PN-AAM-017

ISN 15351

Agriculture Technology for Developing Countries

Technical Series Bulletin No. 28

Soil Improvement, Rainfall Conservation, and Erosion Control in Developing Countries

Office of Agriculture
Bureau for Science and Technology
Agency for International Development
Washington, D.C. 20523

SOIL IMPROVEMENT, RAINFALL CONSERVATION, AND EROSION CONTROL IN DEVELOPING COUNTRIES

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PREFACE

Developing countries are highly dependent on productive agriculture, not only to provide for the welfare of each nation's population, but also to meet needs for international trade. The agricultural populations of developing countries account for some 50% to 80% of total human population. The effective use of arable lands and grazing lands is in the hands of these agricultural population sectors. The degree of profitability and prosperity of these farmers and herders requires among other things, an efficient system of soil improvement, rainfall conservation, and erosion control. There is reason to believe that the great advances in these aspects made by developed countries in the recent century, may be repeated in the developing regions of the tropics and subtropics. This bulletin discusses the basic principles of sound land management, that are applicable to the present situation in developing countries. Great improvements appear feasible.

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SOIL IMPROVEMENT, RAINFALL CONSERVATION, AND EROSION CONTROL IN DEVELOPING COUNTRIES

Introduction

This bulletin undertakes to outline principles and procedures for progressive improvement of land and soil productivity in developing countries. Lands and the soils that cover them, occupy a crucial role in the productivity of all agricultural areas. The phenomenal increase in productivity of agricultural lands in developed countries of the world during the current century are proof that man's management of lands and soils can radically change their native capability. In those countries the application of scientific discoveries is responsible for the advances in both crop and forage production, and in the essential support for profitable livestock enterprises of all types.

There is justification for the belief that similar progress can be made in all developing countries by pursuing programs of agricultural scientific discoveries of how to manage lands and soils, so that they become more and more productive in successive years. Such improvements are not a single year's effort; but each year should produce a new level of productivity on which to build for further advances in following years. It is essential that each year's effort provide a net increase in income to the native farmers and herders, so that these producers may take the subsequent steps for even greater productivity and profitability.

It is clearly evident that progressive improvement of the productivity of lands and soils requires that an equitable system of land tenure be established for users of the land. The prevalent system of yearly allocation of lands to individual farmers and herders, does not provide the security of user-rights that will foster longer term beneficial management. The authorized users of lands must have government assurance of sustained exclusive use of specified lands, to encourage them to undertake land and soil improvement. Such authorized allocation of lands should establish methods and amounts of payment for substantial investments of continuing value by the user in the event his lands are transferred to other users. This is an equitable arrangement widely used in developed countries, that insure fair financial arrangements for both the land owner (private or government) and the tennant manager of the land.

Section I deals with soil improvement; Section II describes rainfall conservation by retaining rains on the land by infiltration into the soil profile, for use by crop plant roots; and Section III discusses the principles and practices of soil erosion control - both water erosion and wind erosion.

This publication recognizes that top priority must be given to subsistence and survival of the family units; and that additional production for market outlets must be economically profitable to the producing farmers and herders.

I. Soil Improvement

The objective in soil improvement is to improve productivity for growth of selected crops adapted to the environment, and more vigorous growth of forages for ruminant livestock feed. Although some benefits may be derived

from growing superior strains or varieties of each plant type, the greatest response of such superior plants is made possible by altering the soil's nutrient supplying power, or improving the available soil moisture supply, or some combination of these. The alteration of the soils nutrient supplying power is largely chemical in nature, but the enhancement of moisture supplies is largely physical in nature. These types of treatment will be discussed below:

A. Chemical aspects of soil improvement

(1). Essential nutrient elements are required by all growing plants. The major nutrient elements obtained from soils by plants are:

Nitrogen (N)

Phosphorus (P)

Potassium (K)

Calcium (Ca)

Magnesium (Mg)

Sulfur (S)

In addition, growing plants need small amounts of certain minor elements; and deficiencies in any of these may prevent response to the major nutrients. These are:

Boron (B)

Copper (Cu)

Iron (Fe)

Manganese (Mn)

Molybdenum (Mo)

Zinc (Zn)

All plants (crops, forages, trees, and shrubs) must obtain these essential plant nutrients from the soil. The soils of the tropics and subtropics are quite diverse in origin and in their present status of fertility. The current supply of these essential nutrient elements in any area may be determined by taking respresentative soil samples from specific locations; and by laboratory analyses of these samples to reveal the available supplies of each nutrient element. The important crop and forage plants also have differing specific requirements for mineral nutrients to make satisfactory growth. Any deficiencies in nutrient supplying power of soils should be corrected by the use of fertilizers or soil amendments, to meet the needs of the plant types being grown as harvested crops or as forages.

Most commercial fertilizers are formulated to provide nitrogen, phosphorus, or potassium, or some combination of these. Soil amendments may provide calcium and/or magnesium (usually as limestone); and generally are needed on strongly acid soils. The choice of fertilizers and soil amendments should provide for correction of any nutrient deficiencies revealed by laboratory testing of field soil samples. The final evaluation is the responses of the crop or forage plants to application of selected fertilizers on soil amendments. The increased productivity produced by such treatments must be economically profitable, to be adopted. the methods of field application of fertilizers is quite important in producing profitable results. An even more aspect is that each year's management of every field should raise the long term productivity of soil to a higher level.

Thus, the cumulative effect of using commercial fertilizers depends on the residual effect of each years treatments.

COMMERCIAL FERTILIZERS AND THEIR USE IN STIMULATING GROWTH OF CROPS AND FORAGES.

Characteristics of Commercial Fertilizers

A. Characteristics of Phosphate Fertilizers

1. Rock phosphate (finely ground)

The average phosphate content is 34% (P_2O_5). Rock phosphate carries abundant calcium, but has very low content of magnesium and sulfur. It contains no potassium (potash). However, rock phosphate contains significant amounts of the 6 "trace" elements (boron, copper, iron, manganese, molybdenum and zinc).

2. "Single" superphosphate

The average phosphate content is 16 to 20% (P_2O_5). (It is produced by treating rock phosphate with sulfuric acid).

Single superphosphate contains large amounts of calcium and sulfur, plus substantial amounts of the 6 "trace" elements. It also contains significant amounts of cobalt, that is an important nutrient for livestock. Single superphosphate is deficient in magnesium and potassium (potash).

3. Di-Ammonium phosphate

Contains about 46% phosphate (P_2O_5) and 18% Nitrogen (N). It contains no calcium, no sulfur, no calcium, no magnesium, and very limited amounts of the 6 "trace" elements.

4. Mono-Ammonium phosphate

Contains about 55% phosphate (P_2O_5) and 11% Nitrogen (N). It contains no calcium, magnesium, potassium, or sulfur, and very limited amounts of the 6 "trace" elements.

5. Triple superphosphate

It contains about 45% phosphate (P_2O_5) (produced by treating rock phosphate with phosphoric acid). It contains moderate amounts of calcium, but no magnesium, no potassium, and no sulfur. It contains very low amounts of the 6 "trace" elements.

(NOTE: the "trace" elements are quite essential for plant growth, but are needed in relatively small amounts. They are Boron (B), Copper (Cu,), Iron (Fe), Manganese (Mn), Molybdenum (Mo), and Zinc (Zn).

B. Characteristics of Nitrogen Fertilizers

1. Ammonium Nitrate contains 33% Nitrogen (N). It contains no other major nutrient elements, and no "trace" elements.
2. Urea Contains about 45% Nitrogen (N). It contains no other major nutrient elements, and no "trace" elements.

C. Characteristics of Potash Fertilizers

1. Potassium Chloride contains 60% potash (K_2O) but contains no other essential plant nutrient.
2. Potassium Sulfate contains 48% potash (K_2O), and 18% sulfur (S) but contains no other plant nutrient elements.

D. Characteristics of Magnesium Fertilizers

1. Dolomite limestone contains about 10% magnesia (MgO), and abundant calcium, but no other plant nutrient.
2. Magnesium sulfate contains about 14% magnesia (MgO), and 14% sulfur (S), but no other plant nutrient.
3. Sulfate of Potash-Magnesia contains about 20% potash (K_2O) and 18% magnesia (MgO) but no other plant nutrient.

E. Mixed Fertilizers

Mixed fertilizers are those containing two or three of the major nutrient elements; Nitrogen, Phosphate, Potash. Most nations now require that mixed fertilizers be clearly marked as to the "plant food content." For example: a 5-10-5 fertilizer must contain 5% by weight of nitrogen, 10% of phosphate, and 5% of potash. Another example is 8-5-4, in which the nitrogen content is 8%, phosphate 5%, and potash 4%.

When all 3 major nutrients are present, the fertilizer is sometimes called a "complete" fertilizer. However, the ratio of nitrogen-phosphate-potash does not insure that it will affectively balance the soil deficiency in such components.

When fertilizers contain only two of the major nutrient elements, the guaranteed analysis should show this, as follows: 10-10-0 which means that both nitrogen and phosphate are present, but no potash.

It must be emphasized that guaranteed analysis of a fertilizer in no way provides an indication of crop plant needs on a specific soil, in either the ratio of nutrient elements needed, or the amounts required to produce vigorous plants.

It should also be noted that the required guaranteed analysis of a fertilizer only showns the content of nitrogen, phosphate and potash. It does not reveal the content of other essential nutrient elements, including calcium, magnesium and sulfur. Nor does the guaranteed analysis of the fertilizer reveal the presence or amounts of the essential "trace" elements; boron, copper, iron, manganese, molybdenum, or zinc. The probable amounts of such nutrient elements may be estimated from the selection of fertilizer materials used in formulating the specific mixed fertilizer. The foregoing information on rock phosphate, and single superphosphate (which contain certain accessory elements) is useful in evaluating the usefulness of the fertilizer that may be locally available.

Where the fertilizer that is available, contains appreciable amounts of nutrient elements other than nitrogen, phosphate, and potash, the content of such elements should be included in the guaranteed analysis.

NOTE: For more detailed information on the contribution of vigorous legume crop plants to additions of nitrogen to the soils, see Technical Bulletin #12, Office of Agriculture, Bureau for Science and Technology, USAID-Washington.

Replacing Nitrogen Fertilizer with A Nitrogen-fixing Legume Crop in Farming Systems.

A vigorous growing legume crop such as the various types of beans, peas, groundnuts, and soybeans, will not only provide itw own supply of nitrogen, but also leave a substantial residue of nitrogen in the soil, that may support a following crop. This trait of legumes is caused by special strains of

root-nodule bacteria (Rhizobia spp.) that convert free nitrogen in the soil air, into nitrogen compounds. The amounts of air-nitrogen converted into nitrogen-rich compounds may amount to the equivalent of 100 Kg of Urea per hectare, or 150 kg of Ammonium Nitrate per hectare. In general, about 50% of the fixed nitrogen in legume roots and nodules is released for use by the following crop, and the remainder becomes available in subsequent crops on the field.

Farming systems may be planned to replace much or all of the nitrogen fertilizers otherwise needed to grow grain crops, oil seed crops and many vegetable crops.

F. Animal Manures

Animal manures have been used in historic times, by all cultures, to improve crop plant growth. Much of the nitrogen and potassium in animal excrements is in the urine. In developed regions the urine is absorbed in the straw or bedding of livestock enclosures, along with the feces, and the mixture is applied to arable lands in preparation for crop production. In less developed countries, most of the manure that is collected and applied to lands, is the solid excrement. The solid excrement (feces) contains low amounts of all the essential mineral nutrients for plant growth, but this manure has the unique property of being highly available to plants. The explanation for this unique characteristic is that the feces have passed through the aminals digestive tract which produced "chelated" compounds that remain soluble under a wide range of soil conditions. These "chelated" forms of the 6 "trace" elements are an important part of the effects of manures on plant growth. Although solid manures have relatively low contents of the 6 major nutrient elements (nitrogen, phosphorus, potassium, calcium, magnesium and sulfur), when applied in amounts of several hundred kilograms per hectare, the benefits to plant growth are quite significant.

The effective use of animal manures for fertilizing crops generally insures against deficiencies in the "trace" elements, since these trace elements are uniquely absorbed by plant roots.

Manures are most effective when placed in soil below the plant row. A suitable practice is to open a furrow to about 10 cm, spread manure in the bottom of the furrow, and cover with a few cm of soil. If commercial fertilizer is used also, it may be spread on top of the manure. Seed may be placed on the partially closed furrow, and covered with a few cm of soil. This placement of manure insure early availability of the nutrient for the seedlings roots and sustained nutrition of the crop during growth.

The sustained use of manures provides a progressive improvement in soil fertility as the manures gradually decompose (for several years) in the soil. Spreading manure on land surfaces without incorporation in the soil, wastes large amounts of the nutrients by leaching, erosion and consumption by soil insects.

Effective Use of Fertilizers in Rainfed Agriculture

Commercial fertilizers and soil amendments should be used only to the extent that plant growth is stimulated, so that the benefits exceed the costs. Laboratory testing of representative soil samples from specific fields should provide the necessary information on the current nutrient supplying power of the soil. Further proof as to the benefits from use of fertilizers should be provided by actual field trials, with the materials that are carriers of the nutrients in short supply. However, the testing of soil samples is a prudent evaluation, of which nutrient elements that should receive most attention.

The nitrogen supply of the soil is estimated from other factors than the current chemical level of nitrogen. Leguminous crops (all beans, peas, groundnuts, etc.) leave a residue of organic matter that decomposes to release nitrogen for the following cropo. Also, soils with substantial organic matter (as humus) release nitrogen gradually during the following growing season. Thus, the need for nitrogen fertilizer is estimated by previous cropping and the nature of the response of the crop to be grown, to nitrogen fertilizer. Since nitrogen fertilizer is the most expensive of all fertilizers, maximum use should be made of legumes in crop rotations to supply this nutrient. In some systems, a legume may be grown in mixture with a non-legume (such as cowpeas and millet) to provide nitrogen to the non-legume. Nitrogen fertilizer is usually not needed for any leguminous crop.

Phosphates are generally needed on upland soils of the tropics and subtropics. The choice of the most beneficial phosphate fertilizer is influenced by soil acidity (see following section), and the accessory elements carried in the specific form of phosphate fertilizer. Rock phosphate (finely ground) is satisfactory on strongly acid soils only. On all other soils, superphosphate is more readily available to crop plants.

Single superphosphate is generally much more effective than triple superphosphate or di-ammonium phosphate because of the natural content of calcium, magnesium, sulfur, and the 6 "trace" elements. The amounts of phosphate fertilizer that produces economic benefits, depends on the type of crop to be grown. Food grain legumes (all peas, beans, groundnuts, etc.) and forage legumes require substantial phosphate. The final measure of benefits must be determined by field trials on the important crops. Where phosphate is needed, the additional crop yields from suitable applications is generally highly profitable.

Potassium (potash) is often necessary to supplement phosphate fertilizer, but is rarely profitable when used alone. It may be provided in a mixed fertilizer, or as an addition of muriate of potash, or sulfate of potash-magnesia. The latter is important where other sources of magnesium are not provided in mixed fertilizers. When adequate phosphate and nitrogen are provided for higher yielding crops, it becomes essential to supply potassium in abundance, since a deficiency in potassium may largely limit response to other nutrient elements.

Fertilizer placement in the soil is very important. Although nitrogen fertilizers will enter the soil with rainfall, this is not the case for other nutrient elements. For greatest benefits, all fertilizers, including nitrogen are best placed in the soil in the proximity of crop plant roots as the seedlings grow and mature. A feasible practice for row crops is make a furrow 10 to 15 cm deep, and spread the selected fertilizer in a band at the bottom of the furrow. About 5 cm of soil should be pulled on top of the fertilizer, and seed placed on the soil bed, seed should be covered with an additional 2 to 4 cm of soil, leaving an unfilled shallow furrow of 5 or more cm depth. This open furrow will accumulate rainfall and insure rapid seed germination. By this system, the crop plant seedlings rapidly grow into the banded fertilizer, and support growth to plant maturity.

In districts where machine services are available to farmers, there are simple machines that will open furrows, meter out fertilizer, cover with soil, drop seed and cover, all in a single operation.

For solid plantings of forage grass and legumes, and for green manure crops not grown in rows, it is essential that fertilizers be broadcast over the surface of the field and disked into the soil to a depth of 5 to 10 cm.

It is quite important that seed not be in direct contact with fertilizer, since this would seriously damage germination and growth of the crop plant.

Progressive improvement in soil fertility from year to year, is feasible with continued use of appropriate fertilizer for each crop grown. When fertilizer and lime or other soil amendments are applied to fields in amounts found to produce profitable yields, there is a residue left in the soil that benefits the following crops. When such prudent fertilizer useage is accompanied by desirable crop rotations, and the use of animal manures, the crop producing capability steadily increases.

In the developed countries of the world such soil improvement has been carried on for many decades, with the result that crop yields have more than doubled in the recent decades. Similar progress appears quite feasible on the arable lands of the tropics and subtropics.

Soil Acidity

Soils in humid regions of the tropics and subtropics often are strongly acid. Exceptions are some alluvial soils, and soils derived from volcanic ash. The acidity levels of humid soils are generally strongly acid. This acidity is an important factor in agricultural production. The tolerance of acidity by individual crop species determines their adaptation to the local soils. For example, cowpeas grow well on strongly acid soils, but dry beans require soils with low acidity or some degree of alkalinity for best growth.

Not only is the degree of acidity important; but strongly acid soils have large amounts of toxic soluble aluminum, or iron, or manganese that adversely affect acid sensitive plants.

Soil acidity is measured in pH units as shown in the accompanying Chart (Figure 1). For the world as a whole, there are soils in all of these categories of soil acidity. The regions of low rainfall are the sites of soils in the alkaline range of soils.

Soil acidity has a pronounced effect on the solubility of essential mineral nutrients. This is important, since low solubility results in low plant uptake of nutrients in the root zone. The accompanying chart (Figure 2) shows that the highest availability (solubility) of the major nutrients occurs when soils are neither strongly acid, nor strongly alkaline. However, the "trace" elements (Boron, Copper, Iron, Manganese and Zinc) are most soluble in acid soils. Molybdenum is an exception.

Liming soils to reduce or correct excessive soil acidity has long been practiced in developed countries. Recent research in Peru on the acid soils of eastern slopes of the Andes, as well as in other tropical humid regions with acid soils, shows that applications of finely ground limestone not only reduces or corrects tht toxic effects of soluble aluminum (or iron and manganese), but also it permits successful growth of acid-intolerant crop species such as maize, soybeans etc., as well as many vegetable crops. With adequate lime applications to reduce the acidity to pH levels of approximately 5.5 together with appropriate fertilizers to meet crop plant needs, it is economically feasible to grow a wide variety of crops, in seccessive years, without any fallowing, or slash and burn, which has been a traditional way of "resting" arable lands in the tropics.

This is an exceedingly important development, since it means that great areas of tropical lands now may be farmed continuously with quite profitable yields. The amounts of limestone required to bring the acidity level of soil to pH 5.5 or above must be determined by actual testing of the soils, area by

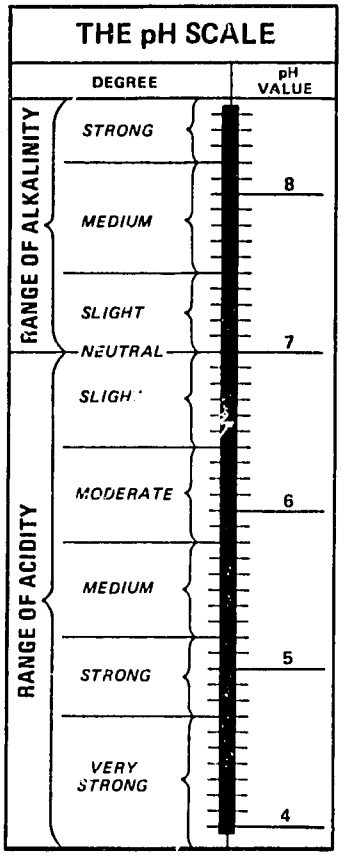

Fig. 1. The pH scale showing the ranges of soil acidity and alkalinity at which plants grow. (Courtesy, National Lime Association).

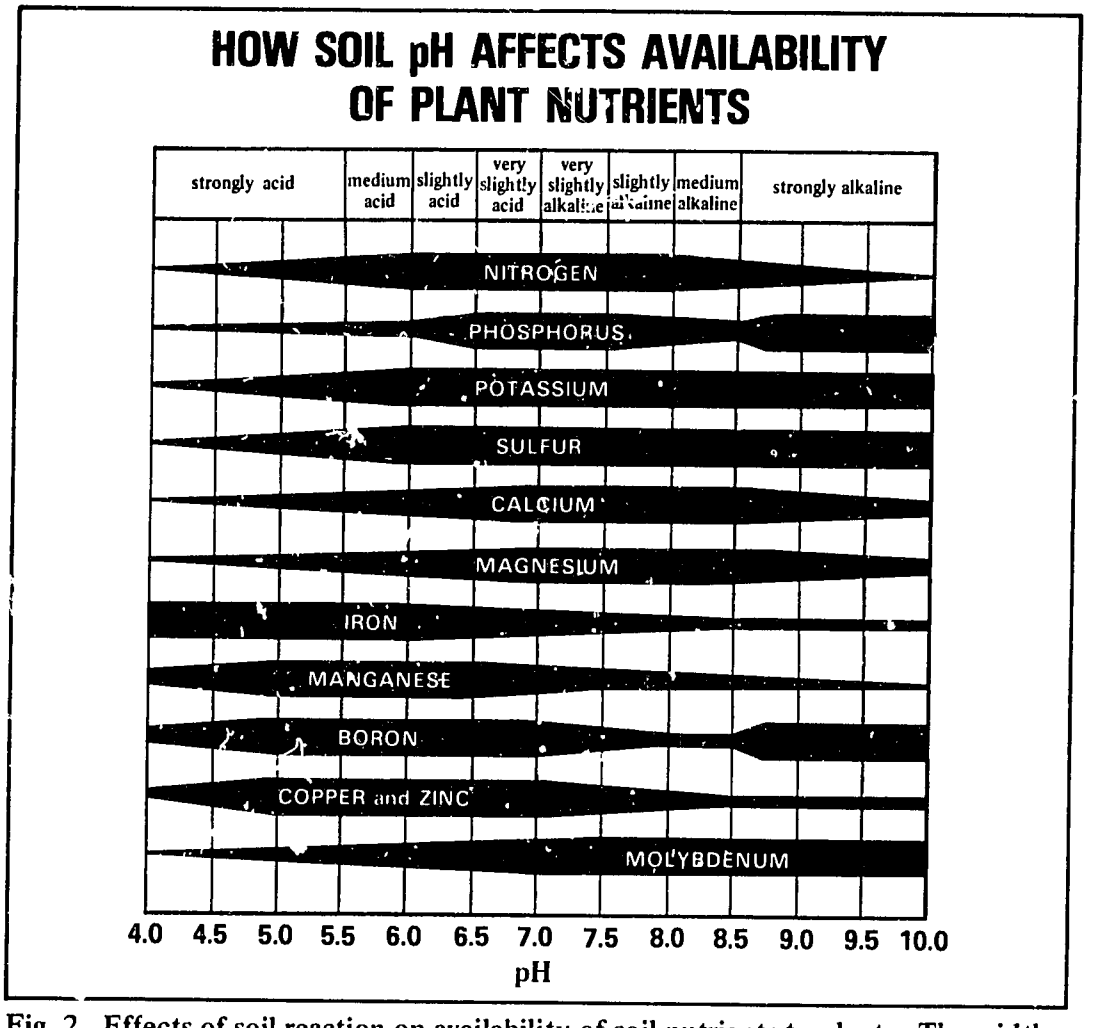

Fig. 2. Effects of soil reaction on availability of soil nutrients to plants. The width of the bar indicates the relative availability of each element with a change in soil reaction (pH). (Courtesy, National Plant Food Institute).

area. The availability of local supplies of lime rock that can be pulverized for spreading on arable lands, is a regional problem that can be solved by geological surveys. However, such limestone deposits are found in all parts of the world. This knowledge on how to make all acid arable lands become continuously productive is a great advance that is now at hand.

Ground limestone applied to acid soils contributes adequate amounts of calcium to meet the nutritional needs of all types of crops. However, only the type of limestone called dolomite also supplies magnesium, an essential nutrient element for all green crop plants. In regions where dolomitic limestone is not found, it will be necessary to provide magnesium in the fertilizer, by incorporating sulfate of potash-magnesia in fertilizer formulations, or by adding magnesium sulfate. Magnesium is an integral part of chlorophyll, the green pigment that is essential for plants to trap sunlight energy for growth. Magnesium has other important functions in plant growth; and any deficiency must be corrected to insure benefits from use of fertilizers, with improved plant varieties, and for effective cultural practices. Magnesium is generally deficient in soils of humid tropics, as well as in some soils of subhumid climatic zones.

II. Rainfall Conservation

Each of the following climatic zones generally have problems of extending the growing season beyond the period of rains, by storing rainfall in the soil profile for crop and forage plant growth.

Climatic Zones	Average Annual Rainfall	Length of the Dry Season
a. Wet-dry tropics	1,000 to 2,000 mm.	3 to 5 months
b. Subhumid regions	500 to 1,000 mm.	5 to 7 months
c. Semi-arid regions	250 to 500 mm.	7 to 10 months
d. Subtropical zone of cool-season rainfall. North Africa & Middle East	250 to 1,000 mm.	5 to 7 months

In each zone, the objective is to retain all rainfall on the lands where rains fall by ensuring rapid infiltration into the soil, to as great a depth as feasible, for sustained delivery of moisture to plant roots during the dry season.

The water holding capacity of field soils is influenced by both soil texture (the relative amounts of sand, silt and clays in the natural soil), and soil structure, which is the organization of soil materials into granules, with connecting systems of pores that may permit entry of water and storage for withdrawal by plant roots. The pores also are occupied in part by soil air, and thus supply oxygen to plant roots.

Soil Texture Classes of Soils

Soil texture varies as a result of the nature of the rocks and other earthy materials left at the land surface by the geologic forces operating in

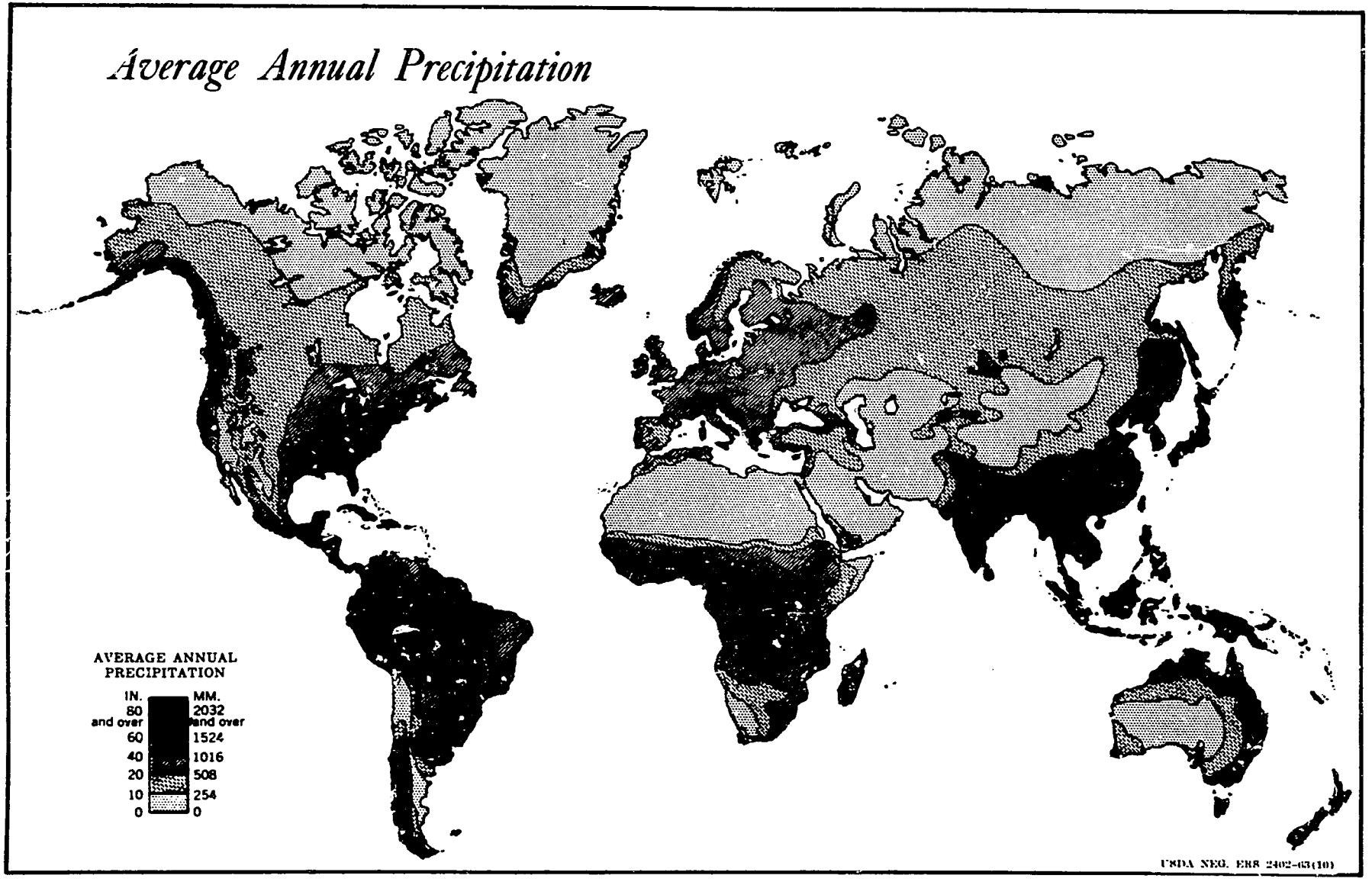

FIGURE 3. Average Annual Precipitation

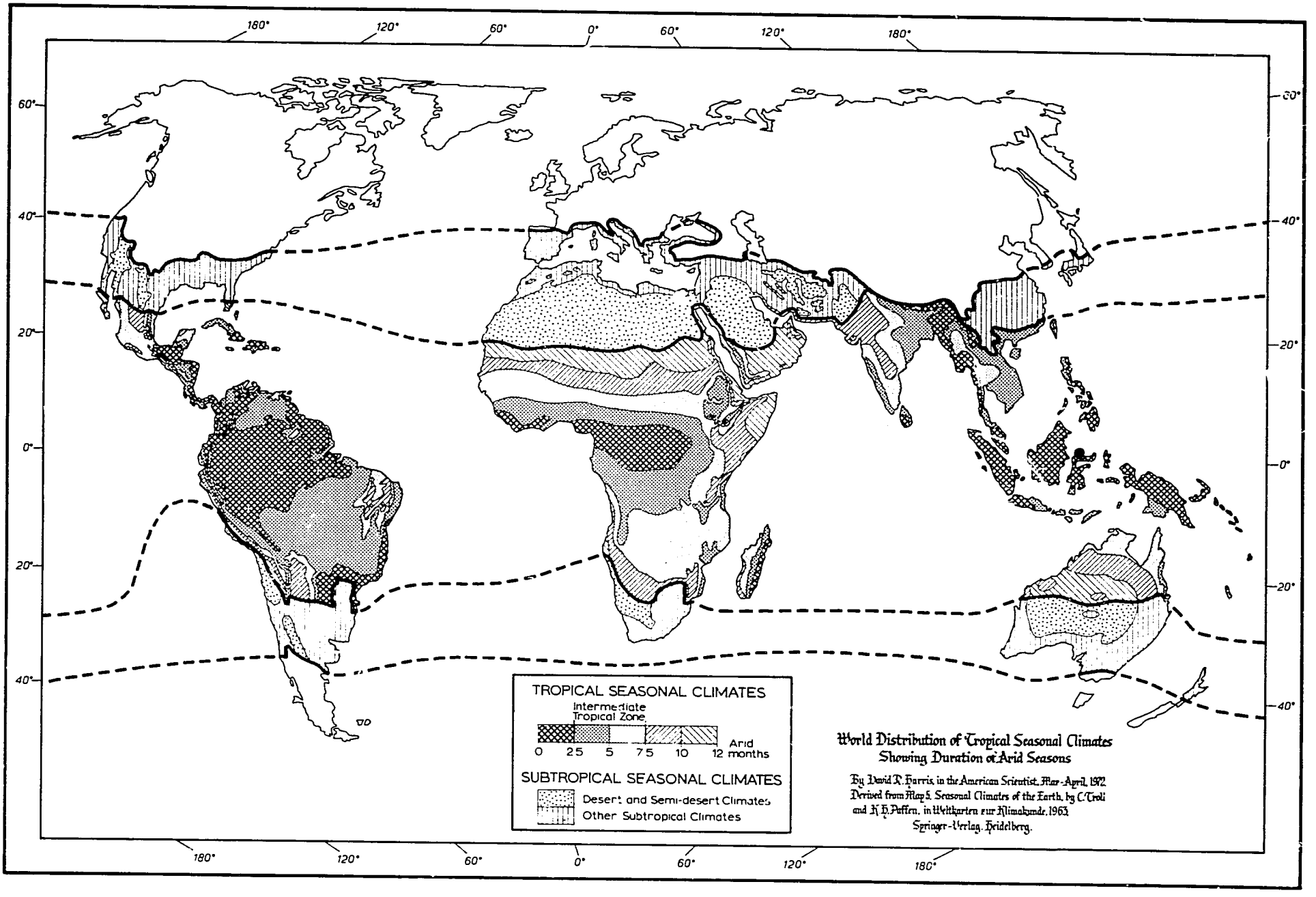

FIGURE 4. Lenth of the "Dry" Season

the earth. The formation of soils by long continued weathering, and by occupation of native plant roots, has produced typical soil profiles for each kind of basic material. On close examination, soils may be seen to have different sizes of soil particles in different abundance of the basic particles of sand, silt, clay and the organic matter contributed by decomposing plant roots, and the bacteria, fungi and insects that digest these plant residues.

Soils may be classified as to texture as follows:

Sandy soils; which are largely sand, with limited amounts of the finer particles of silt, and very fine particles of clay. Easily tilled.

Sandy loams; in which the abundance of silt and clay is somewhat higher than for sands. Easily tilled when moist.

Loams; in which the physical effects of sands, silt and clay are about evenly balanced. Tillage requires animal power or powered machinery.

Silt loams; in which the silt content is quite high, but the soils are more easily tilled than clay loams.

Clay loams; in which the abundance of the very fine clay particles produces a dense soil, with limited porosity. Tillage requires powered machinery, operating when soils are moist, but not soggy.

Penetration of Rainfall into Soils

The effects of soil texture on the surface infiltration of rainfall as it falls are substantial. There is some surface crusting of bare soil on all soil classes, particularly on fields that are continuously cropped without practices

to foster improved permeability. Occasional light rains that quickly evaporate often cause a thin surface crusting that causes rapid runoff of subsequent rains. The presence of a surface soil coating of crop residues that make a partial mulch is helpful in preventing the formation of a water-repellent crust. An additional practice that is useful is the ridging of fields on the contour, so that rainfall may be held for the limited time necessary for moisture to soak into the soil. Where such shallow ridge-furrow surfaces were made for planting the previous crop, they may persist sufficiently to effectively trap rainfall that would otherwise runoff and be lost.

In general, rainfall penetration into sandy soils and sandy loams is fairly rapid where there is no surface crusting. However, for loams, silt loams, and clay loams, it is essential to invoke cultural practices to effectively hold rainfall in place for as long as necessary to ensure penetration of the rains into the soil profile. Contour tillage and planting, together with crop rotations that foster mellow soil structure, as well as crop management to reduce the beating action of rainfall on exposed soil surfaces, are usually effective in retarding runoff loses.

Storage of Rainfall in the Soil Profile

Soil structure is the organization of soils into granules that are made up of sand, silt, and clay particles generally held together with soil organic matter (humus) that is the decomposed remains of roots and stems from previous crops, as well as animal manures that may have been placed in soil. These granules produce a porous structure, with the spaces between and surrounding granules occupied by soil air or soil moisture. The degree of porosity and the size of the pores are essential for improved capacity of the soil to take

in and store moisture. This stored moisture may be very substantial in mellow soils, and this is the source of water for plant growth.

Soil structure may be made more favorable for storage of water by tillage of heavy textured soils that have become densely packed, accomplished when soils are moist but not soggy. However, such tillage requires power tillage tools, and does not penetrate deeply. The most effective method of improving structure is by fostering massive growth of plant roots. Cereal grains and grasses have fibrous roots that penetrate the soil mass as deeply as it is well aerated; and the annual crop of such roots, as it decomposes, contributes to desirable soil granulation. Leguminous crops in the rotation have tap roots that penetrate deeply and supplement grass roots in opening up the soil mass. Legumes also contribute fixed nitrogen that is needed to decompose dead roots and contribute to increasing the water-holding capacity of the soil profile.

Thus, abundant root growth of adapted crops not only penetrates the soil more deeply than tillage, but also increases the total amount of stored moisture to supply growing crops after rains cease. The selection of appropriate crops, and the type of rotation followed, should improve the water storage capacity of the soil profile, in each successive year. This is a natural method of making the most effective use of limited rainfall.

It should be noted that the growth of soil improving crops, particularly a mixture of forage grasses and forage legumes, not only retains virtually all rainfall while it is growing, but also contributes strongly to improved soil structure for improved soil moisture storage for the following tilled crops. When such grass-legume mixtures are planted on land contours, they also retard any rainfall runoff. Such soil improving crops should be harvested as forage for ruminant livestock to derive full values from this type of land use.

For row crops, the period when the exposed soil surface is subject to beating rains is crucial to moisture conservation as well as for controlling soil erosion caused by rain. Plant rows placed on the land contour should be supplemented by distributed plant spacing to provide a complete canopy of leaves as soon as possible during the growth period. To achieve this, it is best to have individual plants spaced more closely, rather than planting in hills. The desirable number of plants per hectare of land, adjusted to the amount of rainfall expected, if they are individually spaced so there is no competition between plants, and the land surface is completely shaded. This is not possible where weak seed is planted in hills to be thinned after seed germination. Twelve thousand spaced plants per hectare will make better use of rainfall than 4,000 hills of 3 plants each.

In efforts to improve soil structure of arable lands, it is useful to include an annual soil improving crop (such as Sudan grass/cowpea mixture) in the crop rotation, about once very 3 or 4 years. For longer term rotations, the growing of a perennial forage mixture of adapted grasses and legumes, for about 2 years before returning to arable annual tilled crops, would make greater contributions to improved soil structure.*

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*For more information on farming systems and crop rotations in regions of limited rainfall, see pp. 98-103 of "The Status and Challenge of Dryland Agriculture in Developing Countries of the Tropics and Subtropics," issued in 1981 by the Bureau for Program and Policy Coordination, Agency for International Development, Washington, D. C.

Table 1. Suggested Short Crop Rotation - 3 Years

1. Grain crop (Millet or sorghum)
2. Food grain legume (Pigeon peas or grain cowpeas)
3. Forage crop (annual) (Sudan grass/forage cowpeas)

	Year 1	Year 2	Year 3	Year 4
Field A	Grain Crop	Forage Crop	Food Grain Legume	Grain Crop
Field B	Food Grain Legume	Grain Crop	Forage Crop	Food Grain Legume
Field C	Forage Crop	Food Grain Legume	Grain Crop	Forage Crop

III. Soil Erosion

Soil erosion is the great "robber" of productive agriculture. It causes the loss of precious topsoil that is a major source of plant nutrients and that supplies essential water and air for all plant roots. All plants, animals, and human beings are dependent on soils, directly or indirectly; for foods, and for all other products of the lands, whether they occupy arable lands, permanently grazing lands, woodlands or forests.

Topsoil is being eroded at an alarming rate throughout the tropics and subtropics. These losses can be brought under control by well planned management practices, that provide improved productivity wherever practiced. This section deals with management practices to halt further soil erosion losses, and to repair the damage caused by previous unwise management. Effective erosion control should be a major concern of all farmers and herders who rely on appropriate crops and plants for subsistence, for markateable products, and for future productivity. Soil erosion is of two kinds; that caused by rainfall runoff, and that caused by winds on bare land surfaces.

Soils generally have three layers - the topsoil of variable depth of perhaps 10 to 30 cm; the subsoil that underlies the topsoil, and may have a thickness of 10 to 30 cm; and the third underlying layer of parent material that may become soil when exposed by extensive weathering and plant root occupation. The essential aspect is that the uppermost layer only, is the layer that may be managed by the farmer to halt erosion, to improve the permeability of the topsoil for rapid absorption of rainfall, and for the storage of stored moisture in the soil profile for use by plant roots. The

slowing down of rainfall runoff so that it is stored in the soil, and effective soil management to produce a soil structure that resists loss of soil by water erosion, are important aspects of erosion control. Soils vary greatly in their erodibility, and the feasible management practice to cope with local soil conditions must be adjusted to such problems.

The natural topsoil (Horizon A) on lands not damaged by erosion losses of soil material, contains most of the useful chemical nutrients needed for crop plant growth. Also, well managed lands will readily accept rainfall and store it for plant growth. The benefits of good soil management should result in higher crop yields each successive year.

Subsoil (Horizon B) is low in organic matter, rather poorly aerated and low in the essential plant nutrients. When topsoil is lost by erosion, crop yields on subsoil are much lower than on topsoil, even with corrective treatment by tillage and by effective use of fertilizers and soil amendments. Improvement of subsoils for crop growth is slow and costly.

The parent soil material, underlying the subsoil, has much lower capacity for supporting crop growth; and eroded soils that have lost both topsoil and subsoil generally are so poor in crop productivity that they are abandoned.

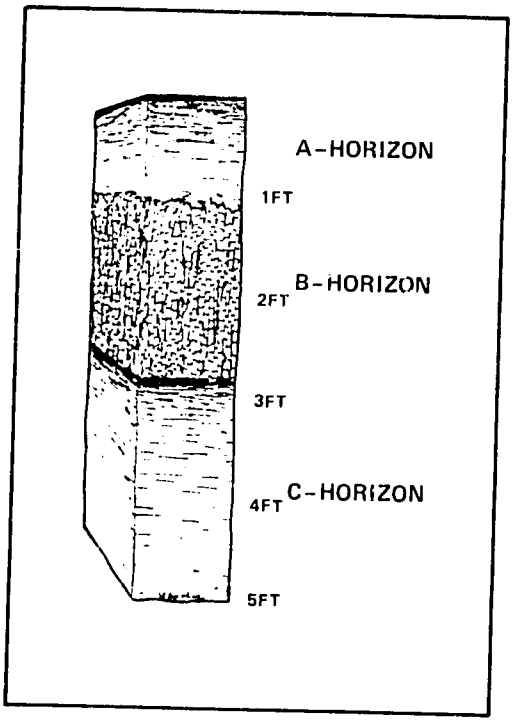

FIGURE 5, A schematic drawing of a soil profile, where no topsoil (A Horizon) has been lost by erosion.

The A Horizon is the topsoil layer that contains most of the fertility elements required by growing plants. It has a higher humus (organic matter) content than the subsoil Horizon B) which results from repeated occupation by plant roots, that have decomposed to produce humus. The nutrient elements are more abundant than in subsoil, and they are in compounds more readily available to growing plant roots. The soil structure is mellow (friable), with pore space that provides soil seration, and water holding capacity.

The B Horizon is subsoil, that is important for water holding capacity to support crop plants, but is less fertile, and generally is more compact than topsoil. There are usually more clay particles in the subsoil, and very small amounts of humus.

The C Horizon is the lower layer of parent materials from which the upper horizons have been created by weathering and occupation by plant roots. Natural soil formation from parent material may require 20 to 50 years, depending on temperature and rainfall.

A. Soil erosion by water may vary in degree of top soil loss. In early stages, the fine materials (clays and organic humus) are carried away by surface flow of rainfall runoff. The most valuable portions of the topsoil then are lost. This loss will be greater when soil surfaces are bare and subjected to the beating of raindrops. This type of erosion is termed sheet erosion.

The continuation of sheet erosion, usually leads to channelization of the soil surface, by rivulets of water that are more powerful in carrying away the more valuable soil materials. The channelization of surface flow of water, may continue to produce gullies usually cut through topsoil, subsoil, and underlying parent material. The stabilization of gullies is difficult and costly. The control measures to prevent land destruction should start with the prevention of sheet erosion. At that stage, management practices are most effective.

Control measures for checking soil erosion.

It should be noted that 2 separate factors intensify erosion by water. One factor is the slope of the field surface; the greater the slope, the more rapid will be the rate of rainfall runoff. The second factor is the natural erosiveness of the particular type of soil; caused by unstable soil structure. Some soils are so unstable when tilled, that they should be planted to perennial grass-legume forages (for use as livestock feed) or to permanent tree crops (such as forest and woodland, or fruit and nut trees growing in permanent grassland cover). It should be noted that water erosion of soils is most severe i regions of torrential rains.

On many arable soils there are several successive management practices that may be taken to halt and control erosion losses:

1. Contour stripping.

All sloping lands should be tilled and farmed on the contour of each field. This provides a succession of minor soil barriers to downward flow of rainfall runoff, so that water movement is slowed down, and any soil particle movement is prevented. Also, there is greater opportunity for the soil to store rainfall through to the soil profile where it will benefit plant growth. In periods of very heavy rain, in excess of the amount of rainfall readily entering the soil profile, this water is led off the field slowly by moving laterally, instead of concentrating on down slope runoff.

Contour stripping does not interfere with tillage or cropping. All movement is across the slope, which requires far less labor and power, than farming up and down slopes. The initial laying out of contour lines may be done by visual inspection by an experienced soil conservationist; who will also estimate the width of each contour strip suitable to the type of soil and the landslope. Thereafter, all farming may follow these initial contour lines.

Contour strip cropping fits very well into crop rotations, so that other management provides for enhancement of soil improvement suited to the family farmland. The growing of a solid plantings of an annual soil improvement crop on every 3rd or 4th contour strip, is very effective in slowing down the rainfall runoff down the slope, as well as greatly improving soil structure for successive row crops, but in addition it is a valuable source of livestock feed to be used in the dry season. (See earlier section on soil improvement, for adapted annual soil improvement crops.)

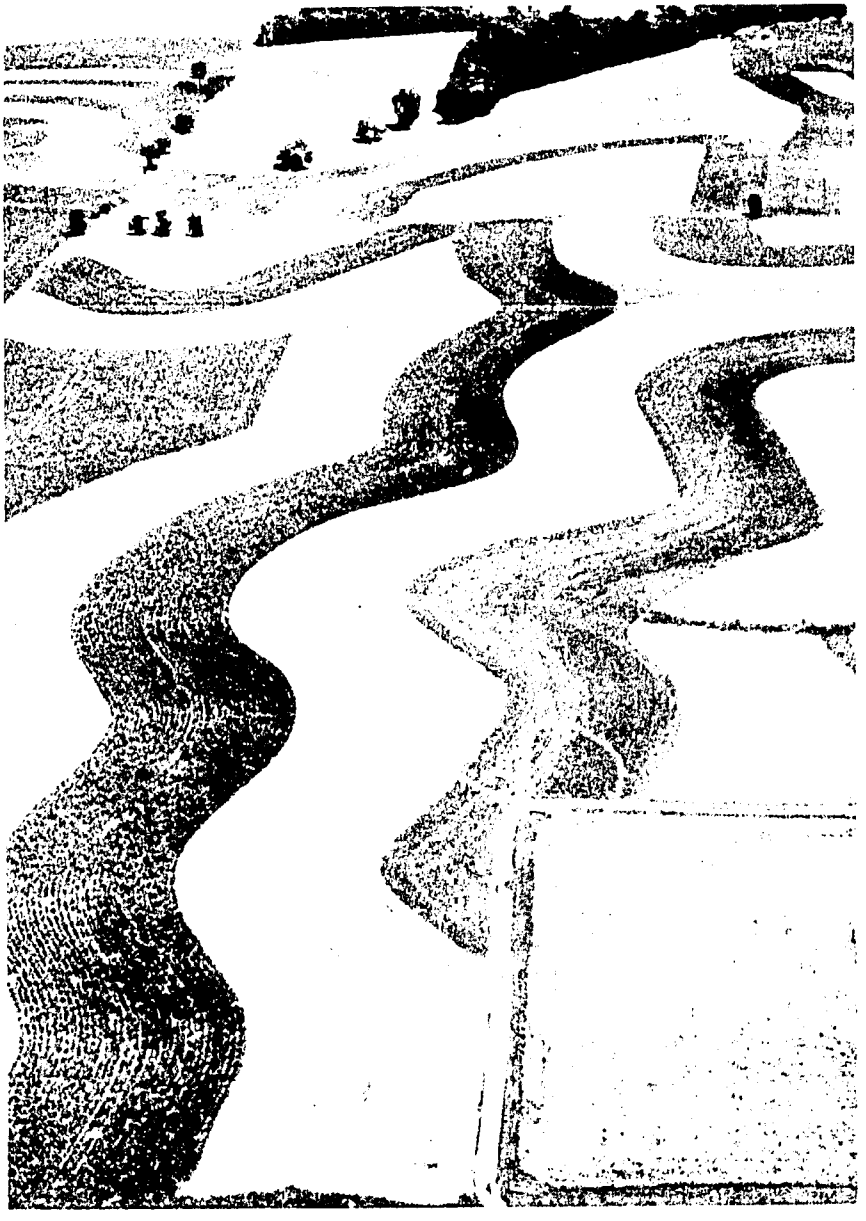

FIGURE 6 Contour strip cropping, as a low cost system of reducing soil erosion by rainfall, on sloping fields.

2. Terracing arable lands for soil erosion control.

Where water erosion of soils is a severe hazard, because of steeper slopes, or highly erosive soil types, the most effective control measures are the formation of terraces on contours. The simplest of these are made with plows or offset discs, that follow the contour lines and buildup ridges of native soil by successive passages of the tillage implement. These terraces should be designed by a competent soil conservation engineer, to include ultimate delivery of runoff water by successive gentle steps from each terrace to the bottom of the slope, without dangers of uncontrolled gullying.

Farming of lands that have been terraced must follow the contours. The tops of each terrace and the channel above the terrace will often be planted with perennial sod crops of adapted perennial forage legumes and grasses. The intervening fields may be cropped by the most productive arable crops. The farming system should include such beneficial practices that enhance productivity and soil improvement, as those described in the foregoing section on soil improvement.

The role of perennial forage crops on steep and erosive lands.

On some land areas in many farming areas the production of tilled crops is impractical from the standpoint of erosion control, as well as for profitable use. Where the sloping soils are capable of supporting high yields of forages for livestock, they are best utilized by planting mixtures of

FIGURE 7, A terrace made by plowing on the land contour. By back-plowing several times, a permanent terrace is formed, to control rainfall runoff, and foster penetration of rainfall into the soil profile. These terraces may be cropped along with the land strips between terraces.

perennial adapted forage legumes and grasses. These solid plantings should provide adequate erosion control, and provide grazing in seasons of rains, or be harvested for hay or grass silage for dry season feeding of livestock. The critical season for such plantings is at planting time, when there is no live plant cover of soil. Since such lands usually are bare at time of planting, the seeding should be planned to occur at the beginning of the rainy season, when rains are usually gentle and unlikely to cause erosion. Here, also, it is advisable for all tillage to be carried out on land contours to minimize potential erosion damage.

After 2 or 3 years of forage production on such lands the soil structure may be sufficiently improved to permit annual cropping on contour strips for one or two years before returning to perennial forage plantings.

The role of supplemental forage crops of livestock enterprises on family farms*

Such supplemental forages may be grazed, or cut and fed green, or harvested as hay, or preserved as silage. Most importantly, these forages should provide feed for ruminant livestock during the dry seasons of rainfall-deficient climatic zones. Where a forage legume is included in seeded forages, the resulting feedstuffs are rich in protein and in digestible energy. This forage will supplement feed from permanent grazing lands, that are limited to active growth during the season of rains.

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* See companion bulletin on "herbaceous forages for support of ruminant livestock on family farms in the tropics and subtropics."

This high quality feed will improve reproduction of the breeding herds and flocks; it will support and extend the milk flow of all lactating animals; it will be excellent feed for growing young stock; and it will supplement standing dry forage for mature stock being maintained for sale.

This supplemental feed is highly essential for support of work animals on family farms, including oxen and buffaloes. These animals require high energy feeds to maintain strength and dependability in seasons of heavy work. Adequate feed supplies on a daily basis is absolutely essential for profitable use of animal power on family farms. Animal power is generally essential for profitable farming in all developing countries.

B. Control of Wind Erosion

(1) On arable lands

Whenever strong seasonal winds occur, there are hazards of wind erosion on all bare land surfaces. On arable lands, rough tillage in anticipation of winds may provide temporary protection. A more dependable treatment is any practice that provides a dry mulch of crop residues, or a cover of growing plants.

Wind erosion removes the most valuable part of the topsoil - the fine clay particles and the organic matter called humus. These fine particles that are most easily lifted by strong winds, contains the valuable plant nutrients, leaving only sands and stones. Moreover the winds produce drifts of sands and silts that have low water holding capacity, as well as being low in fertility.

Treatments to reduce wind erosion may include rows of planted trees as wind barriers across the direction of winds, to protect planted fields. Since strong persistent winds usually occur during the dry season, it is useful to leave a stubble of crop residues, at heights of 15 to 20 cm, when the crops are harvested. Crop residues above heights of 15 to 20 cm may be removed for feed, since the stubble is the most active factor in reducing wind velocity at the level of bare ground.

Fields that have been planted in strips on land contours will be protected when the solid planted strips alternate with tilled strips. Wind erosion is not a problem on lands occupied by perennial solid plantings of forage legume-grass mixtures. It is essential that arable lands not be devoid of all crop residues and stubbles during the expected season of strong winds.

The most dangerous time for damaging wind erosion to occur is at the beginning of the season of planting, when strong winds may cut off or damage young seedlings of new plantings when they are easily injured by blowing sand. Ridging of the planted fields, with seed planted in the bottoms of shallow furrows between ridges, has been effective under some conditions. The ridging must cross the prevailing direction of strong winds, and not be parallel to the wind.

(2) On permanent grazing lands (range lands)

The damage caused by continuing strong winds on grazing lands occurs only when the land is bare of vegetative cover of low growing grasses and legumes. These bare surfaces are usually caused by overgrazing and overstocking. The most effective measures for preventing wind erosiosn is to remove livestock when the forage still provides a continuous plant cover. This practice also is the most rewarding type of management to permit recovery and reseeding of forages on rangelands, and to insure the maximum forage growth in the following season of rains.

Repeated depletion of plant cover, in successive seasons of strong winds, actually creates desert conditions. Complete resting of rangelends by prohibiting all grazing is a long-term and costly method of range regeneration, that is not always successful. Research is underway in some regions to determine lower-cost and more dependable methods of re-establishing vegetative soil cover. For the present, prevention of desertification by control of livestock stocking rates is strongly urged on all managers of such grazing lands. When accompanied by rotation grazing so that each grazing unit area is provided an opportunity to recover after a period of grazing, is essential to preserving the more palatable types of forage plants.

When the foregoing management methods are followed, it may be useful to undertake additional methods of re-establishing vegetation on denuded areas. The reseeding with more aggressive grass and

legume forage species, from other regions of the tropics and subtropics has been successful, when planned and carried out by forage specialists. Range research stations should be depended on to identify those forage species better adapted to local soils and climates than the native forage species. In addition, it is sometimes feasible to improve soil fertility by judicious use of fertilizers, that will satisfy mineral nutrient requirements of introduced forage legumes. The choice of fertilizers should be guided by soil testing of the areas to be treated, followed by actual field tests to evaluate the benefits from such replanting. It should be emphasized that re-establishment of superior types of forage plants is not warranted until problems of overstocking and overgrazing are resolved, and the grazing practices have been modified to provide periodic rotation of grazing animals, so that range plants are allowed an opportunity to recover from each grazing period. However, the encouraging aspect of these useful practices is they are low cost, and do not require costly land treatments. It is obvious that these practices become feasible to herders when they are assured of exclusive use-rights on a continuing basis. Without such assured tenure, there is little inducement to practice prudent management to produce stronger rangelands, with sufficient plant cover to prevent bare soil subject to wind erosion. These same practices are effective in preventing rainfall runoff losses.