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Garrity, D.P. 1996. *In:* Ong, C.K. and Huxley, P (eds.) Tree-Crops Interactions: a physiological approach. CAB-International. pp. 299-318

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Tree-crop interactions are fundamentally altered on slopes by the dramatic soil spatial changes that occur as terraces develop behind contour vegetative barriers. Tree-crop interactions on flat land are complex phenomena in their own right. But on sloping land the introduction of trees (or other vegetation) in contour hedgerows adds a new dimension. In time the hedgerows result in dramatic spatial changes in the properties of the soils of the entire system.

Hedgerow systems alter the length of slope, degree of slope, soil profile depth, and soil chemical and hydrological properties. These changes may be quite drastic over short distances. This review emphasizes 'tree-soil-crop' interactions, for it is the major soil spatial changes that transform the nature of the species interactions on slopes.

The chapter reviews current understanding of these soil changes and how they interact with tree-crop competition in production systems. First, the conventional row-wise pattern of alley crop response on flat land is contrasted with the patterns observed in contour hedgerow systems on slopes. Second, the factors underlying the uniquely skewed response function on slopes are discussed in terms of a tillage-induced 'scouring' effect, with emphasis on the spatial soil fertility changes that occur. The flat-land row-wise crop response pattern across the alleyway (convex parabolic) shifts on slopes to a skewed response surface with (often) drastically lower yields in the upper alley, and maximum yields in the lower-middle alley zone. The process of natural terracing behind vegetative barriers is conceptualized as the creation of a series of micro-landscapes. Aggregate and local effects of vegetative barriers on soil loss are examined. Third, a model integrating the two major processes, species competition and soil scouring, is presented. The chapter concludes with a discussion of the serious sustainability implications of these processes, and the urgent research needed to address them.

Species interactions on slopes

On slopes, as well as on flat land, a common row-wise pattern of crop response across the alleyways of an alley cropping system during the early years is a convex parabola. This is true whether the hedgerow is a pruned leguminous tree or a grass (Fig 1). The progressive decline in crop productivity as rows approach the hedgerow are attributed to a combination of above-ground and below ground competition. The dome-shaped spatial response pattern is characteristic for upland rice (Salazar *et al*, 1993). It is less frequently observed in the case of maize, which often has a more neutral response, with less evidence of the hedgerow-proximity yield depression observed by rice (Garrity *et al*, 1995).

A third pattern, that of a concave parabola, has been observed in limited cases (*eg* dry season cowpeas in Samzussaman, 1994) This result implies a stimulatory effect of

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Garrity, DP. 1996. Tree-soil-crop interactions on slopes. In P. Huxley and C Ong (eds) Tree-crop interactions. Commonwealth Agricultural Bureaux (Int'l), London. [in press]

proximity to the hedgerow (perhaps a drought-mitigating microclimate effect). Thus, care is necessary in generalizing about the expected pattern of crop spatial response to hedgerows. Similarly there are major differences among hedgerow species in their tendency to reduce crop yields in adjoining alley zones (Garrity *et al*, 1995). Also, the patterns may change as the trees age.

Because agroforestry is very often practiced on sloping lands, a key issue is how slope may alter these relationships. First, there are several ways in which slope may *directly* impinge upon and alter tree-crop interactions. Three of these phenomena will be discussed briefly, before we turn to the main issue of how within-alley soil redistribution changes the system.

Competition for light. On flat land, intercrops of dissimilar height are ideally laid out in a N-S row direction (ie. perpendicular to the solar path). This maximizes direct sunlight penetration down the row. The principle applies equally on slopes, but if contour planting is practiced the control of row direction is rarely possible. Indeed, the aspect of the land (ie. the direction the slope faces) is often highly variable. Slopes that either face east or west, with the perennial component laid out in contour lines, will tend to optimize sunlight penetration to the crop because the rows will be more-or-less in a N-S pattern; the configuration being analogous to N-S planting on flat land. With slopes facing away from the sun (eg north-facing fields in the northern hemisphere) light penetration to the dominated species is most severely reduced.

Tree root growth. This may be asymmetrical on slopes. Solera (1993) found that the density of roots was considerably higher in the soil upslope above 3-year-old pruned hedges of Cassia spectabilis than in the soil downslope below the hedges. This was particular true for the density of fine roots. This study was done on a site with approximately 20% slope in which a 50-cm high terrace riser had formed.

Field hydrology. This is directly affected by the presence of hedgerows. Kiepe (1994) observed that effective steady infiltration rates within the hedgerow were 3 to 7 times greater than in the adjoining alleyways. Agus (1993) also observed a major contrast in infiltration rates between the upper alley and the hedgerows. Clearly, hedgerows exhibit the potential to capture and store in the profile much more water than occurs in their absence, particularly in climates with serious water-deficits. This advantage is countered by the tendency of the perennial root systems to explore and exploit a large soil volume in potential competition with a shallower-rooted annual crop (Hauser, 1993). When terraces develop, further major changes in field hydrology are induced.

Skewed Distribution of Crop Yields in Sloping Alleys

There have been few long term observations of crop yields in contour hedgerow systems on slopes. But where these are reported, it is commonly observed that the yield response tends to become skewed after a few years: A distinct pattern of low yields on the upper rows of the alley and higher yields on the lower rows. Solera (1993) found that after 5 years of upland rice cropping between *Gliricidia sepium* hedgerows on a Typic Hapludox with 20% slope in the Philippines, yields on the upper rows were 50% lower than those on the lower rows within the alley (Fig 2). Without added P fertilizer the differential between the upper and lower alleys was even more pronounced. A similar response was recorded with *Cassia spectabilis* and *Pennesitum purpureum* (Napier) hedgerows. At a nearby location Agus (1993) obtained a yield depression in the upper alley rows with both rice and corn associated with *Gliricidia* after 4 years.

In 5-year old hedgerow systems of either leguminous trees (*Leucaena leucocephala* + *Cajanus cajan*) or grass (*Paspalum conjugatum*) on an Ustic Kandihumult of 21-35% slope in Thailand, Turkelboom et al (1993) reported reductions in rice yields of greater than 50% in the upper alleys, compared to the middle and lower areas. Peden (pers. comm. 1993) has observed a comparable yield depression in hedgerow trials in Uganda.

The pattern of response that is typically found does not indicate that the phenomenon can be explained as a manifestation of competition by the hedgerow component. Solera (1993) excluded both above-ground and below-ground hedgerow competition by intensive pruning and installation of 50-cm deep plastic barriers installed 30-cm from the outer of the hedgerows. He found that the spatial pattern of yields was unchanged (Fig 2). Ramiaramanana (1993) and Turkelboom *et al* (1993) investigated this issue with contour hedgerows composed of uncompetitive low-biomass producing grass strips. They could not account for the large yield depressions they observed in the upper rows of the alley compared to the lower rows as a competition effect. Clearly, processes other than hedgerow-crop competition were operating.

Contour Hedgerows: The Conventional Paradigm

The early literature on contour hedgerow systems extolled the advantages of vegetative barriers in reducing soil erosion on sloping fields (Young, 1989). The natural development of terraces was observed. This was highlighted as evidence that soil loss was being effectively controlled.

Figure 3 shows a widely held but erroneous view of a model of terrace development - occured with pruned tree hedgerows. Similar schematic drawings of hedgerow systems are found in the agroforestry literature. Note the emphasis on the buildup of soil behind the barrier. In this scheme the 'new' soil layer is deepest at the hedge, and overlays the old surface to a progressively thinner extent upslope. But there is no indication of soil redistribution within the alley from the upper part to the lower part. The process of within-alley soil redistribution, and its serious implications, were not appreciated until quite recently.

Soil Spatial Fertility Gradients

Soil may be redistributed across the alley quite rapidly after hedgerow installation on moderate to steep slopes . Basri et al (1990) reported a 60-cm drop in soil level between the alleys after 2.5 years on a field with 25 % slope. Fujisaka (1992) observed similar rates of terrace development on several farmers fields in Claveria, Philippines. A tendency toward rapid terrace riser development was frequently observed in trials on a range of other soil types (Sajjapongse 1992).

Rapid terrace development was associated with a reduction in crop yield in the upper alley zone, in many cases (Solera, 1993; Agus, 1993; Garrity *et al*, 1995). Suspecting that soil fertility was a factor in producing the skewed grain yields, researchers began to more carefully monitor the pattern of soil properties across the alleyways. In a *Cassia spectabilis* hedgerow experiment (Garrity *et al*, 1995), soil organic carbon was found to vary from 1.7% near the hedgerow in the upper part of the alley to 2.8% near the lower hedgerow. Available P was twice as high in the lower zone compared to the upper. Soil pH was unchanged but exchangeable aluminum increased. These patterns were observed in the subsoil (15-30 cm) as well as in the surface soil, and occurred within four years of hedgerow establishment.

Agus (1993) sampled 5 points across the alleyways between *Gliricidia* contour hedgerow, and observed a quite linear soil fertility gradient. Exchangeable calcium, organic C, pH, and Bray-2 extractable P increased from the upper to the lower part of the alleyway, exchangeable Al decreased, while K and Mg were unchanged. Samzussaman's (1994) row-wise study of soil properties elucidated linear increases in organic carbon (from 2% to 3 %) and nitrogen (0.20% to 0.27%) on an Oxic Palehumult. (Figure 4). Turkelboom *et al* (1993) monitored soil organic carbon on an entire slope transect. They observed a "saw-tooth" pattern, with a tendency for SOM differences across the alleys to accentuate on the lower slope terraces (Fig 5)

Why does such fertility accumulation occur towards the barrier strips, and why does it happen so rapidly?

Tillage erosion dominates water-induced soil transport

Terracing tends to reduce the slope length (a primary effect) and slope angle (a secondary effect). This reduces the energy of water to move soil particles downslope. The upper alleyway zone nearest the hedgerow is the area that theory predicts would have the least expectation of soil loss by water erosion (separate direct splash impact from surface flow). Yet this is where maximum soil removal actually occurs. Water gains kinetic energy by flow downhill. Water in the upper alley zone would therefore tend to have picked up least energy. Runoff that may have passed through the bund would have presumably lost much of its energy and deposited soil particles in the hedgerow before emerging in the upper alley zone below.

The vegetative barrier above an alley insures that very little enrichment of soil can occur from above. Nevertheless, it is in the upper alley zone where maximum soil losses occur. The enormous rates of profile scouring observed in many hedgerow systems lead to the presumption that tillage transport must account for the overwhelming amount of soil movement (Turkelboom *et al*, 1993; Garrity *et al*, 1995).

Upper alley scouring, and rapid soil displacement to the lower alley, seem particularly prominent where draft animal plow systems are used. The plow efficiently turns soil downhill, and makes frequent tillage practicable. Philippine hedgerow farmers normally plow 4-6 times per year for two successive annual crops. The rate and type of scouring appears to be related to way in which plowing operations are done. This is not usually done with the express objective of accelerating the flattening of terraces. Rather, it is a by-product of 'normal' soil management operations, although some farmers have been known to increase plowing frequency to flatten their terraces faster (Mercado, 1993, pers. comm.).

In Claveria, farmers conduct plowing operations in the alleyways following three different patterns. Each has distinct effects on the pattern of soil re-distribution. The scouring process also occurs with hand hoe farming in Thailand on steep slopes (Turkelboom *et al*, 1993). However, scouring is not always observed. It is conspicuously absent when no-tillage is practiced continuously, or when hand-hoeing is done superficially (as in shifting cultivation).

The Gap in Erosion Modeling

Much work has been done to develop models of water-induced erosion, but these have little utility in situations in which tillage transport is the dominant process. The modeling of soil erosion in contour hedgerow systems should be re-oriented to give more attention to tillage processes: A fresh challenge to researchers.

In such modeling efforts it will be important to separate the water and tillage effects on natural terrace formation. Collecting data for this will require innovative approaches, because soil movement will have to be investigated over small spatial areas within the alleys. The mesh-bag method proposed by Hsieh (1992) may be useful in examining water-induced transport over such small areas, and for mapping the degradation/aggredation at the soil surface over the face of the alleyway. Another approach is measuring soil loss from erosion experiments with collectors embedded at the lower side of a single alleyway (isolated from run-on water by physical barriers) compared with losses from an entire slope of hedgerows. Monitoring tillage-induced micro-shifts in surface soil can also be attempted by uniformly embedding small pellets in the soil and later examining their distribution (eg with a metal detector).

Landscapes, Hedgerows and Erosion: A Reappraisal

There is widespread evidence that vegetative barriers composed of trees, grasses, or other species tend to reduce aggregate soil loss from sloping agricultural fields. Agus (1993) observed a 70-80% decline in soil loss with hedgerows of *Gliricidia* + Napier with rainfall of 1200-1500 mm; over 90% of this was bedload sediment, the rest was suspended. On a range of sites in Indonesia, Philippines, Thailand and Vietnam, IBSRAM researchers found that contour hedgerows reduced soil loss 49 to 89 % compared to conventional farming, which had incurred erosion levels ranging from 5 to 413 t/ha in 3 years (Sajjapongse, 1992).

Results of this nature have impressed scientists and policymakers that contour hedgerows are seen as a superb way to control accelerated erosion on sloping agricultural fields (Young, 1989; Garrity, 1994). Thus, it is puzzling to discover that, in many cases, the annual crop yields in the alleys do not show any advantage compared with open-field results, even on a per-planted area basis, *ie.* ignoring the loss of land to the hedgerows. (Turkelboom *et al*, 1993; Ramiaramanana, 1993). This is despite the fact that soil erosion is dramatically reduced from rates that would seem unsustainable (100-300 t ha^{-1} yr^{-1}), and substantial amounts of biomass may be added to improve soil fertility. This occurs even on fields with relatively non-competitive grass strips (*eg* bahiagrass) or natural vegetative strips (Turkelboom *et al*, 1993; ICRAF, 1994).

Why does such effective soil conservation seem to have such apparently small effects on crop performance? The explanation may lie in the nature of erosion on open slopes. Recent work that monitored patterns of soil movement across entire slopes and watersheds has confirmed new insights on the patterns of soil loss in a landscape (Busacca et al, 1993; Brown et al, 1991a and 1991b). These workers found that soil loss was not clearly or simply related to the slope gradient or elevation on the slope.

In a landscape, most of the soil loss occurs only on the upper summit positions of slopes, and on the tops of 'knobs' (see Fig 6). The great majority of the area, located in mid-slope positions experiences little or no net soil loss, although the slope gradient in those landscape positions is often the steepest (Fig 6). Surprisingly, at this site net erosion was confined to just two areas, a small portion of the landscape.

On a generalized slope model such as that in Fig 7, the 'Shoulder' area exhibits maximum erosion. The Footslope may receive substantial deposition. But little or no net soil loss may occur on the Upper Linear and Lower Linear landscape positions, although they have much the greatest slope angle.

The implication for contour hedgerow systems is profound: Hedgerow experiments are most often laid out on the linear slope positions, and results are compared with adjacent open field treatments on the same slope positions. Although the open field treatments may exhibit very high total soil loss, little net loss may actually be occurring on the mid-slope positions. Losses are coming from above, and being deposited below. Monitoring of Cesium-137, which was deposited neturally as radioactive fallout, shows that in reality nearly every ton of soil loss at the mid-slope is replaced by soil from above (Busacca *et al,* 1993).

This net loss applies to soil movement due to tillage as well as to water erosion. Tillage gradually removes the topsoil from the ridges, knobs, and shoulders of a landscape. Soil from all points tends to slump downward on disturbance, but these are the only areas that do not receive a replenishment of soil from above.

The Alleyway as a Micro-Landscape

In contour hedgerow trials, it is the mid-slope areas on adjacent open fields that are often compared with the vegetative barrier treatments. We may now suspect that the open field mid-slope may, in many cases, not be experiencing a net soil loss, even though the landscape as a whole is doing so.

What may be the case where the midslope area is cordoned off to water in-flow by perimeter barriers? It is considered 'correct' procedure to so isolate the area from which erosion measurements are to be interpreted. However, this procedure may introduce an artifact into the measurement: The area of the erosion plot experiencing net soil loss may be confined to areas where deposition from above is blocked, either by an artificial perimeter barrier or an exposed topographic position. Thus, a zone of degradation may be created on the upper side of any sloping field or experimental run off plot, simply by creating an effective barrier to soil movement on the upslope boundary. Scouring will occur in the zone immediately below, due to lack of potential for soil enrichment from upslope.

The contoured sloping field can, therefore, be regarded as broken into a series of alley-hedge repeating units: A series of micro-landscapes with erosion/deposition behavior analogous to that detected at the macro level on whole landscapes. The alleyway may be seen to exhibit the same soil movement properties as the landscape, albeit with a simplified and repeating morphology.

Modeling Crop Performance Across the Alleys

The row-wise performance of crops in alleyways subjected to scouring (eg Fig 3) suggests a response surface that is determined by two phenomena: The classical hedge-crop inter-species competition for growth resources, and the soil scouring during terrace formation. The conventional response function of crop yield or dry matter may be represented as the integrated effect of these two independent sets of processes. Fig 8 illustrates the generalized response surfaces that tend to be observed in situations where both processes are operating, compared to the response surfaces observed where the independent processes are desegregated. In future, as more work focuses on the disaggregation of the integrated effect we should be able to model the interaction between these effects as part of a more general understanding of the entire tree-crop system.

The diagram illustrates the utility of dividing the alleyway into homogeneous zones in which the species competition effect and the scouring effect are differentially active. A minimum of five zones, rather than three, as used in other tree-crop interaction studies, seem necessary to capture the response surface and analyze contributing processes to this skewed distribution. The scouring deposition effect creates a radically more favorable crop environment above, as opposed to below the hedgerow, but species competition in the area of direct interface (the upper and lower zones) tend to deflate the differences among their integrated effects on performance.

It is useful to subdivide the central area of the alleyway into three subzones: The mid-alley with (theoretically) no net soil gain/loss, and the areas just upslope (soil removed, without major tree interference) and downslope (soil gain, without major tree interference). The lower-middle zone tends to reveal maximum response from the topsoil deposition (Figures 2 and 8). Exceptions to this general model will be expected. For example, Mercado and Garrity (unpublished) have observed situations where the middle-alley zone has a distinct yield depression compared to the adjoining upper-middle or lower middle zones. This apparently happens when plowing consistently leaves a back-furrow in the alley center.

As a first approach to modelling the crop effects, van Noordwijk and Garrity (1995) proposed a parabolic distribution of relative crop yields across the alley (see curve A on right side of Fig 9), with an average yield of 1 (no net benefit or loss due to the hedgerows) and the distance (X) scaled from 0 to 1, the yield (Y) may be described as[1]:

$$Y = p X (1 \quad X) + 1 - p/6 \tag{1}$$

where the parameter p determines the shape of the curve. If the topsoil fertility (F) is redistributed, without net losses or gains, it may be represented by:

$$F = q X + 1 \quad 0.5 q \tag{2}$$

where the parameter q determines the gradient. By multiplying [1] and [2] we obtain a yield curve of the form:

$$Y = pqX_3 + pX_2 a(1.5q-1) + X(p(1-\frac{2q}{3}) + 1-\frac{p}{6}-\frac{q}{2}+\frac{pq}{12} \tag{3}$$

This is a two-parameter cubic equation in X, which might be fitted to data sets as shown in Figure xx to attempt to unravel the interactions. The figure gives examples for three values of q reflecting three stages of terrace formation by soil redistribution. In this multiplicative model the effects of top-soil depth and tree-crop interactions act independently on crop yield. A consequence of the linear soil fertility gradient and the symmetric shade and mulch interaction curve is that the effect on average yield is neutral (which is shown by integrating [3] over the interval of 0 to 1).

Samzussaman (1994) used the SCUAF model to examine long-term trends in soil properties of contour hedgerow systems with data validation from Philippine trials in Luzon (Oxic Palehumult) and Mindanao (Typic Hapludox). It was apparent that without compartmentalizing the model by alleyway zones, predictions may be unrealistic. It will be necessary to include hedgerow effects on soil spatial properties in models of soil and crop response to contour hedgerow farming systems. In fact, modeling contour hedgerow systems more comprehensively presents an important and crucial challenge in the next generation of research. It is because these systems are so complex that simulation will prove useful in addressing a host of new concerns about their viability and management.

Is Farming on Natural Terraces Sustainable?

It is generally assumed that scouring effects will dissipate with time as a terrace surface stabilizes and more organic matter can be retained in the surface soil in the upper zones. However, it is not known how long this process may take on different sites and under different management regimes. It is not surprising to expect that any short-term losses due to scouring may appear to make the investment in contour hedgerow installation and maintenance unattractive to farmers. For example, some farmers in Leyte Province in the Philippines that established natural vegetative strips for soil conservation nevertheless fallowed them after a few years. Soil loss control was apparently effective, but it could not prevent nutrient depletion due to the export of nutrients by continuous cropping, as fertilization was not practiced.

Thus, we urgently need to know:

1) Are scouring effects a short- or long-term phenomenon, and

(2) How can they be effectively avoided or alleviated?

It may be argued that scouring is only a temporary phenomenon and, as has been observed with scraped soils in other contexts (eg in creating lowland rice fields), the productivity differential between the scraped area and the depositional area will gradually equilibrate. On deep soils with reasonable soil organic carbon levels, the scoured areas may no doubt recover in a few years. The evidence indicates that the effect may be relatively short-term on narrower terraces, and on certain soils; but on wider terraces and other soils the yield depression may last for many years. On strongly acid ultisols, oxisols, and inceptisols, the solum may be quite deep physically, but these soils are often 'chemically shallow' due excessive subsoil acidity due to soluble aluminum. Scouring scrapes off the more fertile topsoil, thus restricting crop rooting depth.

In situations such as reported by Agus (1993), the aggregate grain yields were still higher with tree legume hedgerows than on open slopes, although a scouring effect was evident. But in other cases they were similar or lower (Ramiaramanana, 1993; Turkelboom *et al*, 1993). The absence of short-term benefits to crop yield is certainly evident in such cases, and a deterrent to adoption. (We are currently monitoring longterm hedgerow trials to observe when and under what species combinations and management practices the upper alley yield depression may disappear.)

On calcareous soils with a shallow solum over limestone parent material (a common upland soil in parts of Southeast Asia) a contrasting problem arises: Scouring removes the entire topsoil down to unconsolidated rock. The loss of productivity is permanent and drastic.

Some ecologists have also questioned the terracing of landscapes as an alternative to shifting cultivation (Ramakrishnan, 1990). In high rainfall climates, flat terraces tend to stimulate much greater leaching losses than on sloping fields due to greater vertical infiltration. The additional leaching losses may partially offset the advantages in soil conservation. The permanent terraces also tend to lead to continuous cultivation, creating severe soil nutrient depletion. Without nutrient importation from off-field through significant quantities of fertilizers or manures, crop yields cannot be maintained. In such cases, terracing may lead to a less sustainable agricultural system than conventional rotation fallowing.

Considering the degree of uncertainty that still prevails concerning the effects of vegetative barriers on landscape processes, and on system sustainability, research must bring to bear more analytical and critical tools to understand them. Within the subset of landscapes where vegetative barriers are useful, we need to know how to cope with the scouring process. The last section addresses this issue.

Coping with the 'Scouring' Effect

There are three basic ways to try to cope with scouring: To avoid it, alleviate it, or change the cropping system to live with it. The research agenda for each is briefly addressed.

Reducing the intensity of tillage. To avoid scouring a farmer must not practice primary tillage too frequently. In zero or minimum tillage systems there is less tendency for hedgerow risers to develop or for soil scouring to occur. There are many variations of reduced tillage that smallholders can adopt. Ridge tillage appears to be one of the most promising ones, in which alternating unplowed strips are maintained indefinitely. Timeliness of field operations, *eg* harvesting and planting, can reduce the number of tillage operations required. Adapting the ridge till concept to small-scale farmers has received almost no attention to date.

Adjust biomass and nutrient inputs. To alleviate scouring it is logical to consider changing the spatial pattern of nutrient inputs. The application of crop residues, hedgerow prunings, animal manure, and fertilizers may be biased to the upper alley zones. Since scouring tends to redistribute topsoil nutrients downward naturally, application to the upper alley may ensure a more even distribution in the long run. But it may also be argued that application to the lower zones with more favorable soil may make more efficient use of limited nutrient inputs. This depends on the comparative nutrient utilization efficiencies of crops growing in the different zones. Practical answers to these fertility management issues, and an underlying predictive knowledge about them, should be at the top of the agenda for immediate research.

Change the Cropping (or Hedgerow) System. The final strategy is to accept the scouring effect and to alter the cropping system to adjust to the changes (particularly if they are drastic). Substitution of perennials (*eg* fruit or timber trees) for annual crops, or more tolerant annuals (*eg* cassava), are practices that have farmers have experimented with. Researchers and farmers must learn better how to the degraded zone that a conservation technology may created.

Cognizant that the highest soil fertility is found inside the hedgerow strip, Turkelboom *et al* (1993) has even suggested that this 'sleeping' fertility be exploited by periodically moving the hedgerows downslope and cultivating the former hedgerow area. The idea is more practical with a grass strip than with trees. Such species as pigeon peas (*Cajanus cajan*) may be suitable for this; they naturally die off after a couple of years, making it easy to relocate the hedgerow.

Conclusion

Contour hedgerow systems attempt to exploit and conserve the available soil fertility on slopes in more efficient ways. They may dramatically reduce off-field soil erosion, but can accelerate soil degradation through soil redistribution downslope within the alleyways. In developing natural terraces, crop production is an integrated function of two processes: Hedge and crop species interference, and a soil scouring effect. The scouring effect creates further complexity in the management of such systems.

The contour hedgerow concept has now been widely recommended. Unfortunately, it is often indiscriminantly applied through standard extension packages. Superficial expectations about hedgerow intercropping performance have often been wrong. A concerted research effort is now urgently needed to elucidate the processes more fully, model the interactions, and gain a predictive understanding of when, where, and how contour hedgerow systems embody a superior technology for hillslope agriculture. In particular we need to understand the three basic ways to cope with the scouring effect: Avoiding it, alleviating it, or changing the cropping system to live with it.

REFERENCES CITED

Agus, F. 1993. *Soil processes and crop production under contour hedgerow systems on sloping Oxisols.* Phd Dissertation, North Carolina State University, Raleigh, NC, USA. 141 p.

Basri, H, A R Mercado Jr, D.P. Garrity. 1990. *Upland rice cultivation using leguminous tree hedgerows on strongly acid soils.* IRRI Saturday Seminar Paper, March 31. Agronomy, Plant Physiology, and Agroecology Division, International Rice Research Institute, Los Banos, Philippines. 32 p.

Brown, R B, N H Cutshall, and G F. Kling, 1991a. *Agricultural erosion indicated by Cs-137 redistribution: I. Level and distribution of Cs-137 activity in soils.* Soil Sci Soc Am J 45:1184-1190.

Brown, R B, G.F. Kling, N.H. Cutshall, 1991b. *Agricultural erosion indicated by Cs-137 redistribution: II. Estimates of erosion rates.* Soil Sci Soc Am J 45:1191-1197.

Busacca, A J, C A Cook, and D.J. Mulla, 1993. *Comparing landscape-scale estimation of soil erosion in the Palouse using Cs-137 and RUSLE.* J. Soil and Water Cons. 48:361-367.

Fujisaka, S. 1992. *A case of farmer adaptation and adoption of contour hedgerows for soil conservation.* International Rice Research Institute, Los Banos, Laguna, Philippines.

Garrity, D P, A. Mercado Jr, and C. Solera, 1995. *The nature of species interference and soil changes in contour hedgerow systems on sloping acidic lands.* In Kang, B T (ed) Alley farming, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Hauser, S. 1993. *Root distribution of Dactyladenia (Acioa) barteri and Senna (Cassia) siamea in alley cropping on Ultisol.* I. Implication for field experimentation. Agroforestry Systems 24:111-121.

Hsieh, Y P. 1992. *A mesh-bag method for field assessment of soil erosion.* J Soil and Water Conserv. 47:495-499.

ICRAF. 1994. Annual report for 1993. International Centre for Research in Agroforestry, Nairobi, Kenya.

Jones, A.J., L.N. Mielke, C.A. Batles and C.A. Miller, 1989. *Relationship of landscape position and properties to crop production.* J. Soil Water Conserv. 44:328-332.

Kiepe, P. 1994. *Effect of Cassia siamea hedgerow barriers on soil physical properties in Machakos, Kenya.* Geoderma (submitted).

MBRLC. 1988. *A manual on how to farm you hilly land without losing your soil.* Mindanao Baptist Rural Life Centre, Davao del Sur, Philippines.

Mercado, A. 1993. Personal communication, Claveria, Philippines.

Ramakrishnan, P S. 1990. *Agricultural systems of the northeastern hill region of India.* In Gliessman, S R (ed) Agroecology. Springer-Verlag, New York. pp 251-274.

Ramiaramanana, D M. 1993. *Crop-hedgerow interactions with natural vegetative filter strips on slopic acidic land.* MSc thesis, University of the Philippines at Los Banos. 141 p.

Salazar, A, Szott, L T, and Palm, C A. 1993. *Crop-tree interactions in alley cropping systems on alluvial soils of the Upper Amazon Basin.* Agroforestry Systems 22:67-82.

Sajjapongse, A. 1992. *Management of sloping lands for sustainable agriculture in Asia: An overview.* In Technical report on the management of sloping lands for sustainable agriculture in Asia, Phase I (1988-1991). Network Document No 2, International Board for Soil Research and Management, Bangkok, Thailand. pp. 1-15.

Samzussaman, S. 1994. *Effectiveness of alternative management practices in different hedgerow-based alley cropping systems.* PhD dissertation, University of the Philippines at Los Banos.

Solera, C R. 1993. *Determinants of competition between hedgerow and alley species in a contour hedgerow intercropping system.* PhD Dissertation, University of the Philippines at Los Banos. 135 p.

Turkelboom, F., S. Ongprasert, U. Taejajai, 1993. *Alley cropping on steep slopes: Soil fertility gradients and sustainability.* Paper presented at the International Workshop on Sustainable Agricultural Development: Concepts and measures, Asian Institute of Technology, Bangkok, December 14-17. 16 p.

van Noordwijk, M, and Garrity, D P. 1995. Nutrient use in agroforestry systems. In Proceedings of the 24th International Colloquium of the International Potash Institute, Basel, Switzerland.

Young, A. 1989. *Agroforestry for soil conservation.* CAB International, Wallingford, U K.

FIGURES

Figure 1. Terrace formation and crop growth in a contour hedgerows system of upland rice and leguminous trees on a strongly acid Oxisol. Adapted from Basri et al., 1990

Figure 2. Yield response of upland rice across the alley between hedgerows of Gliricidia sepium with and without root barriers (plastic), trenching, or double-depth plowing (dd plowing). Claveria Misamis Oriental. 1990. (Solera, 1994)

Figure 3. Illustration of a conventional view of terrace development behind vegetative barriers as the accumulation in 'new' soil, without soil redistribution from the upper alley zones to the lower zones. Recent studies show this model to be unrealistic. Source: MBRLC (1988)

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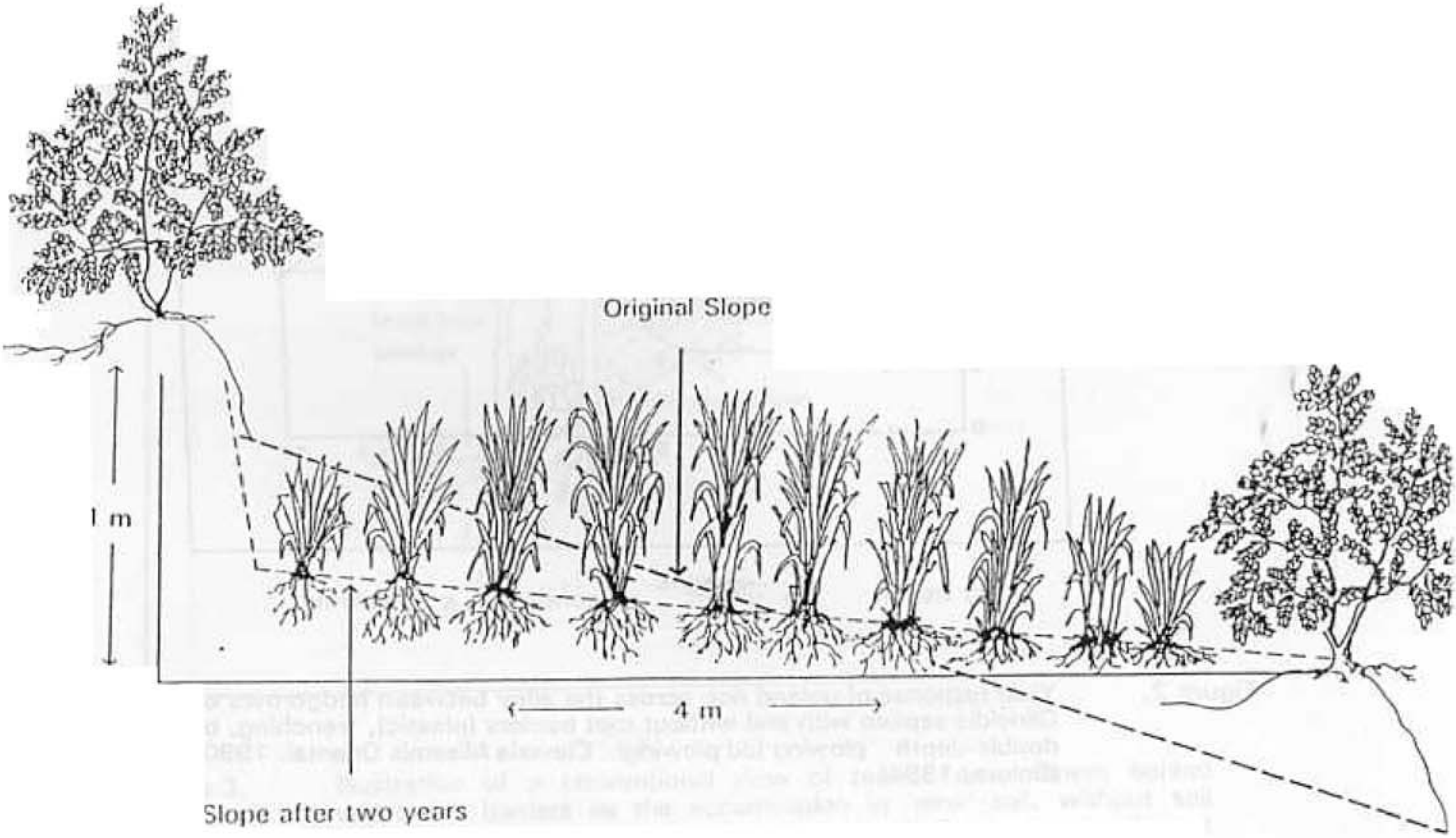
Figure 8. Models of Row-wise yield of alley crops as an integrated function of species interference and scouring.

Figure 9. Three stages in the process of terrace formation by soil redistribution and effects on crop yields (van Noordwijk and Garrity, 1995)



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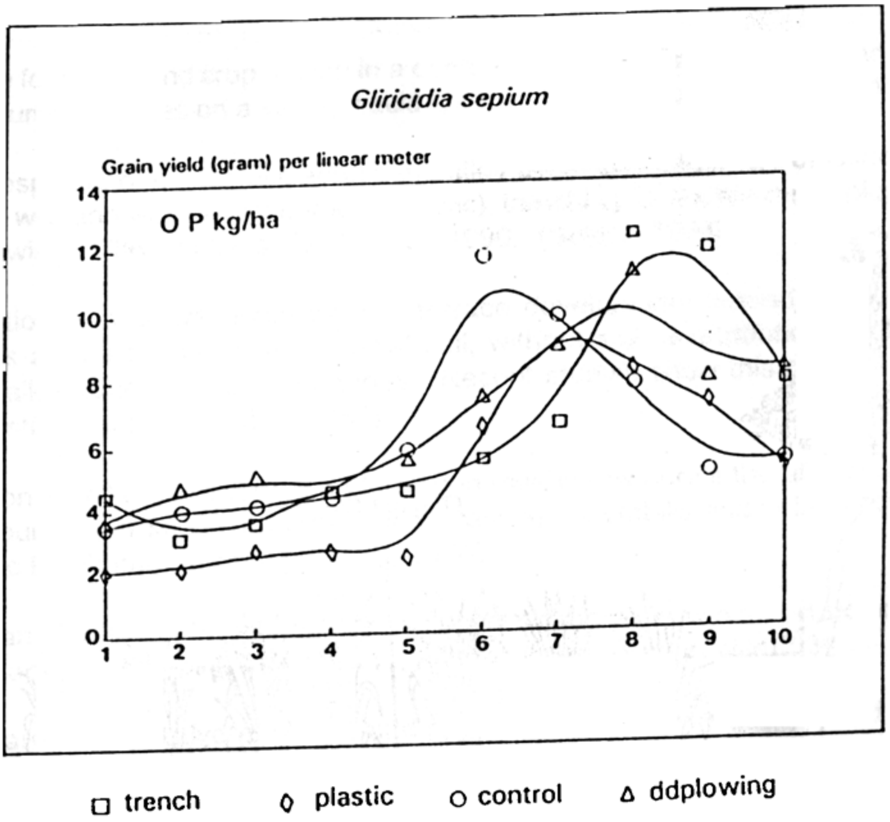

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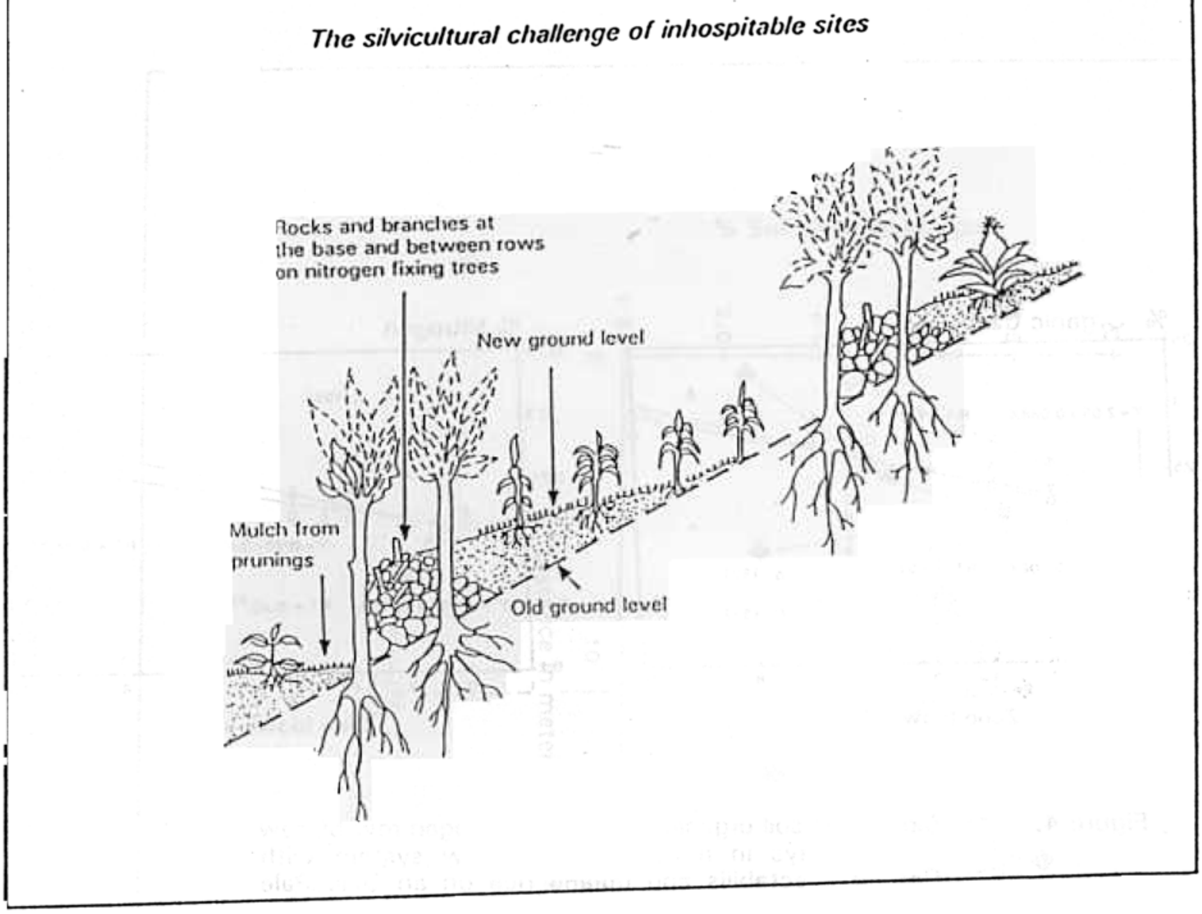

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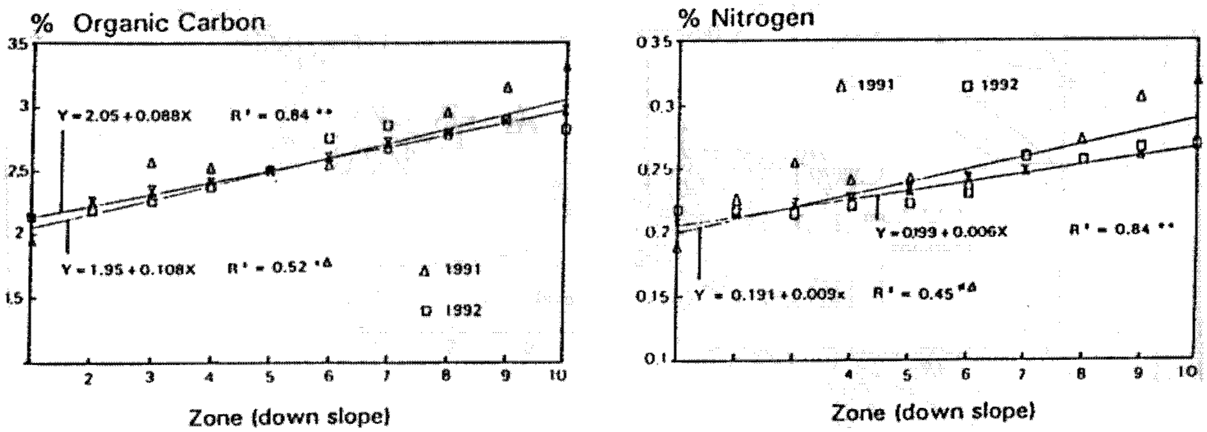

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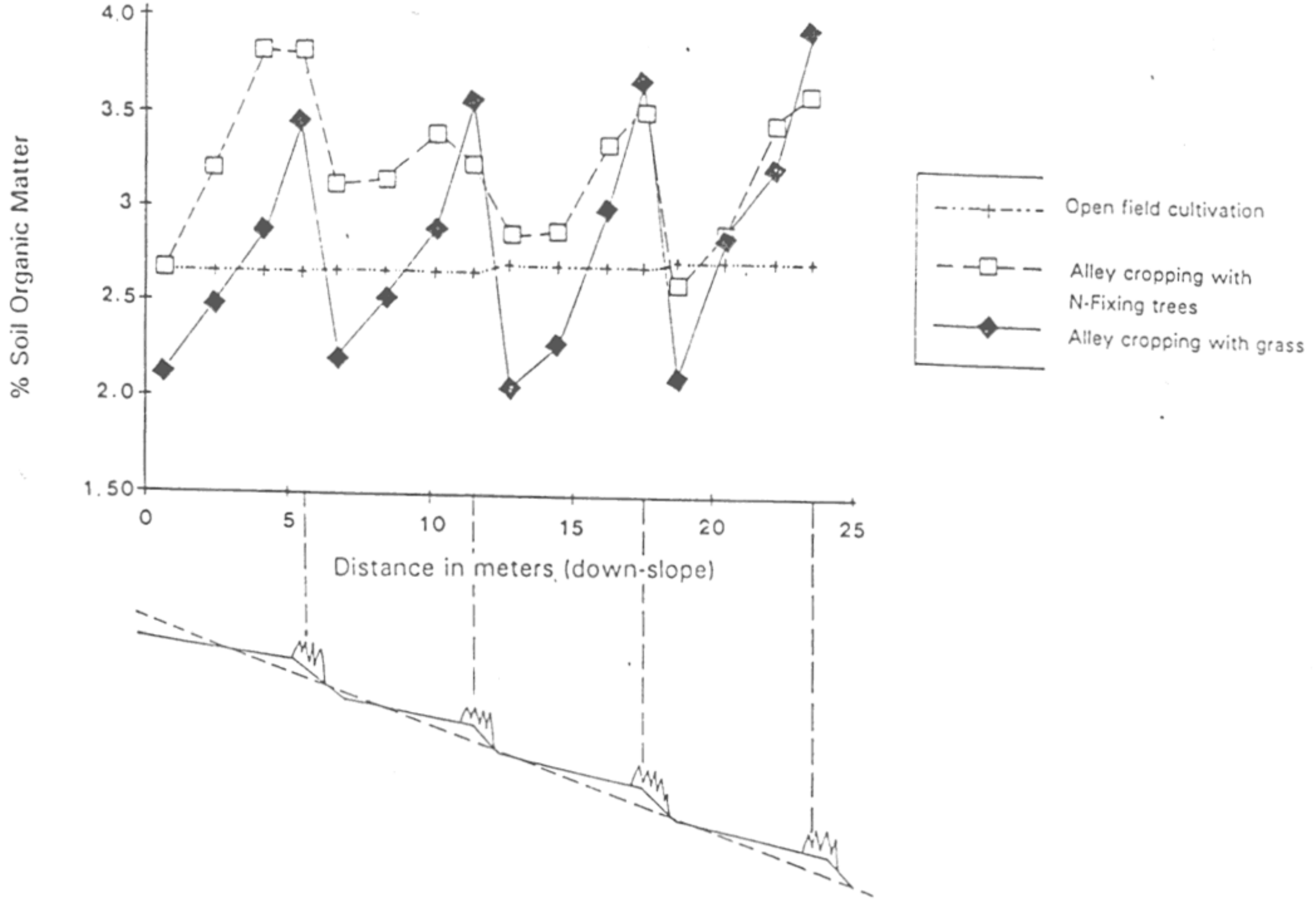
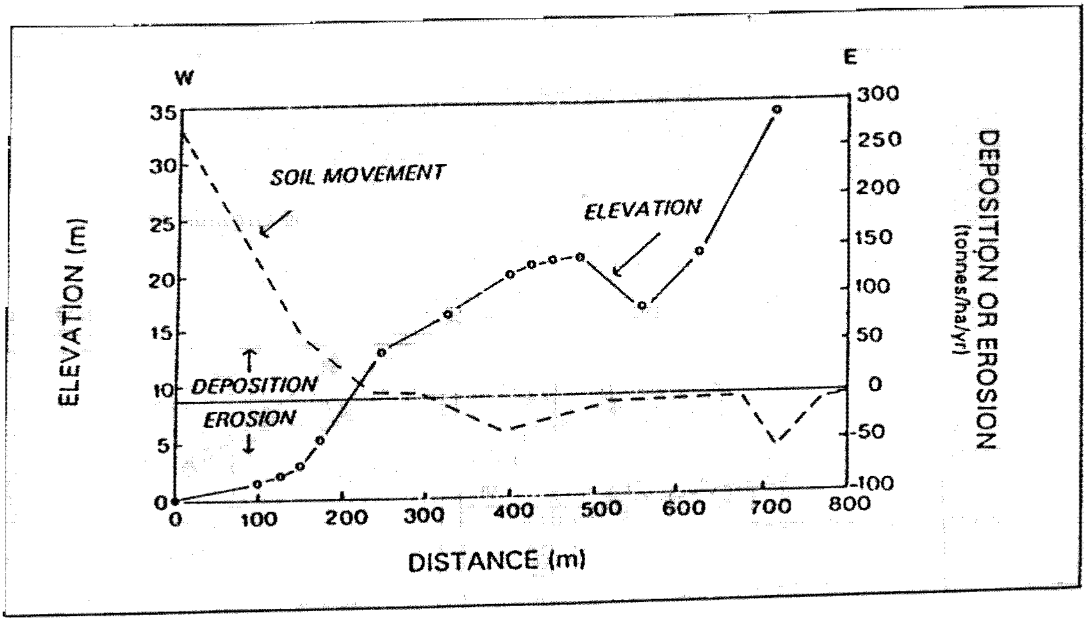

% Soil Organic Matter
4.0
3.5
3
2.5
2.0
1.50
0
5
10
15
20
25
Distance in meters (down-slope)
Open field cultivation
Alley cropping with N-Fixing trees
Alley cropping with grass



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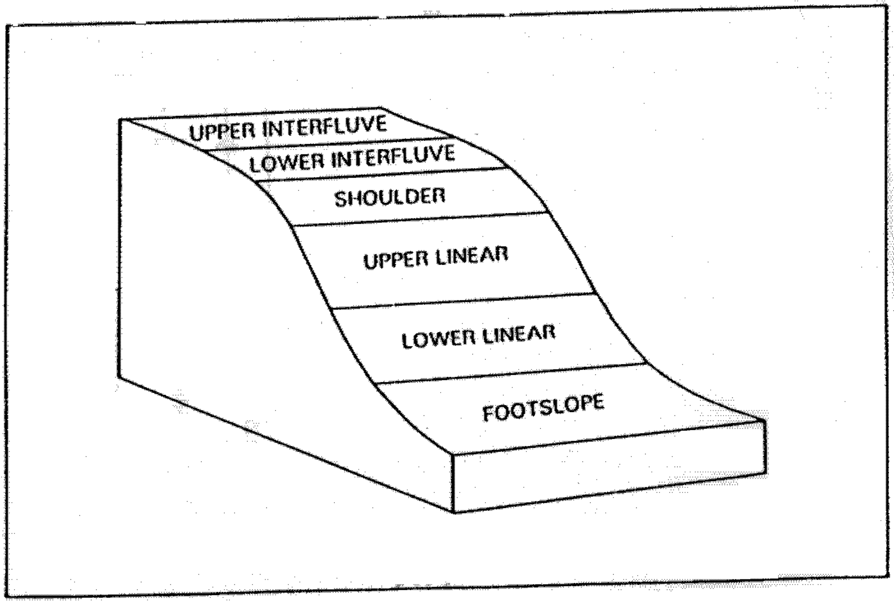

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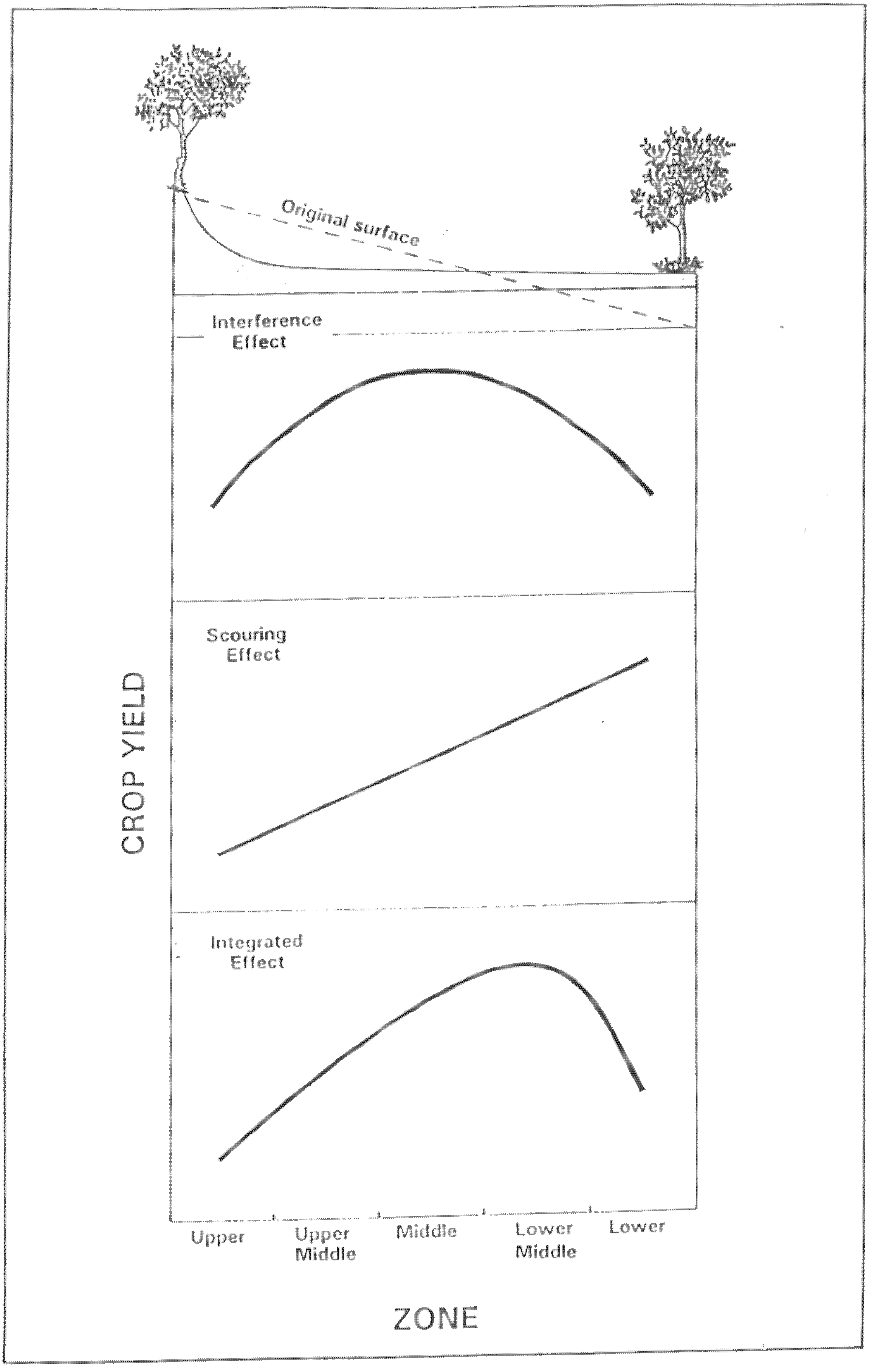

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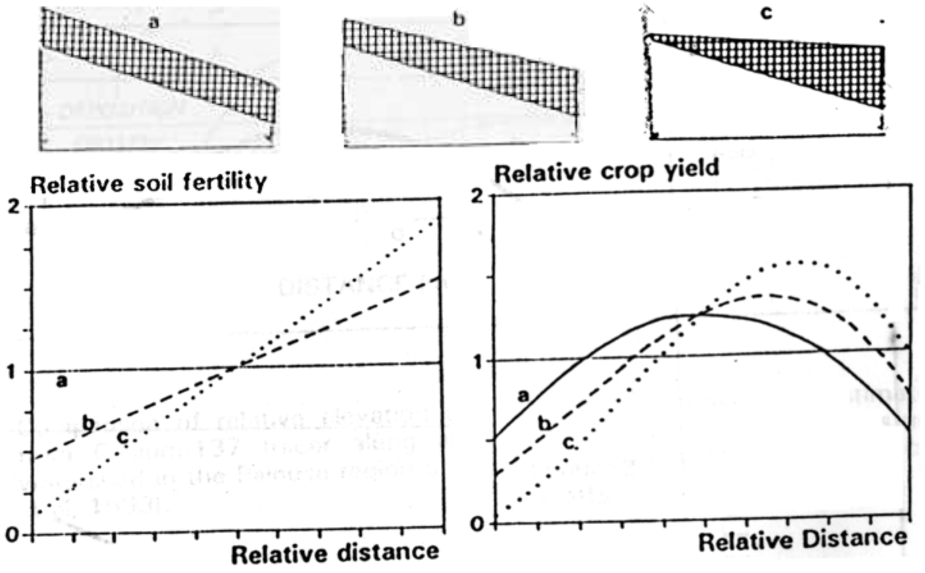

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