential for weed regrowth in the period between wet-season crops, and during the dry season. We found that the only practical way to plant on permanent ridges without prior tillage was to use an in-the-row band-spray of herbicide. This reduces the quantity required to about one-third of that required for a whole field application. Further refinement of the band-spray technique would probably enable the herbicide quantity to be reduced even further. Prices for glyphosate have been falling as the number of firms marketing the product multiply. Currently, at least six companies are competing in the production and marketing of different glyphosate products in Indonesia.

Will small farmers adopt herbicides in future as part of their crop production system? No one knows the full answer to this question, but it is clear that many already are using them. Many farmers in Claveria now use glyphosate and other herbicides for specific applications to complement their animal-powered weed management, especially where it reduces manual labor. Our studies in Indonesia have shown that many upland farmers are using glyphosate in opening land that has been in grass fallow. As discussed above, even villages of shifting cultivators are integrating herbicides into their crop production system to expand the potential to use *Imperata cylindrica*-infested land, and to save labor in cultivation. The cost of labor relative to other production factors is expected to continue to increase. Therefore, it is quite likely that use of herbicides by upland farmers will accelerate rapidly in the coming decade. Such a trend would parallel the experience in wetland rice in the Philippines, where herbicide use was unknown in the early 1970s, but was ubiquitous by the late 1980s.

Are Zero-tillage Systems Practical?

Zero- or no-tillage systems involve complete elimination of mechanical seedbed preparation and weed control. They rely on herbicides to kill or suppress weed growth. Exceptional beneficial effects of the no-till system have been consistently documented in North America (Phillips *et al*, 1980; Griffith *et al*, 1986). Their effectiveness in minimizing erosion has also been demonstrated for a wide range of soils in the tropics and subtropics (Lal, 1976,1984). In Thailand, Ryan (1986) observed that soil erosion dropped from 12.2 t/ha for conventional tillage to 0.8 t/ha for no-tillage. Research in Indonesia has shown the usefulness of no-till farming for erosion control and for producing satisfactory crop yields (Suwardjo et al, 1984).

No-till farming, however, has a number of serious drawbacks. Many soils have a tendency to become compacted over time as a result of no-tillage. This is particularly the case with low-activity clays with low organic matter content (Lal, 1984). Compaction can set in after only 2-3 years after adopting a no-till farming system. Also, weed control with no-tillage can be exceptionally difficult in tropical environments, requiring frequent and heavy applications of herbicides. Rapid weed shifts further complicate the herbicide strategy. Management has to be unusually sophisticated to overcome these and other problems as they develop. Thus, despite high yields, and labor savings, complete no-till systems with heavy chemical inputs may not be the most practicable or efficient alternative (Zaffaroni and Locatelli, 1980).

These drawbacks are particularly cogent for small farmers. I view permanent-ridge tillage as an appropriate solution intermediate between full-tillage and zero-tillage. Ridge-till eliminates land preparation time and costs. It cuts soil loss down to a fraction of the conventional level. However, it retains the practical flexibility of conventional inter-row cultivation, and it requires only a small fraction of the investment in the amount of herbicide needed in no-till. Thus, it appears to be much more conducive to limited-resource farmers that are short of labor and cash.

The greatest short-term prospect of no-till farming in the tropics may be in the lowlands rather than the uplands: Specially in broadcast-seeded, irrigated wetland rice. Several studies have shown satisfactory yields of lowland rice in the Philippines with a no-till system (Mabbayad and Buencase, 1967; De Datta and Karim, 1974; Sharma and De Datta, 1986). Excellent control of the water level in the paddy makes no-till a more practical alternative, as the water level is an important tool for complementing the weed control effectiveness of herbicides. No-tillage has the potential to eliminate the heavy power and labor requirements of plowing and puddling in rice production. Thus, there is much current interest in further developing the application of no-tillage for such systems.

Conclusions

This brief review of the landscape of conservation tillage in Southeast Asia emphasized that there a range of unique solutions for different types of farmers with a fundamentally different resource base. I separated these into two types: Those who have no access to draft power, and those farmers who do.

Systems for farmers without draft power

1. Smallholders practicing slash-and-burn in natural grass fallows are starting to integrate herbicides in their farming system to manipulate the fallow vegetation from undesirable species (viz *Imperata*) toward more desirable ones (viz *Chromalaena*). Research and development could build upon this innovation to enable many other farmers to enjoy more productive fallows that better sustain their livelihood, and eliminate the need to abandon the land due to weed pressure.

2. Herbicides are being applied in Indonesia to reclaim grasslands for food crop/tree crop systems with government support. Further refinement of the practices is needed.

3. Recent research and farmer experience in Indonesia, Benin, and Central America indicates that practical cover cropping systems have wide potential. Serious work is warranted on how cover crop species and associated management practices can be combined in the myriad farming environments in Southeast Asia where fallowing is practiced.

4. Leguminous tree fallow systems have been developed by selected farming communities. These systems may be uniquely suitable to some major agroecosystems. Knowledge about their dynamics and extrapolability is urgently needed.

5. Complex agroforests are one of the most elegant types of conservation farming in Southeast Asia. Their productivity is remarkable, and their conservation values are unexcelled. Yet they were largely ignored until recently. Much remains to be done to

support the expansion of these systems to stabilize shifting cultivation, and to improve the sustainability of permanent farming systems.

Systems for farmers with draft-power

1 Contour hedgerow systems have proven potential to control soil losses in crop production even on fairly steep slopes (20-50%). Much more needs to be done to refine these systems with farmers input so that solutions are adoptable on a wide scale. The key challenge is to have systems that absolutely minimize labor or produce income-generating commodities in the hedgerow. A particularly promising farmer-developed solution with enormous potential is natural vegetative strips on the contour. The practice has seen major spontaneous adoption in Mindanao, and begs testing and extension in a much wider range of environments.

2. The rule-of-thumb recommendation of hedgerows at one meter vertical intervals is not convenient for farmers. Our results suggest that a 2, 4, or even 8 meter drop between hedgerows may be adequate to reduce soil losses to reasonable levels. Further testing is warranted, but the data indicate that a more flexible, gradualist approach to hedgerow installation may be similarly effective, and much more acceptable to the farmer.

3. Permanent-ridge tillage has been adapted to animal-power systems in Southeast Asia and shows serious promise. The system needs to be more widely tested with farmers in a diverse range of agroecosystems. It seems particularly suitable as a stand-along system for land that with slopes of up to 20%. Combined with contour hedgerows it may enable relatively 'safe' cultivation of slopes that are much steeper than this. It may be an essential partner technology for any contour hedgerow on shallow soils.

4. Tillage research to date has much too experiment-station based. Very few farmer-participatory tillage studies have been attempted. But these are the key to successful innovations. Conservation tillage researchers must build on what farmers are already doing. There are many ingenious ideas out there to be built upon. But we'll never know unless we walk the smallholder's fields, observe his practices closely, and get his reactions to our own flashes of genius, in trials designed jointly and carried out collaboratively.

Final note. There is an striking slogan used in North America to re-orient farmers' thinking about conservation tillage: It says "Farm dirty!" These two words turn upside-down the ingrained culture that has long assumed that a good farmer is one who has clean-tilled fields from fencerow to fencerow. North American farmers are re-thinking their fundamental assumptions about tillage. The area on which conservation tillage is practiced in the United States is in the tens of millions of hectares. It has effectively doubled in just the past six years.

The culture of clean-tilled and clean-weeded fields in Southeast Asia is not so much different from that of North American farmers. Can we imagine what may happen when Asian farmers are introduced to really practical conservation tillage systems, and told that its not a bad idea to "farm dirty"? I suspect there'll erupt a brown revolution that saves the region's precious soil resources like never before. That is one revolution in which everyone would be a winner.

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