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UNDERSTANDING SOIL EROSION AND ITS CONTROL

By
Jim Chamberlain

Technical Reviewers
Robert S. Jonas
Fred R. Weber

Illustrated By
Frederick J. Holman

Published By

VITA
1600 Wilson Boulevard, Suite 500
Arlington, Virginia 22209 USA
Tel: 703/276-1800 * Fax: 703/243-1865
Internet: pr-info@vita.org

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PREFACE

This paper is one of a series published by Volunteers in Technical Assistance to provide an introduction to specific state-of-the-art technologies of interest to people in developing countries. The papers are intended to be used as guidelines to help people choose technologies that are suitable to their situations. They are not intended to provide construction or implementation details. People are urged to contact VITA or a similar organization for further information and technical assistance if they find that a particular technology seems to meet their needs.

The papers in the series were written, reviewed, and illustrated almost entirely by VITA Volunteer technical experts on a purely voluntary basis. Some 500 volunteers were involved in the production of the first 100 titles issued, contribution approximately 5,000 hours of their time. VITA staff included Patrice Matthews and Suzanne Brooks handling typesetting and layout, and Margaret Crouch as senior editor and project manager. VITA Volunteer Dr. R.R. Ronkin, retired from the National Science Foundation, lent his invaluable perspective to the compilation of technical reviews, conversations with contributing writers, editing, and in a variety of other ways.

Jim Chamberlain, the author of this paper, is a program officer for the Nitrogen Fixing Tree Association in Hawaii. A specialist in tropical forestry, he has experience in the Philippines and elsewhere in East Asia. Technical reviewer Robert S. Jonas is a soil scientist retired from over 30 years with the U.S. Department of Agriculture's Soil Conservation Service. Fred Weber, the other technical reviewer, is the author of Reforestation in Arid Lands (VITA, 1986) and a community forestry expert with extensive experience in Africa. All three are active VITA Volunteers.

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UNDERSTANDING SOIL EROSION AND ITS CONTROL

by VITA Volunteer Jim Chamberlain

1. EROSION AND SOIL LOSS

Geological erosion is a natural, continuous process that occurs almost anywhere that water flows on the land. It can also result from the action of wind, changes in temperature, and the activities of living things. Wind dislodges and moves soil particles. Rapid temperature variation between day and night, not a major problem in most tropical climates, affects soil surface structure. Biological agents are lichens, mosses, and animals, including livestock that compact soils and overgraze vegetation cover. Erosion by water receives the most attention in this paper.

Erosion forms many kinds of soil from rock and is controlled by such factors as rock properties, topography, vegetation, and climate. Some forms of erosion result in topsoil removal, rock failures, landslides, slumps, and riverbank cutting.

Erosion is usually accelerated by such human activities as forest destruction, traditional agriculture, grazing, construction, and mining. Whenever vegetation is removed, as when forests are cleared for agriculture, and the ground is exposed to rainfall, soil erosion by water and wind may increase. On sloping land it far exceeds the rate under natural conditions. Accelerated erosion, widespread throughout the tropics, is one of the most serious environmental and socioeconomic problems affecting rural people.

Soil loss is affected by soil composition, type of cover, soil management practices, and microclimate conditions. With highly fertile soils erosion has little adverse effect on productivity but increases production costs. In soils with medium rooting depth and surface thickness, the effects of erosion can be hidden by the use of technologies that work these potentially fragile soils. Erosion of marginal soils with shallow rooting depth, found throughout poor countries, results in continued decline of crop yields. Mismanagement of marginal soils can lead to permanent loss of soil fertility.

Loss of a few centimeters of topsoil can reduce the productivity of good soils by 40 percent and poor soils by 60 percent. In the United States, wind erosion over 30 years caused a loss of 30 cm of topsoil, resulting in a 70 percent decline in wheat yield.

Land-use planning should aim for an acceptable income and a minimal soil loss. Planning for erosion control must consider these factors: soil type, extent of erosion, topography, location of waterways and drainage, runoff diversions, size and arrangements of fields, cropping system, and tillage methods. Vegetation is an especially important tool for erosion control.

2. TYPES OF WATER EROSION

It is important to recognize the kinds of erosion, because each type may require a different approach to its control.

The flow of water over sloping land may be the most erosive factor affecting soils. Soil particles are dislodged or break from the soil mass, disrupting the physical and chemical bonding of soils. Soil erosion by water includes detachment, transport and deposition of soil by raindrops and runoff. Suspended soil particles dislodge other lighter particles through abrasion.

The extent of erosion depends on the amount, velocity, and turbulence of the runoff. The type of abrasive material being transported also affects the extent, which also depends on the energy of flowing water and amount of suspended material. Velocity increases as depth of flow and slope increase. Turbulence increases in proportion to the intensity of rainfall.

The major forms of erosion affecting agricultural lands are sheet, rill, and gully. Sheet erosion is caused by the even flow of water over sloped lands. It removes lighter soil particles, organic matter, and soluble nutrients. Its effects are less apparent than those of other forms, but they can seriously affect soil fertility and farm productivity.

Rill erosion occurs on sloped land dissected by small parallel channels running downhill. If these do not interfere with normal tillage practices they are called rills. Soils that are easily worked are more apt to form rills, and rills typically flow together and form gullies.

Two types of gully erosion create problems on agricultural lands. They are named for their distinctive cross-sections: V-gullies are identified by downward cutting centers, whereas the flat bottoms of U-gullies are parallel to the slope of the field. Control measures for the two types are different, as described at the end of Section 3.

3. AGRONOMIC CONTROL OF WATER EROSION

Tillage Practices

Intense cultivation and harrowing break down heavier textured soils into easily transportable particles. Changing the physical structure of soils through tillage thus can make them more susceptible to erosion. Conservation tillage, the practice of leaving crop residue on the soil surface, can reduce sheet and rill erosion as much as 90 percent.

One type of conservation tillage, called no-till, zero-till, or low-till, eliminates all plowing, disking, and cultivating. The new crop is seeded directly into the crop residue of the previous season. The system conserves soil moisture, decreases runoff, reduces soil loss and helps maintain organic matter. In a research study in Nigeria, zero-till prevented 96 percent of runoff and 99.5 percent of soil loss on 10 percent slopes. Unfortunately, this strict variety of conservation tillage requires special equipment (for instance, to loosen the soil under the crop residue without turning it over) and expensive herbicides.

Contour Cultivation

In India, contour cultivation on 2 percent slopes reduced soil loss by 28 percent and runoff by 61 percent, compared to traditional, up-and-down plowing. It is most effective on 3 percent to 8 percent slopes. On steeper slopes, runoff may concentrate in the furrows and if it breaks through may cause serious erosion. Contour cultivation on steep slopes must be supplemented by other methods.

Vegetation Cover

Well planned and managed vegetation cover can effectively control soil movement. Vegetation protects soil against erosion by reducing water movement and building soil structure. It also affects the soil surface, where running water does the most damage. Vegetation protects soils against erosion in a number of ways. First, it decreases the amount of rain reaching the soil by intercepting rainfall; the decrease was about 12 percent under forest canopy in a project in Indonesia. The decrease, of course, varies with the types of trees and management practices. Second, leaves break the initial erosive power of rain. (However, they may also increase the erosive power if drops concentrate and fall from greater heights.) Third, vegetation prevents the direct impact of rain on the soil, which reduces soil compaction and clogging of soil pores. Fourth, the increased formation of humus by vegetation improves soil permeability and structure, improving its capacity to retain moisture.

During natural fallow periods erosion rates tend to drop due to the formation of a layer of plant litter, invasion of weeds, and buildup of humus and organic matter. In planted fallow areas, on the other hand, erosion rates may increase. For example, in densely planted tree fallows, litter decomposes rapidly, natural ground covers will not grow due to excessive shade, and water flows freely over the land.

Removing the litter layer from under trees may increase erosion from 10 percent to 100 percent. But removal of the canopy without

disturbing the litter layer affects the erosion rate by only about 0.3 percent.

A complete soil cover protects against erosion except on the steepest slopes. The most effective vegetation cover to control erosion is a multi-layered canopy of trees, shrubs, and ground cover. Multiple layers slow the impact of raindrops, increase rain flow over the stems, and increase the litter buildup. Where field crops are grown, cover cropping and intercropping help to control erosion.

Mulching

Mulching covers the soil with materials that reduce soil moisture evaporation and inhibit weed growth. Mulching slows rainfall infiltration and protects the soil from direct impact from rain. Mulches applied before the beginning of the rainy season can reduce soil erosion and runoff. Further, they build soil structure and protect soil from extremes of temperature.

A study in Nigeria showed 50 percent more soil lost from land with no mulch than from land with a mulch layer of 2 t/ha. A 5-cm layer of straw mulch almost eliminated erosion of bare soil. In any location, mulching is likely to control erosion and bring other benefits.

The best mulching materials have a high humus content, along with good infiltration rates and water storage capacity. The properties to look for in selecting mulches are listed below:

o Withstand the forces of runoff; stay in place
o Last for several seasons; slowly decomposing
o Allow water to percolate into the soil
o Ease of application
o Inexpensive; require low maintenance

Crop residues are an excellent local source for mulches, particularly if they are not required for other purposes, such as animal feed, fuel, and roofing materials. If limited supply and high costs are not a problem, crop residues should be tried. In addition to their ability to aid in erosion control, they add humus to the soil.

Cropping Patterns

Changes in the cropping pattern that will help reduce soil movement include intercropping, alley farming, use of grass strips, and pasture improvement. For example, conversion of cultivated land to grassland can reduce erosion by at least 10 percent. Producing feed crops for livestock presents an opportunity to integrate animal husbandry and erosion control. Producing sufficient fodder grasses reduces the need to graze animals; cutting and carrying feed may reduce the space needed by the animals and allow for more crop land. Alternating strips of protected plants (vegetables) with protective plants (fodder grasses) will trap suspended particles and reduce soil movement. It must be noted that the use of protective grass strips is effective only if grazing is avoided.

Crop rotation helps to preserve soil fertility. A rotation of one year of grain millet, wheat, etc.) followed by three to four years of legume pasture may be an excellent alternative to shifting cultivation. But introducing crop rotation often requires a change from traditional methods. The new system may require new markets, for example, as existing markets may change if grain crops are lost for a period of years. Farmers may be reluctant to adopt new cropping patterns without market incentives.

4. PHYSICAL CONTROL OF WATER EROSION

Effective control of erosion requires either a reduction of slope steepness (as in terracing) or of slope length. Both physical and biological interventions are effective, depending on soil character, slope, crop cover, and land-use practice. Frequently, a combination of interventions gives better results than applying just one measure.

Vegetation Strips

Vegetation strips are contour plantings of suitably spaced strips of perennial grasses or shrubs on sloping lands. The objectives are to reduce soil and water loss, reduce slope length, hold soils on the land, and eventually convert the barriers into benches. Dense vegetation strips will stop or slow runoff and will trap moving soil particles. It is important to give particular attention to the layers of vegetation; dense ground covers are more effective than vegetation with a high canopy of trees.

Research in Taiwan showed that vegetation strips work best on slopes of less than 45 percent. Spacing of strips is governed by the distance between crop rows and is normally not more than 8 meters. If strips are used with contour ditches, the distance between then can be increased.

Slope is the most important factor affecting the design of vegetation strips. Table 1 gives approximate dimensions. For grass barriers use fresh cuttings; plant two or three cuttings on each hill; plant 2 close rows to form one grass barrier. The second row should be planted to cover the gaps in the first row so that the plants in the two rows form a triangular pattern.

Table 1
Estimated Spacing Between Grass Strips

In areas where the annual rainfall is 60 to 100 cm, strip width and distance between strips should be increased 20 percent and 10 percent, respectively. With more than one meter of rainfall, increase Width by 50 percent and Distance by 20 percent.

Slope, percent	Width of strips, m	Distance between strips, m
10	5	43
20	8	38
40	13	28

60 20 20

Source: Weber & Stoney, 1986

Horizontal Hedgerows

Horizontal hedgerows may be the simplest physical structure for controlling erosion on steep slopes. To form a hedgerow, plant single or double rows of perennial grasses or fast-growing trees along the contours to block runoff and catch rolling or suspended soil particles. First, mark the contours and set stakes every three to seven meters. Plow the soil along each marked contour into a furrow and remove the weeds before planting seeds, seedlings, or fresh grass cuttings.

The spacing of hedgerows depends on the slope of the field. The average difference in elevation between hedges should not exceed 1.5 m, or about the distance between your eyes and your feet. As the slope increases this distance decreases. Plant seedlings and cuttings no further apart than 15 cm. Wide spacing between trees or grass on a contour will concentrate erosion in the gaps, forming rills and perhaps washing away the young plants.

Only after the seedlings are well established should they be thinned. Remove the weak or small seedlings leaving not more than 6 to 10 cm separating the plants. When trees reach a height of 2 m, prune them back to about 0.5 m (knee height). Trees are pruned to reduce shading of crops, encourage coppicing (regrowth), and produce products needed by the household.

After two to seven years, terraces will develop as twigs, stones, and weeds are trapped on the uphill side of each hedgerow.

Sloping Agricultural Land Technology (SALT)

SALT, developed in the Philippines, has become well accepted by farmers to conserve soil and water. The technology includes a system of diversion ditches, canals, waterways, and check dams or soil traps on steep lands for erosion control. Figure 1 illustrates

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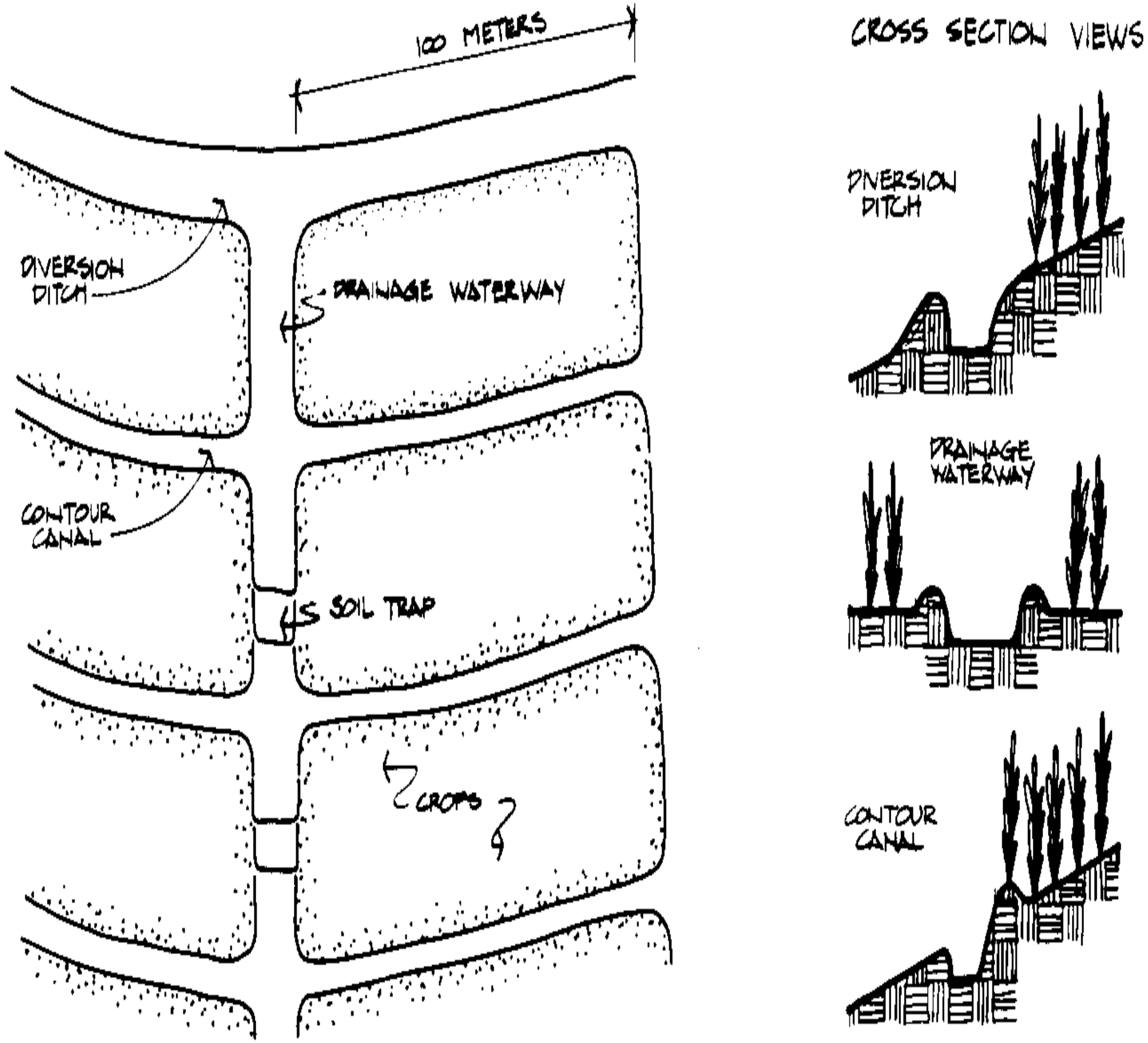

Figure 1: Field Layout Using SALT Techniques

the layout and design of an erosion control system using diversion ditches, contour canals, and drainage waterways.

Diversion ditches, the first line of defense for controlling runoff, are designed to prevent runoff from entering the field. The depth and size of a diversion ditch depends on the slope and depth of soil. In general diversion ditches are one meter wide and one meter deep. The soil from within the ditch is placed just below the ditch where possible and planted with trees.

Contour canals control runoff within crop fields. They are constructed in parallel lines across the slope of the land. A slight gradient encourages surplus water to flow to collection points. On deep soils with adequate percolation, canals are constructed flat to hold water in the canals and increase soil-moisture retention. Contour canals are typically one-half meter wide and one-half meter deep. Wider canals can be lined with grasses. Soil removed in construction of canals is placed on the downslope side just outside the canal and planted with trees or fodder grasses.

Drainage waterways are catchments for water collected in the drainage ditch and contour canals. They concentrate runoff from the fields into constructed and managed channels. The major objective is to provide safe outlets for runoff and prevent soil erosion. The recommended dimensions of a drainage waterway are one-half meter wide and one meter deep. Side walls should slope outward to reduce erosion. Waterways are lined with grass or stone to slow water movement and soil loss. The distance between waterways depends on the slope of the land and the amount of water expected, but is usually less than 100 meters, measured along the diversion ditch. When possible use natural drainage areas; water naturally moves to these places and it will reduce

construction costs.

Soil traps, constructed within waterways to capture suspended soil particles, are 1 m by 1 m pits placed every 35 meters within the waterway. The trapped sediment is a source of nutrient-rich soil to put on crop fields. If soil conditions prohibit construction of soil traps, check dams can be built that slow water movement and catch suspended soil particles. Check dams can be constructed from field stones, fresh branch cuttings from local trees, sticks, or crop residue. Branch cuttings from some trees will sprout and form live barriers serving several purposes by holding subsoil with their roots, producing needed products such as fuelwood, and catching suspended soil particles. Sticks and crop residues used as the main part of check dams will decay and provide only short-term solutions to trapping suspended soil particles.

The steps in laying out a SALT system are as follows: first, mark the location of the diversion ditch. Then locate and mark the contours, about 1.5 m downslope. Remove the soil from the diversion ditch, placing it just below the ditch and planting it with fast growing trees or grasses. Build the contour canals in the same manner, with a slope of 0.5 percent to 1 percent. Build the drainage waterways, planting them with grasses or lining them with stones. Finally, dig soil traps or build check dams.

Stone Walls

Where stones are available, stone walls can be built to reduce

soil and water loss and gradually produce terraces. Walls minimize the length of slopes and removing the stones from the field facilitates soil cultivation. Figure 2 shows the cross-section of

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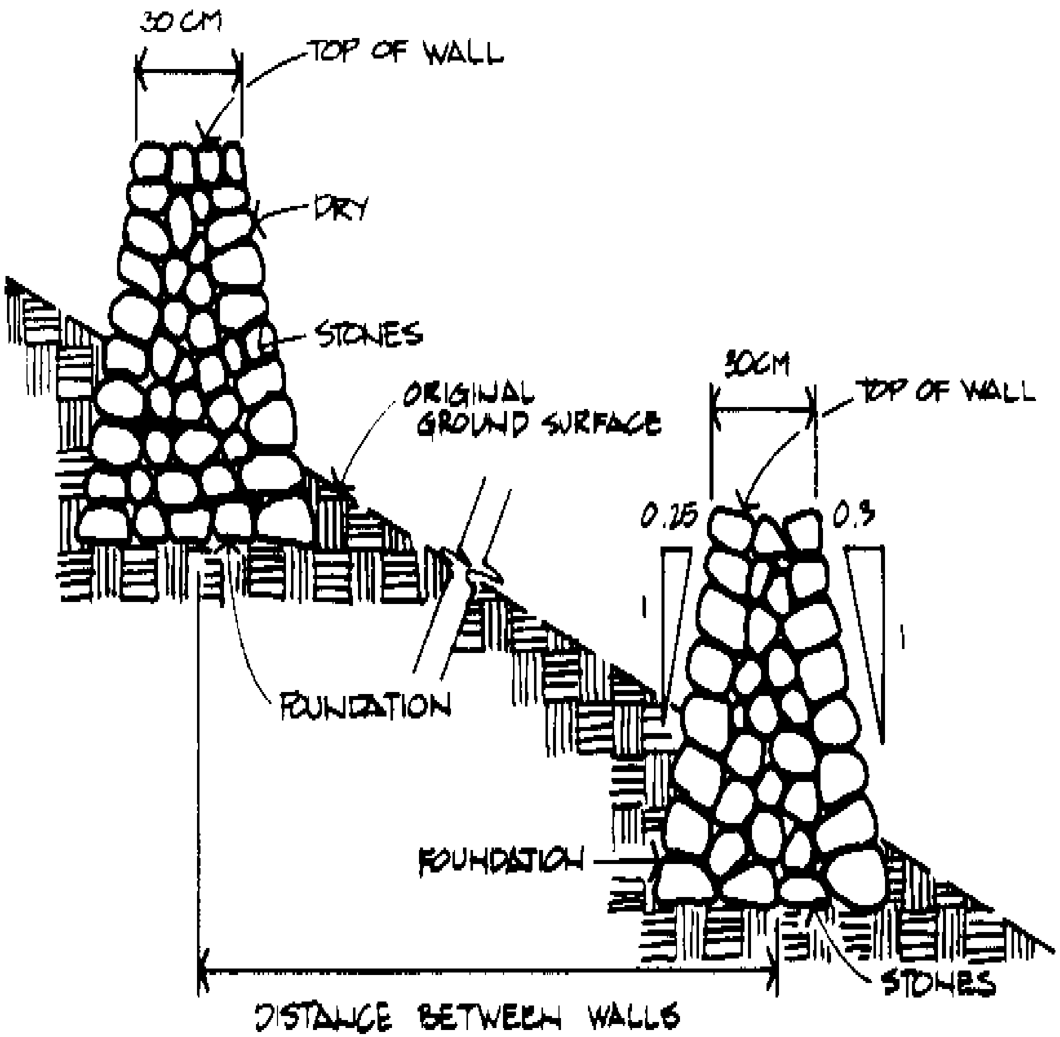

Figure 2: Dimensions of Typical Stone Wall

a stone wall. The outside walls lean into the hillside, while inside walls are almost vertical. The top of the wall should be about 30 cm across and the bottom about one meter. The distance between stone walls is determined the same way as contour canals. To construct a stone wall, first determine and mark the contours with an A-frame level. Excavate the soil to a depth of 30 cm, forming a flat base. Select the largest rocks to form the foundation and outside face. If the wall is built after a terrace has been formed by erosion, limit its height to 30 cm.

Terraces

Terraces are nearly-level strips built along contours. Their main purpose is to intercept runoff and control erosion. Terraces control erosion in many ways. They segment fields into small separate drainage areas and reduce the length of the slope. Runoff and its damage are reduced. Water is conserved on the field or moved off in a controlled manner. Terraces reclaim eroded lands and provide continuous protection of the reclaimed lands. In general, terraces are suitable on slopes up to about 50 percent. Level terraces are best on narrow slopes; outward sloped terraces are designed for steep land.

Unless labor is plentiful, the main constraint of constructing terraces is their very high labor cost. Despite this, terraces are the best means of soil conservation on cultivated lands.

The amount of topsoil is a factor when designing terraces. To ensure that the terrace can be filled, the amount of topsoil should be not less than half the height of the riser. The riser should lean into the slope a little and the length should not exceed 100 meters. Terrace width varies from 2 to 5 meters, depending on several factors: slope, depth of soil, crop spacing, and farm operations.

To determine the Vertical Interval use the formula:

```
D x S VI = Vertical Interval (m)
VI = ----- D = Width of Terrace (m)
100 S = Slope of Field ( percent)
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Slope is calculated by:

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|r
|i
rise |s
S = ---- x 100 ---------------|e
run run
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Sample results are illustrated in Table 2. The spacing in this table may be adjusted for the type of crop and the farming practices. In the case of pasture grasses, with permanent cover, ditches can be spread further apart.

To construct terraces, first survey the area and develop a management plan. Starting with sites that have uniform slopes, determine and mark the contour lines: place the first row of stakes at the top of the slope; walk downhill to the next contour line; set stakes about 3 to 7 meters apart. Clear the land of weeds, shrubs and trees and other obstacles. Finally, cut and fill starting at the bottom contour line; be sure to compact each filled area.

Table 2
Spacing of Flat-Based Terraces at Various slopes

Slope, percent	Spacing Between Ditches (m) Vertical Interval	Horizontal Spacing
5	1.1	22
10	1.6	16
20	2.6	13
40	4.6	11.5
55	6.1	11.4

Source: Liau & Wu, 1987

Figure 3 illustrates three different types of terraces. The formula

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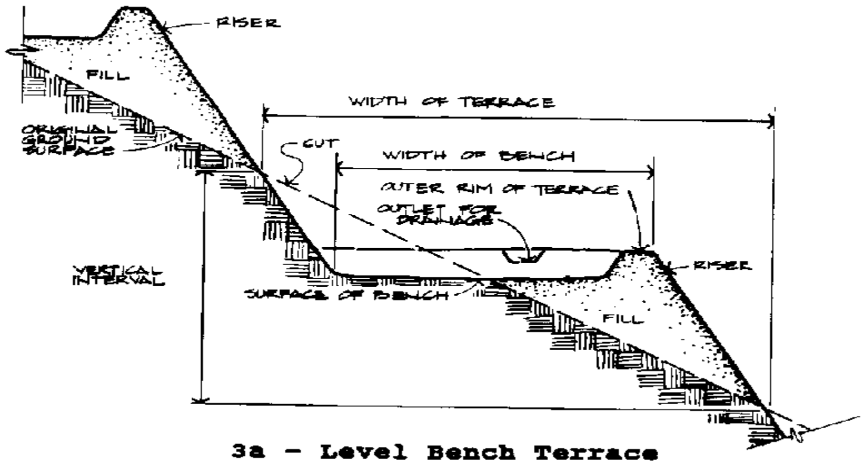
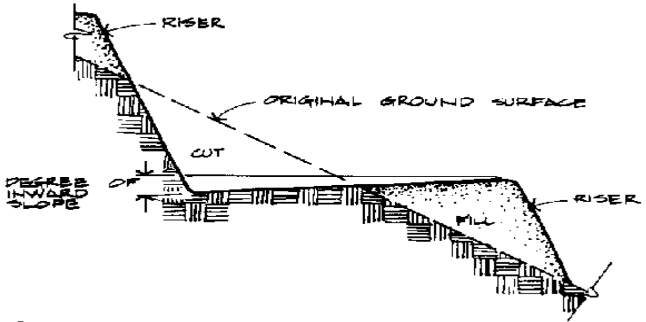
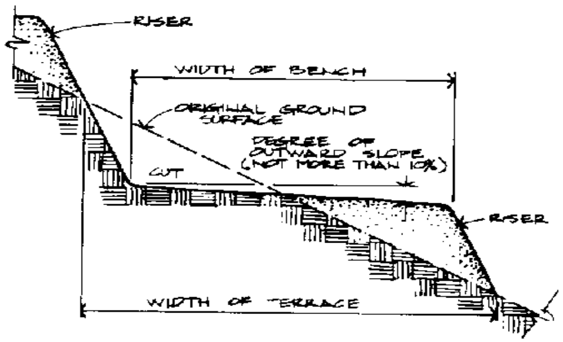


3a - Level Bench Terrace



3b - Reverse Slope Terrace



3c - Outward Slope Terrace

Figure 3: Cross-Sections of Three Types of Terrace
Source: Joint Commission on Rural Reconstruction, 1987.

above can be used to calculate the vertical distance between terraces for each of the three types.

The most important type of terrace for semi-arid regions is the flat channel terrace, sometimes known as the Zingg conservation bench. In Figure 4. the vertical interval (VI), in meters, between

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Figure 4: Cross-Section of the Zingg Conservation Bench Terrace
(The dashed line indicates the original slope.)

Zingg terraces is calculated by:

VI = 0.25 x S + 0.30 VI = Vertical Interval (m)
S = slope (percent)

An A-frame level is a simple, inexpensively built tool to use for mapping contours (Figure 5). To build one, use rope or vines to

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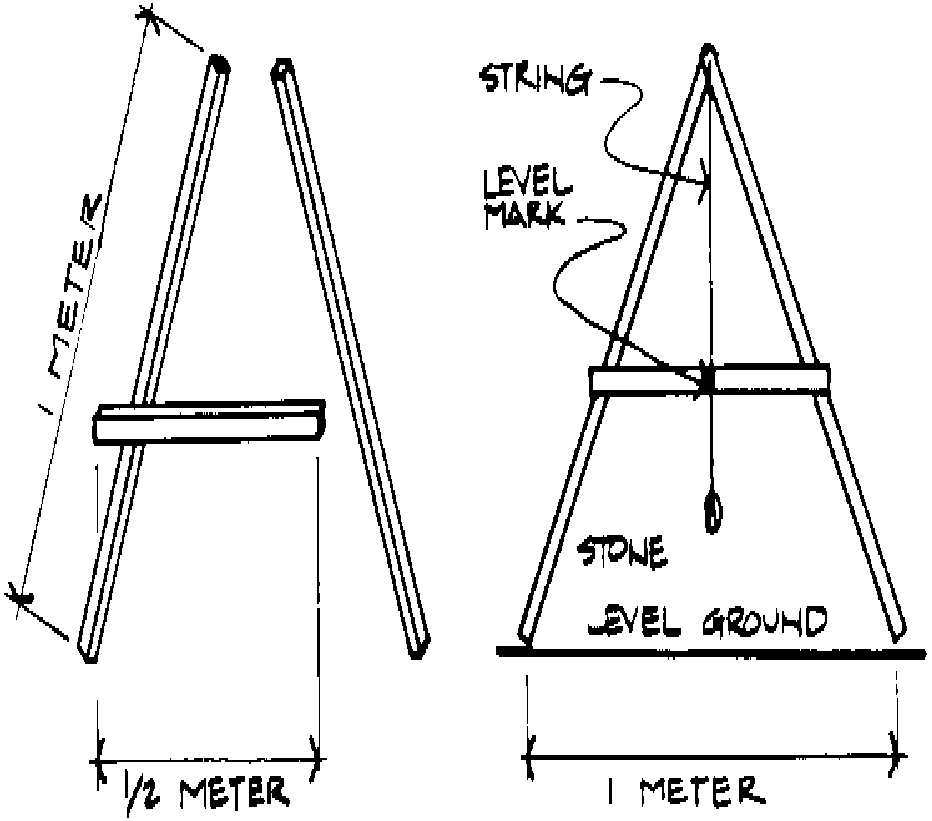

Figure 5: A-Frame Level Construction

securely fasten three poles or bamboo pieces to form a rigid letter "A" 2 m high and 1 m wide at the bottom. Tie string or twine to the joint of two long sticks and tie a rock or weight to the

lower end so that it hangs below the cross-piece of the A.

To calibrate the A-frame level (this needs to be done only once), stand it on level ground and place a stake at the base of each leg. Mark the crosspiece where the string passes it. Then reverse the leg positions of the A-frame and put another mark where the string passes the crosspiece. Now put a permanent mark on the crosspiece exactly midway between the other two marks. In mapping a contour, the string should always pass over this control mark.

To use the A-frame to plot a contour canal below a diversion ditch, walk downhill from the ditch until you can look at the base of the ditch without raising or lowering your head. This is the location of the first contour line. Place the A-Frame on the contour line; set a stake at the base of each leg. Pivot the A-Frame on one leg until the string passes over the center mark.
Set a stake at the base of the new leg position (Figure 7).

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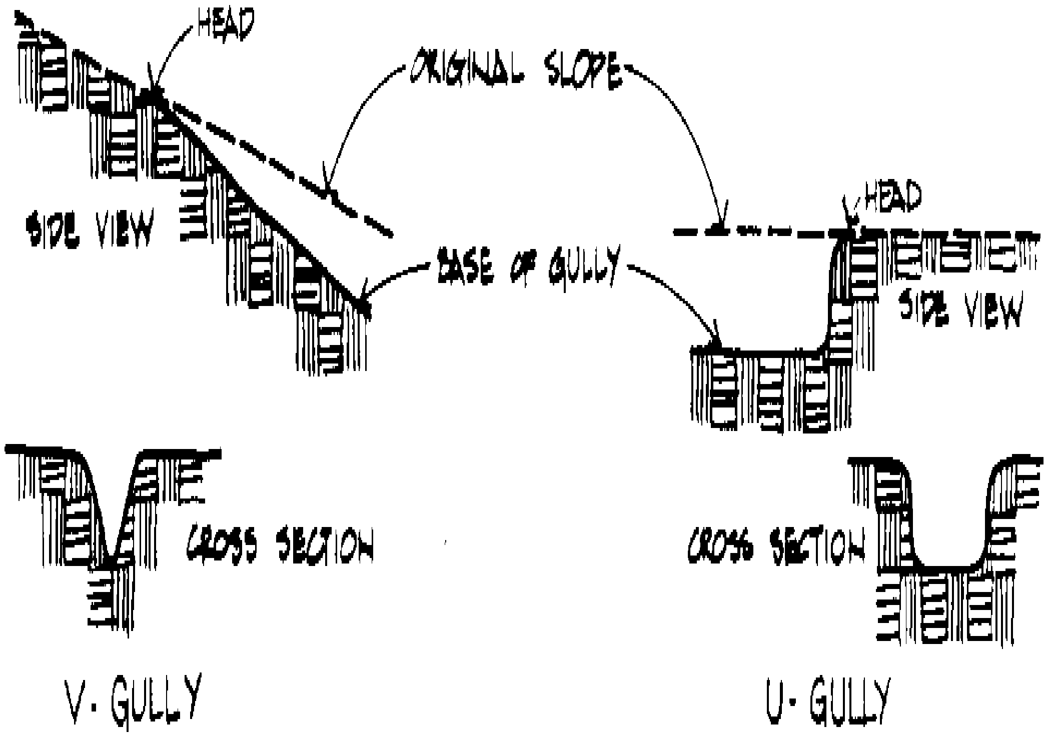

Figure 7: Cross Sections of Gullies Formed by Erosion

Continue to pivot, or "wall", the A-Frame across the slope setting stakes at the base of each leg as the string passes the center mark. If the string does not pass the center mark the A-Frame is not on the contour: adjust the placement of the forward

leg until the string is in the table right place.

Below the first contour line mark the location for the next contour; measure the vertical distance the same way as described above. Continue this process until the entire field has been marked.

<FIGURE 6>

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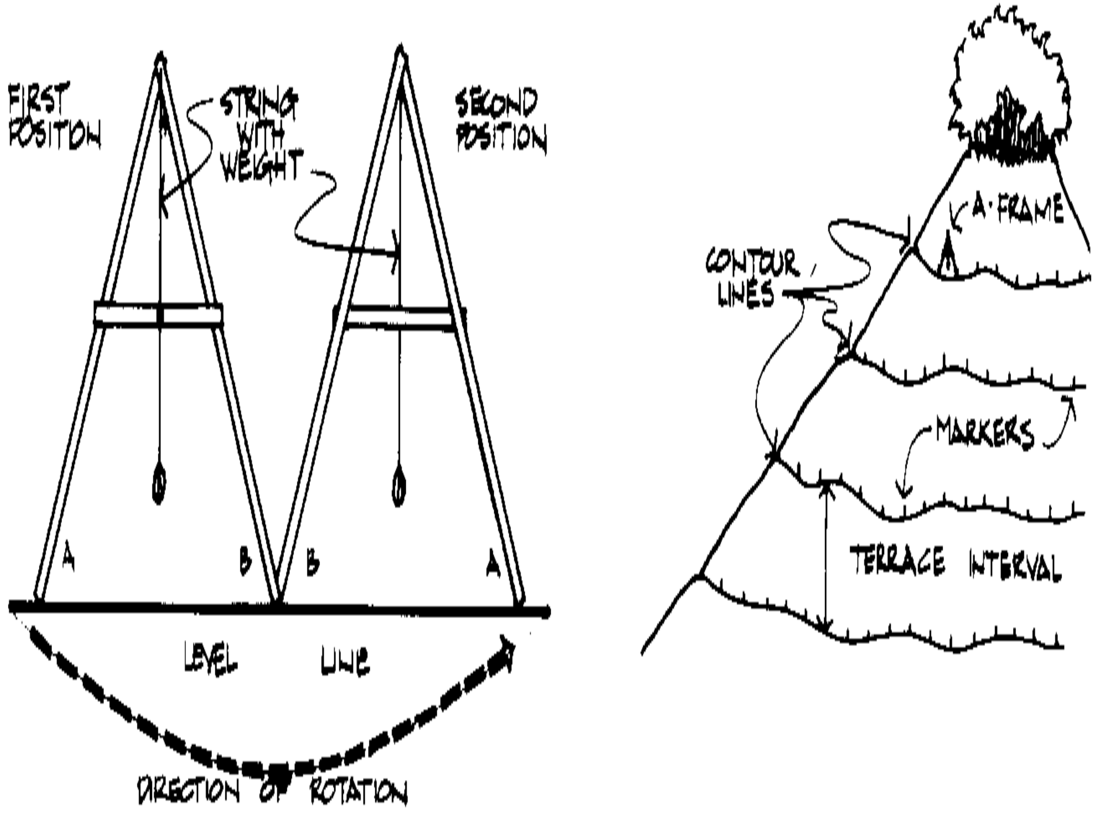

Figure 6: Using the A-Frame Level

Control of Gully Erosion

Gullies are surface channels that have eroded to the point where the land cannot be smoothed by normal tillage practices. They

form when large amounts of water accumulate and concentrate erosion in rills that deepen and form V-gullies or U-gullies, named for the shapes of their cross-sections (Figure 7).

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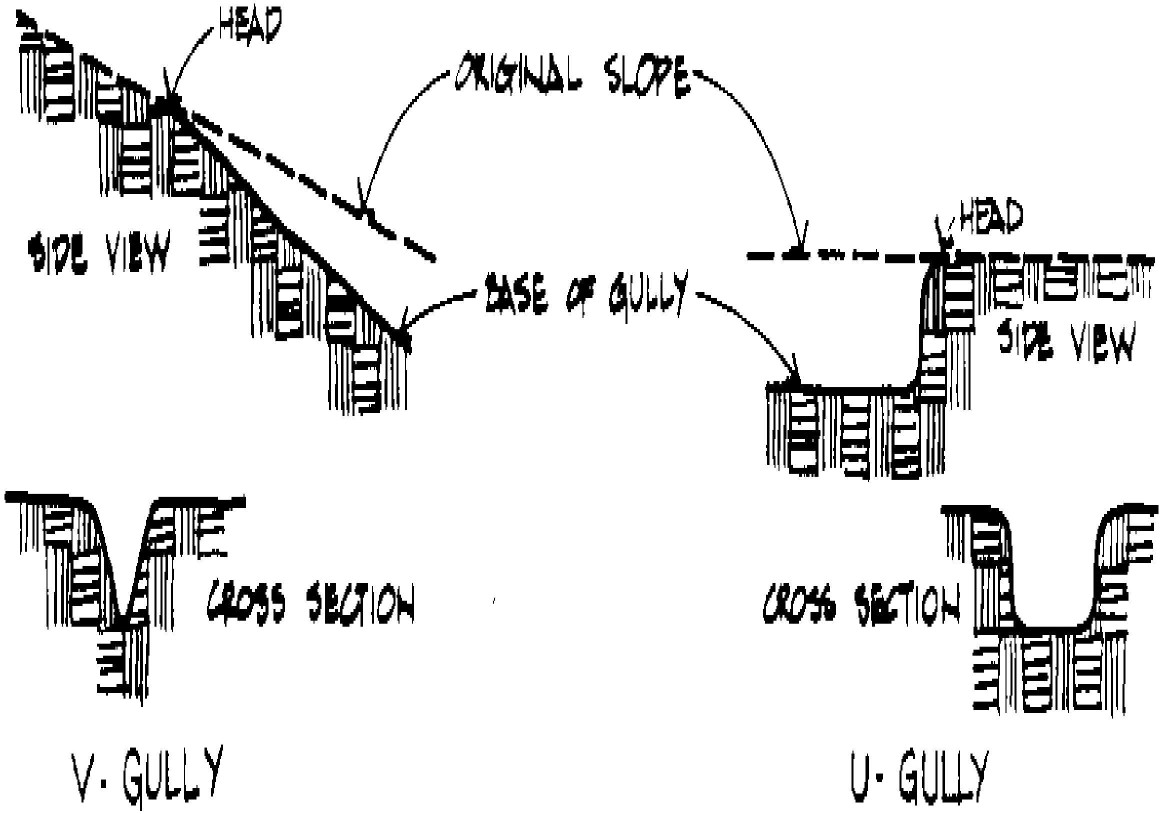

Figure 7: Cross Sections of Gullies Formed by Erosion

Check dams, made of locally available materials such as rocks, stones, stakes, freshly cut branches, sacks of soil, can be built

to shorten gully length and reduce runoff velocity. Areas above check dams fill with sediment and form terraces. The base of each dam should be level with the top of the next downhill check dam. The top of each dam should be concave to allow excess water to flow over its center and should extend past the sidewalls of the gully. Branches cut from some trees will sprout and form live barriers serving several purposes by holding subsoil with their roots, producing needed products such as fuelwood, and catching suspended soil particles. Impermeable check dams prevent water and sediment from moving downslope.

V-Gullies. V-shaped gullies form with downward cutting of the center of the channel. The gradient of the channel center is greater than the slope of the field. Typically, V-gullies deepen downslope and grow in length upslope. Water flows through V-gullies in small amounts but with high velocities.

V-gullies should be eliminated. If shallow, they can be filled with new soil. Immediate control measures are needed to assure that they do not re-appear. Other methods to control V-gully erosion include contour cultivation and strip cropping. A diversion ditch should be constructed around the top of the gully. Protect the outlets of diversion ditches from erosion. Construct permeable check dams within V-gullies to slow down the flow of water and catch sediment (Figure 8). The distance between check

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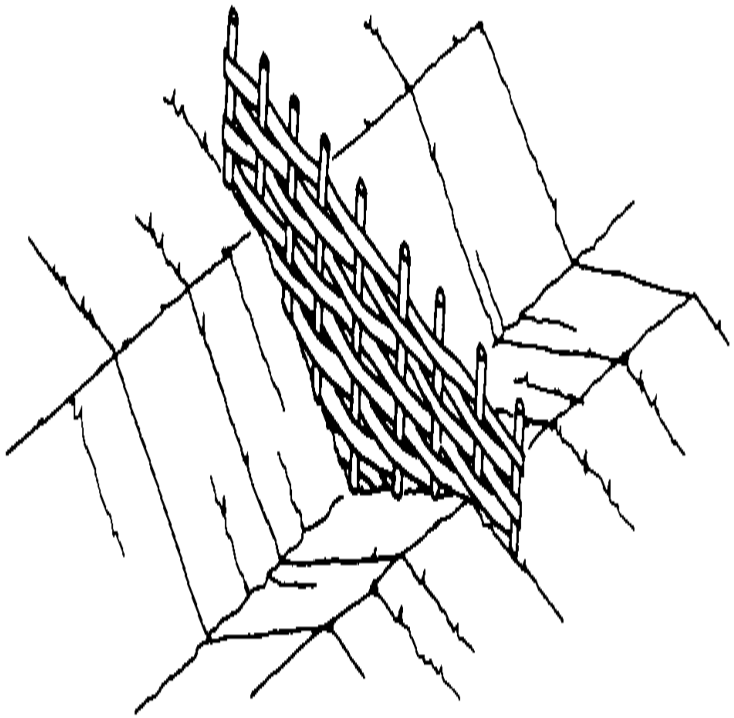

Figure 8: Permeable Check Dam Used in V-Gullies and Waterways

dams depends on slope and amount of runoff; make dams closer together on steep slopes.

U-Gullies. The flat bottoms of U-shaped gullies have slopes parallel to the slope of the land. Water flow is greater, but the velocity is much less than in V-gullies. Control starts at the points where they grow, the head (length) and sides (width). First, raise the bottom of the channel by constructing a series of permanent, impermeable check dams (Figure 9). Eventually, the

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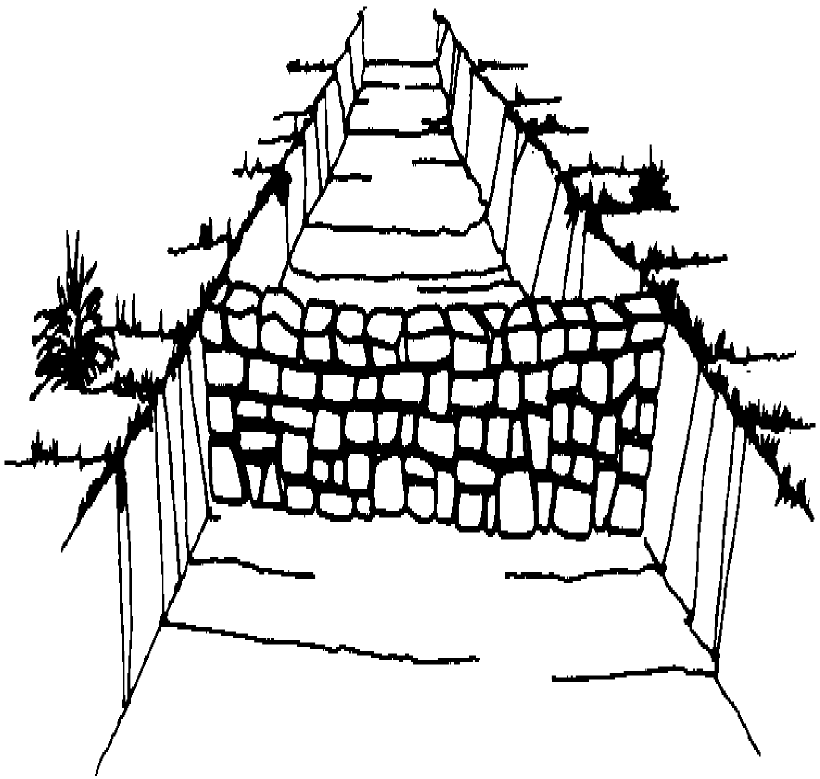

Figure 9: Impermeable Rock Wall Used in U-Gullies

area uphill of each check dam fills with sediment, raising the bottom of the U-gully. Reshape gully walls so that for every meter of rise one meter of horizontal distance is covered. Finally, stabilize the channel by planting grasses, vines, or shrubs.

5. CONTROL OF WIND EROSION

Strong wind detaches soil particles from the surface, transports them, and deposits them downwind. Two danger signs of possibly harmful wind erosion are sand buildup on the downwind sides of obstacles and sediment ripples in fields. Even in a short time, wind can blow away enough soil to greatly reduce soil fertility and crop yields. Wind may expose recently planted seed and prevent germination. The abrasive power of soil particles suspended in the wind can permanently damage small plants.

Loose, dry, and finely granulated soil particles are blown away more easily than heavier textured soils. Wind erosion is favored by sandy soils, smooth surfaces, sparse vegetation, open expanses of land, and strong or turbulent winds. Accordingly, control measures include increasing soil stability and surface roughness. Tillage can compress soils and smooth the surface, and should be limited to the adequate preparation of seed beds and the control of weeds. Conservation cultivation, particularly minimum tillage, is a practical method to stabilize soils.

Physical barriers should be perpendicular to the wind direction. A windbreak is a dense barrier of perennial tree crops and shrubs specifically designed to reduce wind speed for the benefit of annual crops (Figure 10). Well planted and well grown windbreaks

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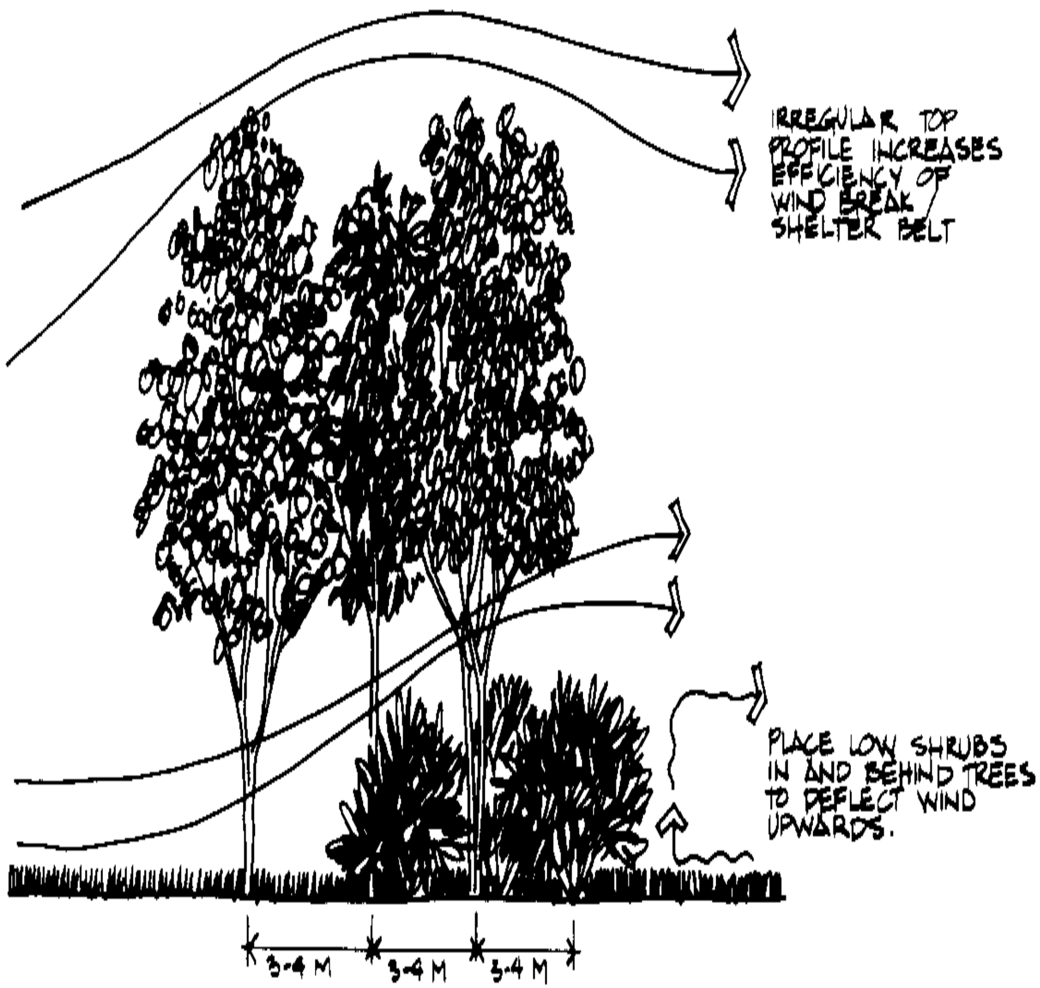

Figure 10: Typical Windbreak

can reduce wind velocity by as much as 70 percent to 80 percent near the barrier. Moreover, a windbreak can modify air temperature within the protected areas and conserve soil moisture by reducing evapotransporation. The relative humidity within the canopy on the downwind side increases. Another important side

effect, especially if already-limited cropland must be taken out of production to plant the windbreak, is the fruit, fuel, nuts, or other produce of the trees.

The effect of a windbreak is proportional to its height. In general the reduction of wind velocity past the windbreak weakens and becomes negligible at a distance of 30 to 40 times the its height. The density of windbreaks also affects the decrease in wind velocity (Fig 11). A dense windbreak reduces velocity sharply

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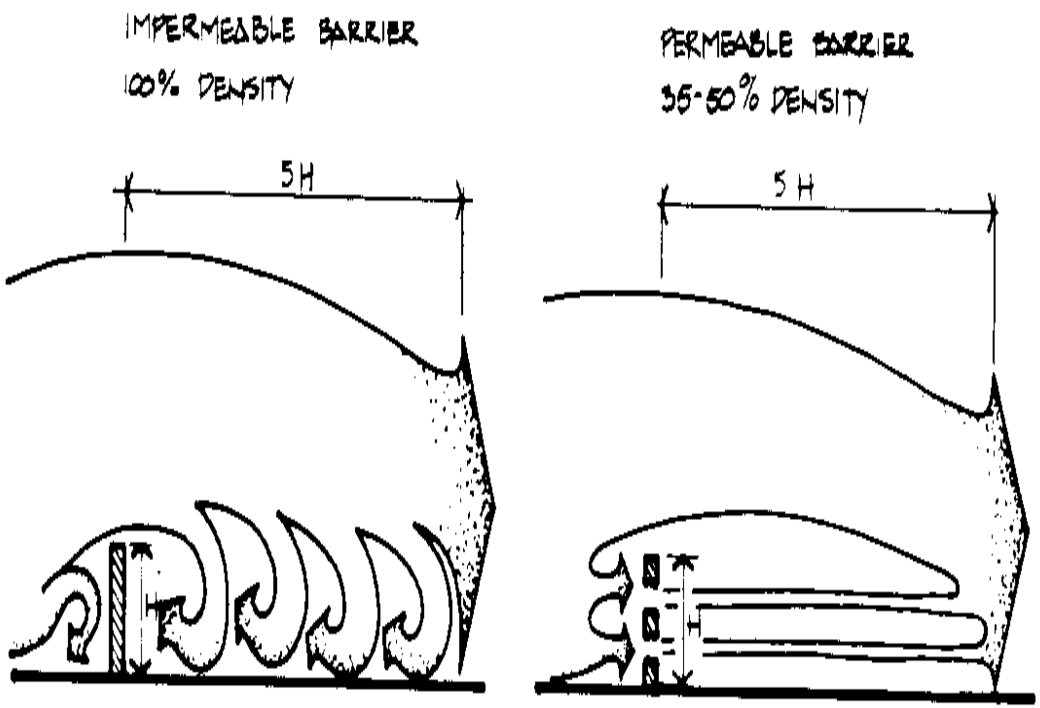

Figure 11: Wind Velocity and Turbulence As Affected by Windbreak Density

and quickly. A windbreak that is too dense causes the wind velocity to recover in a shorter distance, thus reducing the length of the protected area. The most effective density is between 35 percent and 50 percent.

The distance between windbreaks (Figure 12) is critical, but

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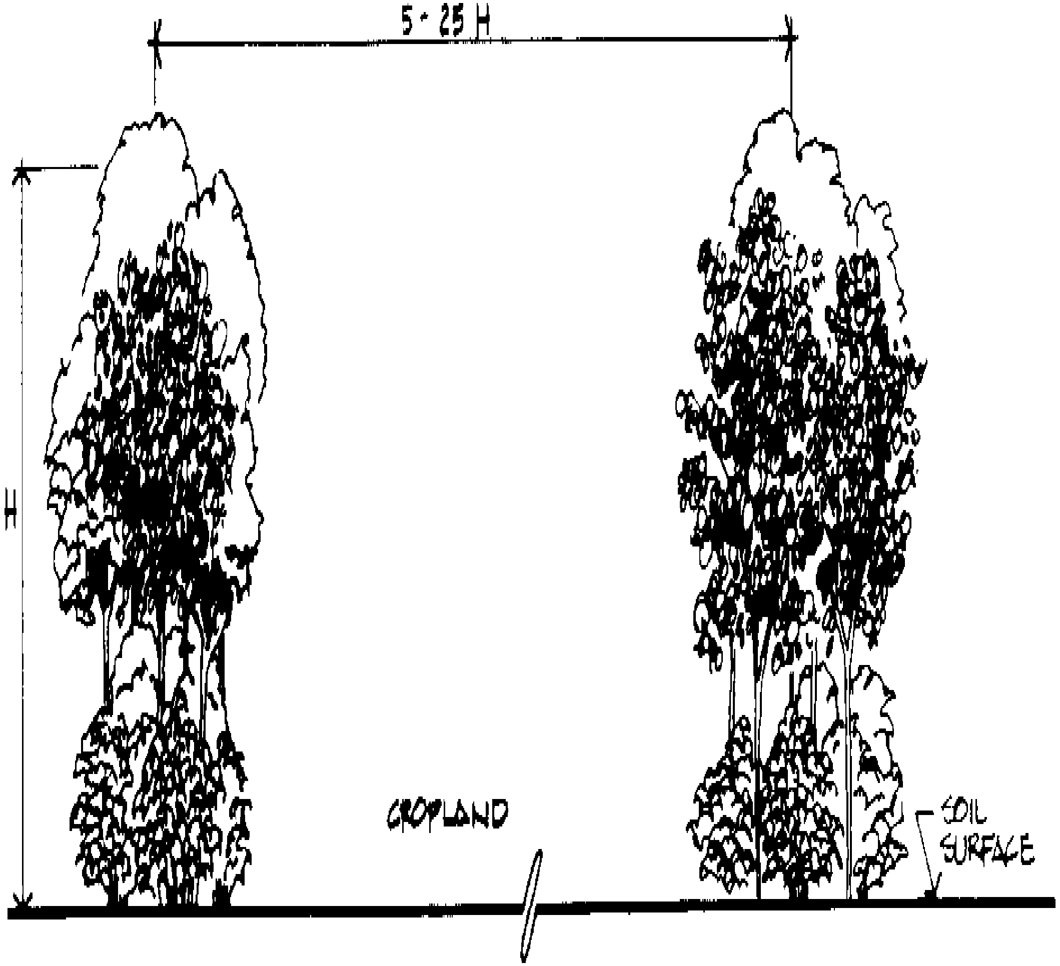

Figure 12: Layout and Cross-Section of Windbreaks

varies with crops and soil stability. The best distance between

barriers shielding forage crops is 10 to 14 times the height. In areas with highly erodible soils, strong winds, or sensitive crops (fruit or vegetables) the distance between windbreaks should be 5 to 10 times the height of the barrier. For moderately responsive crops (wheat, rye, oats, etc.) the distance is extended to 15 to 25 times the height of barriers.

Windbreaks should extend the total length of the field and run perpendicular to the wind direction. Gaps or breaks will accelerate wind through them and increase erosion; allowance for necessary pathways or stock crossings should be made on the diagonal (Figure 13). Windbreaks not perpendicular to wind direction will

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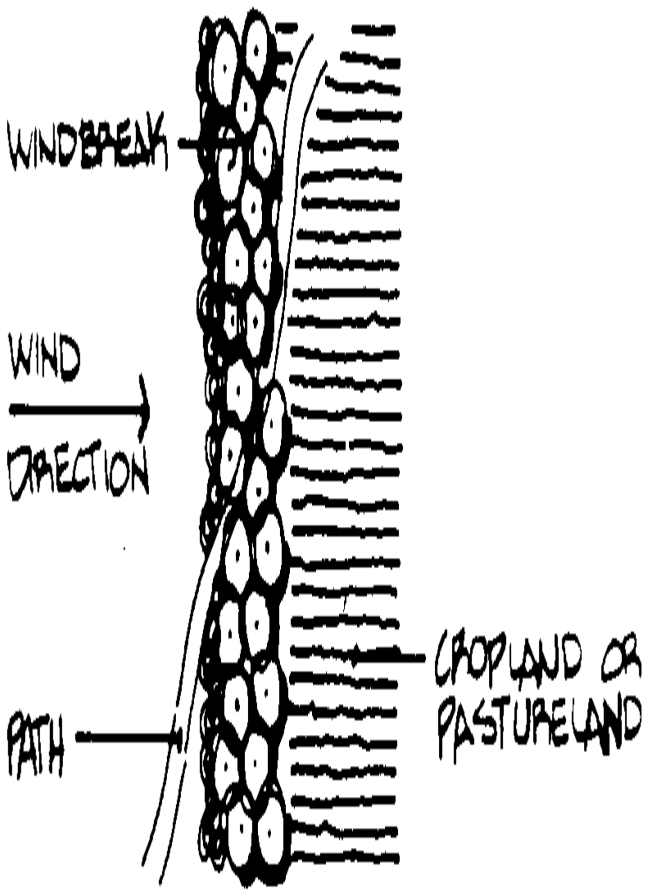

Figure 13: Paths and Stock Trails Cross Windbreak on the Diagonal

channel wind along the barriers. The best shape for windbreaks is created by multiple rows of trees, but this takes more land out of crop production. Local tree species that send deep tap roots and develop narrow crowns are best.

To keep windbreaks viable it is essential to maintain the vigor and growth of the trees by thinning and cutting when necessary.

6. PLANNING FOR EROSION CONTROL

Individually, the control measures discussed above reduce runoff and slow erosion under specific conditions. However, maximal control of erosion is achieved through planned activities that use a variety of control measures. Effective planning involves selecting and developing the best course of action to reduce or halt the movement of soil from crop fields while maintaining farm productivity.

It is essential first to collect all available data about the land. Critical information for land use planning includes soil depth, soil type, drainage characteristics, and slope of the land. A field survey should assess the target area for the severity of erosion; consider the extent of sheet erosion, the space between rills, and the type and spacing of gullies; and determine the texture class of the soil. The field survey also should consider the abundance of stones; the consistency, structure, and stability of the surface; and soil reaction, salinity, and drainage. Frequency, duration, and intensity of rain and wind should also be noted.

In addition, the survey should look at tillage and animal husbandry practices in use, and the resources farmers have available to make necessary changes. In this regard, it is important to engage the farmers' interest and participation by assuring that they are intimately involved in the survey and planning process.

The practices selected to control erosion should be based on a combination of principles. First, the practices should maintain soil infiltration rates at high levels to reduce runoff to negligible amounts. Examples are mulching and vegetation cover. Second, they should safely dispose of runoff from the field. Such physical structures as hedgerows, contour canals, stone walls, and terraces are used for this. Finally, practices must be within the means of farmers to implement and maintain, or they will not be continued more than a season or two.

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