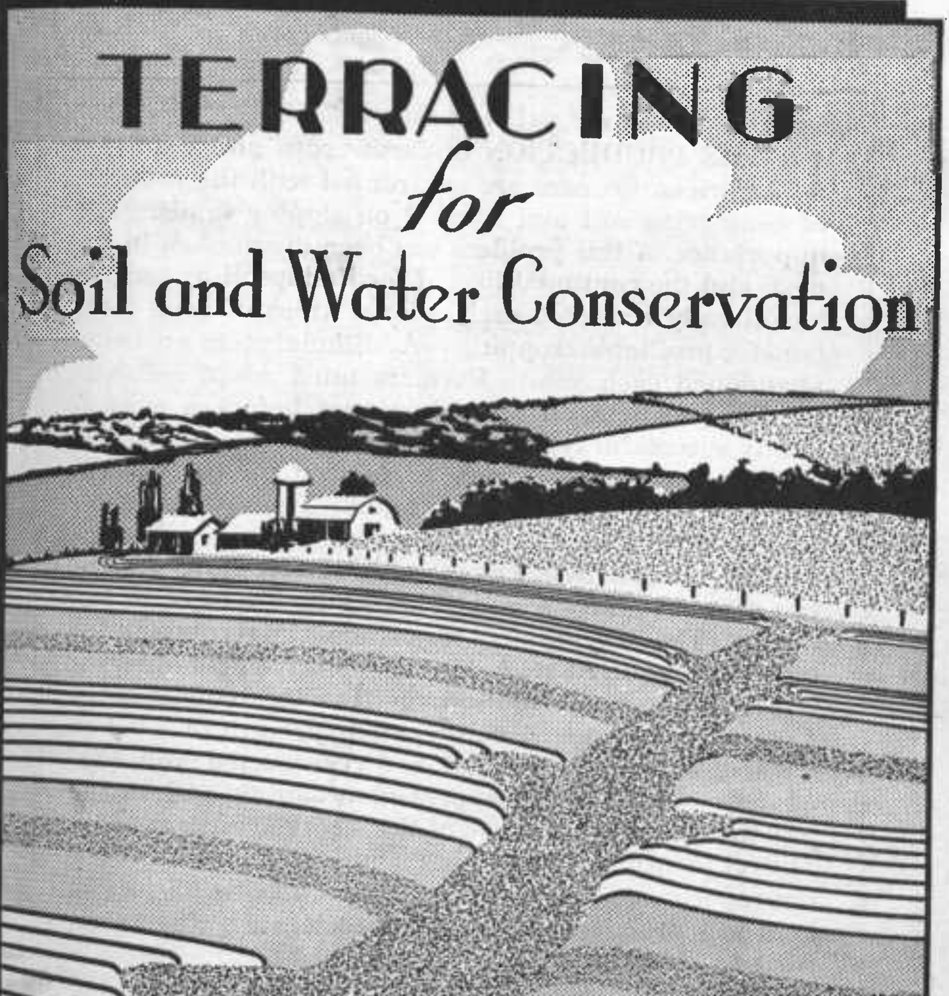
TERRACING *for* Soil and Water Conservation



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TERRACING FOR SOIL AND WATER CONSERVATION

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INTRODUCTION

HISTORY OF TERRACING

SINCE COLONIAL DAYS American farmers have built various types of terraces and hillside ditches to conserve the soil on cultivated fields. For centuries agriculturists of other countries have used terraces effectively to combat soil erosion and facilitate tillage practices on sloping lands. Certain types of terraces are almost as old as agriculture itself. More than 4,000 years ago the Incas terraced their steep hillsides, and over 2,000 years ago the present practice of terracing rice fields in the Philippine Islands was begun by the natives. That terraces are widely distributed is indicated by the terraced vineyards of Europe, the terraced fields of the Orient, and the more recent terracing of wheatfields in Australia.

In the United States hillside ditches and furrows were the forerunners of the present-day terraces. During the latter part of the eighteenth century and the beginning of the nineteenth century farmers in the South began to use ditches and furrows across the slopes of their fields to intercept run-off and retard erosion.[2] This practice was probably introduced by some of the early immigrants from Europe. The term "terrace" in connection with erosion-control measures appears to have been used in this country as early as 1847.

There is evidence that early American farmers introduced in some form practically all the present-day erosion-control measures. Many

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[1] This bulletin is a product of the experience and study of all members of the Engineering Section. It has been prepared under the general supervision of T. B. Chambers, head of the section, who has contributed valuable suggestions. Other members, particularly Hans G. Jepson and G. E. Ryerson, assisted in the preparation of the manuscript. Field engineers also submitted valuable information, and the earlier studies of terracing made by C. E. Ramser and M. L. Nichols have been used.

[2] United States Department of Agriculture Miscellaneous Publication 256, Early Erosion-Control Practices in Virginia.

of the general principles of the procedures used were correct, but the effectiveness of the measures themselves was usually counteracted by inaccurate installation, limited use, and lack of coordination. Even such construction refinements as wide ridges and channels, variable grades, and spacing according to rate of rainfall, soil characteristics, and degree of surface slopes were recognized and advocated by some of the early builders of terraces, but in general farmers were slow to adopt these improvements. Although the old-type hillside ditches or terraces very frequently failed they were sufficiently successful to induce farmers to continue their use year after year.

Many of the early pioneers contributed valuable improvements in the construction of terraces. P. H. Mangum, of Wake Forest, N. C., has long been given credit for a major improvement in terrace construction as early as 1885. Mr. Mangum introduced the wide-base terrace so that tillage operations could be conducted over the entire terrace. A modification of this terrace is extensively used today and in many areas is still called the Mangum terrace. Before the introduction of the wide-base terrace the narrow-ridge terrace had been used. These narrow-ridge terraces could not be cultivated and were allowed to grow to grasses and briars. This, together with inadequate control practices between ridges, gradually led to the development of bench terraces on many areas where they were not desirable.

It was not until terracing received attention from the State agricultural colleges and the United States Department of Agriculture that systematic studies and extensive progress in terrace construction were made. Preliminary studies were undertaken by the Office of Experiment Stations of the Department of Agriculture in 1903 and 1904. Definite investigations of the use of terraces to combat soil erosion were begun in 1915, when C. E. Ramser, who was then drainage engineer of the Office of Experiment Stations, was sent into the Southeast to study the methods of terracing used, the degree of success attained with them, and the factors affecting their success or failure. The report of his findings, published in 1917, was extensively used in later developments. M. L. Nichols, formerly with the Alabama Polytechnic Institute, Auburn, Ala., initiated some of the earlier State experimental work on terracing soon after the publication of Ramser's first report. Nichols' work led to recommendations for some modifications in construction procedure, particularly in the formation of the terrace channel. These recommendations are given in Farmers' Bulletin 1790, The Nichols Terrace: An Improved Channel-Type Terrace for the Southeast. The State experiment stations in Texas and Oklahoma also contributed considerable experimental data on the use of terraces in their respective States.

In 1929 Congress appropriated an initial sum for the establishment of Federal experimental erosion farms in cooperation with the States. Ten such farms were established between the years 1929 and 1934 under the Bureau of Chemistry and Soils and the Bureau of Agricultural Engineering. In 1935, with the unification under the Soil Conservation Service of all Department of Agriculture activities pertaining to soil erosion, these farms were placed under the supervision of that Service. They are located in regions representing wide differences in soil, climate, and farming practices. An important phase of the work on these farms is the experimental study of the capacity of terraces, their effectiveness, design, spacing, construction, and main-

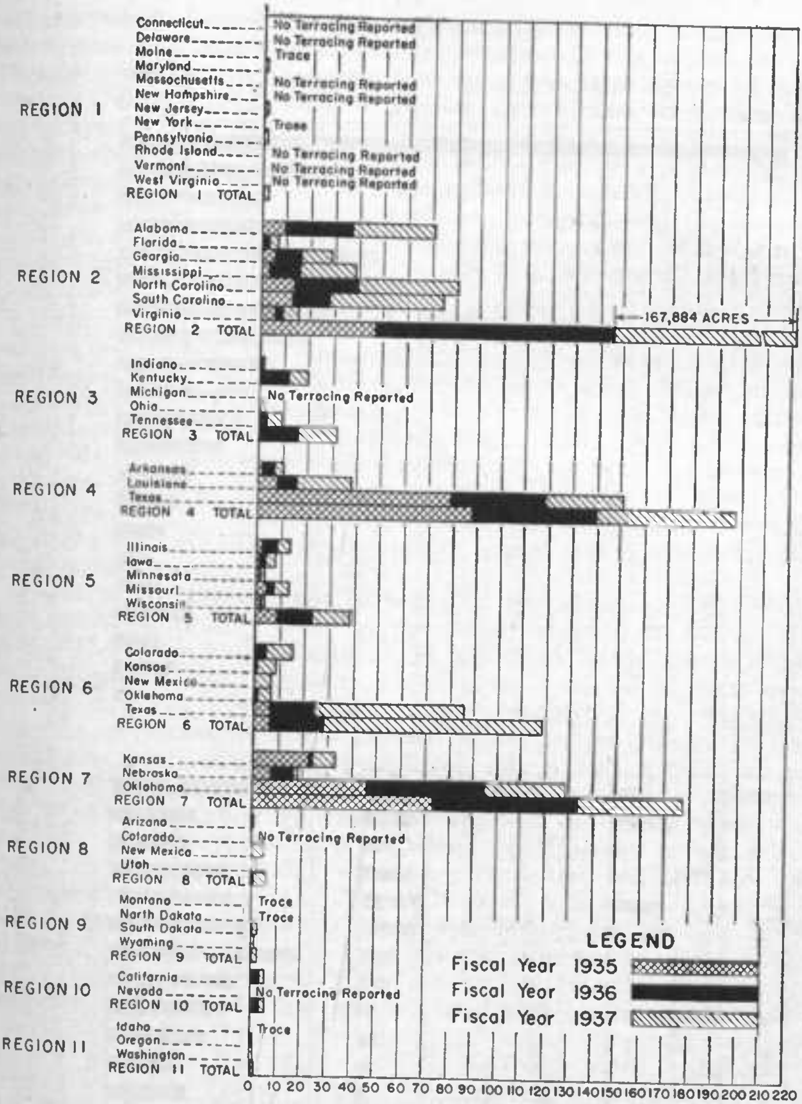

FIGURE 1.—Acreage terraced by the Soil Conservation Service projects and camps during the fiscal years 1935–37.

tenance, and their relation to soils and cropping practices and to the operation of machinery.

One or more soil-erosion demonstration projects have also been established in practically every State to demonstrate proper land management and a complete erosion program to reduce soil loss. The extensive use of terracing on many of these projects affords opportunity for study of the proper application, use, and construction of terraces. Terracing has been materially augmented by the assignment of numerous Civilian Conservation Corps camps to the Soil Conservation Service. The acreage terraced annually by the Service projects and camps during the fiscal years 1935–37 is shown in figure 1.

FIGURE 2.—Acreage benefited by terraces and soil-saving dams, 1915–35, as compiled from reports of the Extension Service, United States Department of Agriculture. Middle Southern States: Arkansas, Louisiana, Texas. Southeastern States: Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Virginia. Central Great Plains States: Kansas, Nebraska, Oklahoma. Ohio Valley States: Indiana, Kentucky, Michigan, Ohio, Tennessee. Upper Mississippi Valley States: Illinois, Iowa, Minnesota, Missouri, Wisconsin.

This brief review of the development of terracing in the United States would not be complete without mention of the important contribution made by the Extension Service of the Department of Agriculture. Since 1914[3] State extension agricultural engineers and county agents have devoted much time to educational work on the use of terracing. Practically all of the terracing reported by the Extension Service (fig. 2) was done before the establishment of the Soil Conservation Service demonstration projects and the national movement to correlate all erosion-control measures. Much of this earlier terracing may no longer be effective because of inadequate maintenance.

SOIL EROSION

Unless controlled, the undermining action of erosion will ultimately, and at no distant date, render large areas of cultivated land in the United States valueless for agricultural use. Millions of acres of once fertile farm land have already been eroded beyond immediate repair. It has been estimated that the rate of plant-food removal by erosion is about 21 times greater than the rate of removal by agricultural crops. This loss by erosion does not include losses incurred through silt damage to bottom lands, water reservoirs, and irrigation channels.

In general, soil erosion may be defined as the loosening and removal of soil from its resting place by the action of wind or water. The two main classes of erosion from the action of water are sheet erosion and gully erosion. Sheet erosion is the removal of surface soil in fairly uniform layers or sheets; gully erosion the removal of soil at points of excessive water concentration, where relatively deep ditches are cut into the surface slopes. As a rule, gullies appear after sheet erosion has occurred for some time, but they may appear without being preceded by sheet erosion, and sheet erosion may occasionally continue indefinitely without the formation of gullies. It may not be as spectacular as gully erosion, but its effects are generally much more harmful. Figure 3 shows a field on which sheet erosion has taken its toll. The intermediate stage between severe sheet erosion and gully erosion is shown in figure 4, and a gullied field in figure 5. Such gullying is a considerable obstacle to regular farming operations and may necessitate abandonment of the field.

Terracing is a valuable preventive of both types of water erosion and, as a conserver of moisture, it indirectly aids in the control of wind erosion. Terraces form intercepting channels that break long slopes into short segments and thereby provide low-velocity surface drainage, which materially reduces the amount of topsoil that can be carried down the slope or from the field by surface run-off. When placed on the contour, terraces retain much more of the run-off on the field, and so conserve water.

TERRACING IN AN EROSION-CONTROL PROGRAM

TERRACING AND AGRONOMIC CONTROL MEASURES

The basic factor that must be recognized in the application of erosion-control measures is the proper utilization of the land. This

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[3] It has been estimated by S. P. Lyle, extension agricultural engineer, U. S. Department of Agriculture, that before 1915 bench terraces and hillside ditches were used on about 2 million acres and the ridge-type terrace on an equal acreage.

FIGURE 3.—Severe sheet erosion on moderately sloping cultivated land.

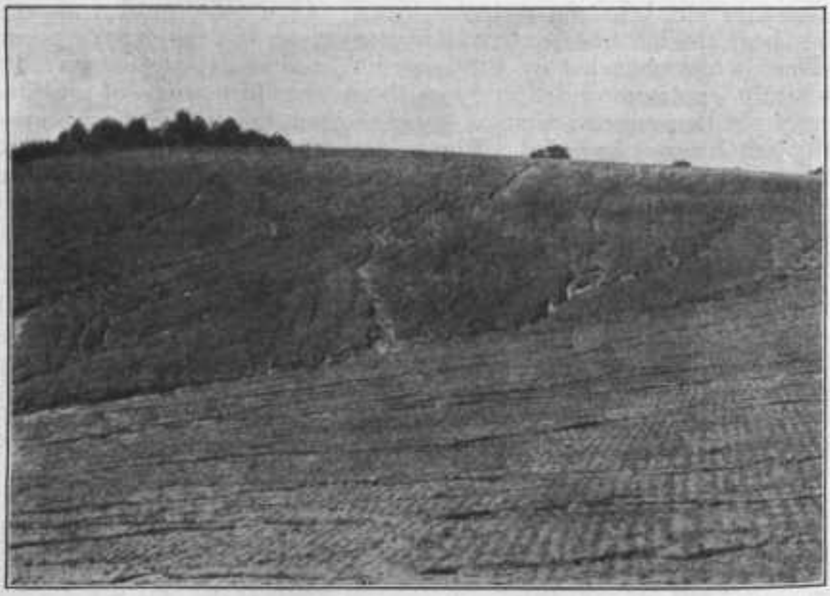

FIGURE 4.—Sheet erosion that has developed into the fingering or shoestring stage of gully erosion.

requires a recognition of the soils and slopes upon which crop production can be carried on without increasing soil losses beyond permissible limits. The erosion-control program would be greatly simplified if all farming operations could be restricted to relatively nonerodible slopes and the more erodible land returned to its natural vegetative cover. Under present economic conditions, however, it is necessary to produce crops on land slopes that will require certain control measures if cropping is to be continued successfully.

Terracing, supported by necessary cropping practices, is primarily applicable on sloping lands that must be used for crops and on which less expensive conservation measures will not provide adequate erosion control. Too often terracing is represented as an alternative to a permanent vegetative cover of grasses or trees. This misconception of use has caused much confusion and misunderstanding in the generally accepted application of these control measures. Terracing should not be considered for land that can be placed or retained under permanent vegetative cover. except possibly where terraces may be required for moisture conservation or diversion of water for gully control or as an aid in establishing a satisfactory cover of permanent vegetation. Neither can terracing be economically justified on lands that can be adequately protected by proper tillage and agronomic measures such as contour tillage, crop rotations, and strip cropping. These measures alone may provide sufficient protection where relatively low rainfall intensities and high soil infiltration rates are encountered, where erosion-resistant soils or relatively flat slopes prevail, and where profitable rotations can be introduced that will provide an erosion-resistant cover during a large part of the rotation cycle, particularly during the rainy seasons. But where erodible soils, long slopes, and high rainfall intensities are encountered and where a large percentage of erosion-permitting crops must be used

FIGURE 5.—Once gully erosion has advanced to this stage it practically prohibits cultivation of a field and greatly reduces its value for any agricultural use.

in the rotation to provide a profitable farm income, the applicable agronomic control measures may give only partial control and must then be reinforced with terracing before adequate protection from erosion can be assured.

Terraces should always be supplemented with the best possible cropping practices because terraces in themselves do not improve soil fertility but serve primarily as a basis for soil improvement and other conservation practices. The use of proper rotations and contour strip cropping and cultivation in conjunction with terracing provides one of the most effective erosion-control combinations now known for cultivated fields. There should be no competitive issues raised in applying agronomic and mechanical control measures. Each has its purpose in a properly coordinated erosion-control program. It is just as serious a mistake to establish only agronomic control measures where they will not provide adequate control as it is to use terraces without support of the necessary soil-improvement and cropping practices. The knowledge of both agronomist and engineer is required in determining the limitations of agronomic control measures and the conditions in each area under which it is necessary to supplement them with terracing.

FIGURE 6.—When terraces are properly constructed and supplemented with suitable tillage practices good farm crops can be produced without excessive soil loss.

When properly applied, constructed, and maintained, terraces are valuable conservers of soil on practically all soil types. They reduce the annual run-off losses on certain soil types and materially reduce the rate of run-off from small cultivated fields. Combined with other beneficial and allied practices such as rotations within the field, strip cropping, and contour cultivation, terraces save fertile topsoil and retain costly seed and applications of lime and fertilizer. The fact that terraces help to conserve soil justifies the expectation that terraced fields will produce better crop yields over a period of years than unterraced fields, which may deteriorate rapidly in cropproducing value because of erosion losses. Since thousands of farmers continue to terrace additional fields year after year the advantages of terracing must far outweigh the recognized disadvantages. Terraces are somewhat costly to build and require some maintenance. Their use may require abrupt changes in traditional farming practices and entail slightly higher tillage costs. Terracing on thin soils may expose subsoil in the terrace channels. Damage may also result from the diversion and concentration of run-off at uncontrolled points unless precaution is exercised. These disadvantages, however, are not especially difficult to overcome if the landowner is really concerned about conservation. Terracing is an erosion-control measure that has been extensively tested and has been found to be acceptable under actual farm conditions wherever it has been necessary and its application in accord with proper land use (fig. 6).

TERRACING EXPERIMENTS AT THE SOIL AND WATER CONSERVATION EXPERIMENT STATIONS

Comparison of the amount of soil moved by erosion from similar terraced and unterraced areas on the soil and water conservation experiment stations of the Soil Conservation Service serves a valuable purpose in indicating the effectiveness of control by terracing under various soil and climatic conditions. It should be recognized, however, that under the experimental technique that has been used at the stations in the past the two measurements are not precisely comparable. It is difficult to select even adjacent areas that are exactly the same in all respects, and, further, certain field variables that cannot be definitely evaluated have developed since the original experiments were established. Before final conclusions can be developed it will be necessary to make some adjustments in the experimental procedure, to secure data that cover a longer period of time and also a larger variety of soil and climatic conditions, crops, and cropping practices.

The run-off measurements given in figure 7 indicate surface run-off, and the soil-loss measurements from the terraced areas measure only the soil in run-off at the end of the terrace channel and do not account for soil lost as silt deposited in the terrace channels and gradually worked over the ridge during maintenance operations. It is thought, however, that the soil loss from this movement can be held to a negligible quantity on terraced slopes if proper tillage, cropping, and maintenance practices are followed, particularly if the furrows are thrown up the slope by the use of a two-way plow for the regular plowing operations. Some of the unterraced experimental watersheds had completely or partly protected waterways, where a part of the eroded soil from the field may have been retained and consequently failed to reach the measuring equipment. On others the gullying produced by unprotected or inadequately protected waterways probably contributed to the higher soil-loss measurements secured from these areas.

An analysis of the experimental information now available indicates that soil loss on the small, terraced areas has invariably been less than on the unterraced areas, except on the more pervious soil types. The greatest difference usually resulted when rains of high intensities occurred during critical crop periods. The experiments indicate that terraces have been more valuable as conservers of soil than of rainfall. The rate of run-off from the terraced areas has usually been less than that from the unterraced areas, but the total annual run-off from the terraced areas has not been consistently less than that from the unterraced. It is believed that a more appreciable and consistent reduction in both the amount and rate of run-off will be secured where level terraces can be used—and practically all of the rainfall can be retained where level terraces with closed ends are applicable.

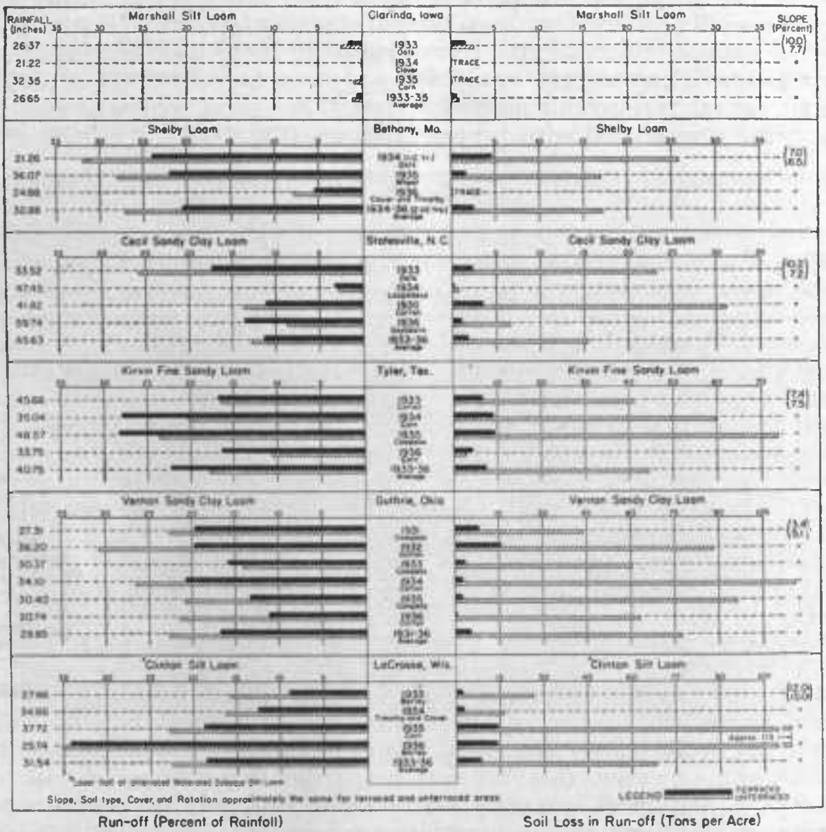

FIGURE 7.—Run-off and soil loss in run-off from field plots on six of the soil and water conservation experiment stations. The terraces were supported by crop rotations and contour tillage, which were also used on the unterraced areas. Except at the Bethany and Clarinda stations the waterways in the unterraced areas where inadequately protected. The higher soil losses reported for the terraced areas at Guthrie during 1931–32 resulted from inadequate outlet protection.

The disturbance of the soil during terrace construction may temporarily reduce crop yields where the topsoil is comparatively shallow, but usually this loss will be compensated for within a few years after construction. With proper cropping and soil-improvement practices the yields on the terraced areas can invariably be increased until they are back to or above normal, whereas the yields on the unprotected area will usually continue to decline as additional fertility and topsoil is washed away year after year. Observations also indicate that terraces pay the greatest proportional returns when used as conservers of soil soon after it is first put into cultivation and the lowest returns when used in an attempt to reclaim cultivated lands already stripped of the topsoil and disfigured with gullies.

HYDRAULICS OF TERRACE DESIGN

Rainfall coming at a high rate is likely to induce considerable surface run-off, which will accumulate in depressions and flow down the slopes. When run-off attains a velocity of about 2 to 3 or more feet per second it is usually capable of loosening and transporting topsoil from unprotected fields. Velocities of even less than this frequently cause erosion on some of the finer clays and sands. At the top of a slope the quantity of run-off is usually small and the movement slow—without power to do much damage. But as the water flows down the slope its volume and velocity increase, and it gains increasing momentum and power to tear away soil particles.

Terracing is essentially a planned surface-drainage system for cultivated lands that cannot be adequately protected by other measures alone. The terraces must intercept the surface run-off before it attains sufficient velocity to erode the soil to any extent. They must carry the surplus rainfall from the field at nonerosive velocities and deliver it to stabilized waterways. This is accomplished by placing a series of terraces across the slope, the first one being located near enough to the drainage divide to intercept all the run-off from the contributing area above before it attains excessive erosive power or a volume that will exceed the capacity of the terrace channel. Each succeeding terrace down the slope is located in a similar manner. The surface slope and the rate and velocity of run-off are therefore the first factors to be considered in the design of a terrace system.

SURFACE SLOPE

On long, steep slopes the velocity and erosive power of run-off are greater than on short, gentle slopes. Terraces are, in effect, a means of decreasing erosion by making slopes shorter. If they are to serve this purpose most effectively, spacing of the terraces must vary on slopes of different degrees of steepness, for the steeper the slope the shorter must be the horizontal distance between terraces. In designing a system of terraces, therefore, it is valuable to know how great an increase in velocity and erosive power can be expected as the degree of slope increases. The full significance of slope in terrace design is not appreciated until its effect on the rate, the velocity, and the erosive power of run-off is realized.

For example, if the slope of a field is such as to produce a run-off velocity of 2 feet per second, theoretically that slope would have to be only four times as great to produce a run-off velocity of 4 feet per second. Yet at 4 feet per second the power of the water to erode or tear away soil is four times greater than it is at 2 feet per second. The carrying capacity of water has an even greater proportionate increase. At 4 feet per second the run-off water can carry almost 32 times the quantity of material of given size than it is capable of carrying at 2 feet per second. If the slope is increased sufficiently to produce a velocity of 8 feet per second the erosive power would be increased 16 times and the transporting power 1,024 times.

Velocity increases not only with the steepness of slope, but with the length of slope. The speed with which water flows downhill is not constant, but increases at a certain rate until it reaches the maximum velocity possible under the conditions on a particular field. The amount of run-off also increases as water travels down the slope owing to the increase in the contributing drainage area. This accumulation of water increases the velocity even more because as the volume of run-off increases, the water tends gradually to concentrate in deep, narrow channels and so moves at a higher rate than it would if evenly spread over the surface of the field. Run-off that starts from the top of a slope with an initial velocity of zero will therefore usually attain a higher velocity and a much greater erosive power at a point 100 feet down the slope than it had at a distance of 50 feet down the slope.

These facts make it plain that much soil will be lost on steep unprotected slopes unless the flow of water down these slopes is checked. Usually the degree of slope cannot be changed without extensive soil movement and disturbance. The velocity and the consequent erosive power of the run-off, which increases with both steepness and length of slope, can be checked by decreasing the length of slope. A series of terraces across a slope does just this, for the length of slope on a terraced field is only as great as the distance from terrace to terrace. The steeper the slope, the shorter must be the interval between terraces. Terraces must be spaced so as to intercept the run-off from the area above each terrace before its erosive power has become great enough to carry away the soil and its volume great enough to exceed the amount of run-off that the channel can carry. Where mechanical protection is necessary on slopes too steep for practical protection by reducing the length of slope the bench-type terrace is used so the surface slope can be reduced as well as the length of slope.

RATE OF RUN-OFF

In computing the required channel capacities. the rate at which run-off will be discharged from the contributing watershed is more significant than the total amount discharged from any particular rain, unless it is planned to store or retain all of the excess rainfall on the watershed. The rate of run-off from a drainage area is influenced by rainfall characteristics and watershed characteristics. The rainfall characteristics are intensity, duration, and frequency. The watershed characteristics that influence the rate of run-off are configuration, size and shape of the drainage area, degree and length of slopes, soil type, physical condition, and vegetal cover. The relative influence of these characteristics of rainfall and watersheds is discussed elsewhere in this bulletin.

Average rates of run-off cannot be used as a safe basis for computing required channel capacities because the terrace would overtop and fail during each storm that produced run-off rates higher than the average. The maximum run-off rates for which the terrace spacing and channel capacity must be designed are likely to occur when rains of high intensities fall on saturated or frozen soil and during periods when fields may be devoid of vegetation. Charts are given in United States Department of Agriculture Miscellaneous Publication 204, Rainfall Intensity-Frequency Data, from which can be determined the maximum rates of rainfall that are likely to occur in different localities during periods of 2, 5, 10, 25, and 100 years. Ordinarily a terrace is designed to take care of run-off from rains of the maximum intensity that is likely to occur during a 5- to 10-year period. Designing for run-off from rains of the maximum intensity likely to occur during a shorter period would result in frequent overtopping and consequent heavy repair costs, and designing for run-off from rains of an intensity that is not likely to occur more frequently than once in 15 or 25 years would involve excessive construction costs. It is conceded that during parts of the year when rates of run-off from fields are below average the full capacity of terraces designed for storm frequencies of 5 to 10 years will probably not be utilized. However, terraces that cannot carry the higher rates of run-off that frequently occur will fail at the very time when they are most needed to retard soil loss (fig. 8).

FIGURE 8.—Overtopping, caused by improper design, construction, or maintenance of terraces, damages both field and terrace.

The capacity in cubic feet per second of any water channel is computed by multiplying the cross-sectional area in square feet by the computed channel velocity in feet per second. For example, a channel with a depth of 2 feet, a width of 6 feet, and a velocity of 1½ feet per second will carry 2 x 6 x 1½=18 cubic feet per second. In determining the size of channel to construct it is usually considered good practice to make it slightly larger than the computed requirements because of the uncertainty of run-off values and the difficulty of maintaining exact field construction specifications through all periods of the year.

VELOCITIES IN TERRACE CHANNELS

Terrace channels of ample capacity must be constructed so as to transport water at nonerosive velocities; otherwise much soil may be carried from the channel with the run-off and serious gullying may develop. The velocity in a terrace channel increases not only as the slope of the channel increases, but as the average water depth (approximately the hydraulic radius) increases and as the surface resistance (coefficient of roughness) decreases.

Under field conditions the roughness of the channel surface is established by soil, tillage, and crop conditions and cannot be varied for the purpose of controlling velocity. The velocity, therefore, can be controlled by adjusting only the degree of slope and the average depth of water in the channel.

The maximum channel gradient that can be satisfactorily used must be less than the minimum slope that produces sufficient channel scouring to injure the terrace. The average depth of flow can be adjusted and the capacity maintained by changing the shape of the cross section of the channel. If other factors remain constant, a narrow, deep channel will produce a higher velocity with greater erosive power than a wide, shallow channel because the average depth of flow is less in the shallow channel. A channel cross section that is wide in proportion to its depth not only retards velocities but also facilitates tillage operations over terraced fields.

From the standpoint of construction, a channel of uniform cross section is desirable. In order that such a channel may take care of the increasing amounts of water being intercepted, the gradient is increased along successive increments of the channel. A variable channel gradient also gives more desirable flow characteristics because the flatter grade in the upper reaches of the terrace tends to retard channel flow and so reduces the tendency for water to pile up in the lower portion of the channel. The final gradient will be limited by the maximum permissible velocities above which scouring will result. Thus, by proportioning the channel area, shape, and slope, the necessary channel velocity and capacity can be secured.

The recommended terrace specifications given under "Planning the Terrace System" have been developed from experimental and exploratory data collected under actual field conditions. They will ordinarily be found to suffice if applied under conditions for which they are recommended. For the man inexperienced in engineering they form a safe basis for terrace design and can generally be used without further computation. The exceptional conditions for which these specifications are not entirely adequate may require the computation of run-off from agricultural areas and the determination of theoretical channel velocities and capacities. Where problems of this type are encountered a competent engineer should be consulted.

TYPES OF TERRACES

Owing to the evolution through which terracing has passed, a wide variety of terrace types has been advocated, and considerable care must be exercised in their selection, construction, and use. Terraces will prove detrimental rather than beneficial if improperly applied, planned, or constructed. Years of experimentation and extensive field observation by interested agricultural agencies have revealed valuable information relative to the different types of terraces and their application to existing conditions.

At the present time there does not seem to be any universally accepted classification of terrace types. The ultimate objective of all terraces is soil conservation. This objective is achieved by terraces that provide proper surface drainage or that increase rainfall absorption in the control of wind erosion. It seems logical therefore to make a functional classification of terraces: (1) The drainage type and (2) the absorptive type.

When the construction characteristics alone are considered a corresponding classification would be (1) the channel type and (2) the ridge type. Classification according to construction should include also a third type, the bench terrace, which is used on the steeper slopes.

In some sections of the country both drainage and absorption are important objectives in terracing, but there are large sections where drainage is of primary importance and other areas where absorption is the principal requirement.

In regions of moderate rainfall and favorable soil conditions intermediate terrace requirements will be encountered, and a dual-purpose terrace incorporating the desired features of both the drainage and absorptive types can be used. Cross-sectional dimensions of all terrace types will differ throughout the country according to the soil type, terrain, rainfall characteristics, and type of machinery to be worked over them, but the fact that these dimensional adjustments must be made to meet local conditions does not invalidate the classification of all terraces according to function.

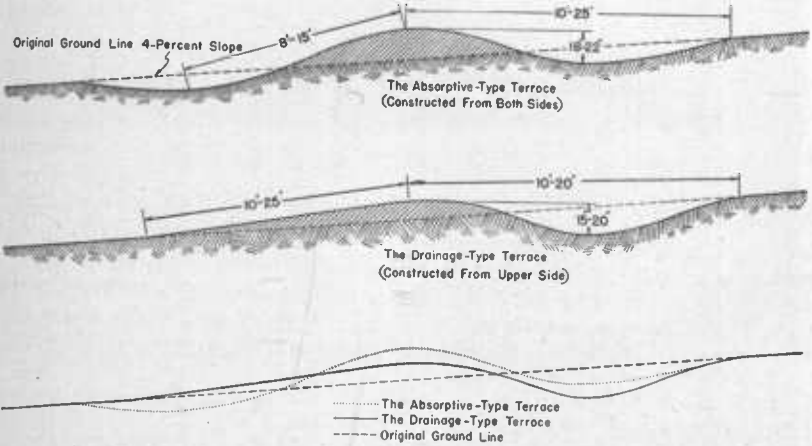

FIGURE 9.—Terrace cross sections after settlement and cultivation.

In figure 9, which shows the cross-sectional differences between the drainage-type and the absorptive-type terrace, both types are shown singly to assist in visualizing the ultimate cross sections desired for each, and one is superimposed on the other to bring out more clearly the variation between the two terraces.

DRAINAGE TYPE

The drainage-type terrace,[4] as the name implies, acts primarily as a drainage channel to conduct excess rainfall from the fields at non-

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[4] The most desirable features of both the Nichols and Mangum terraces are combined in the drainage-type terrace. Mangum's principal contribution has been the idea of modifying the construction of terraces so they could be farmed over, and Nichols has contributed the principle of developing the terrace drainage channel and improving the cross section by construction from the upper side.

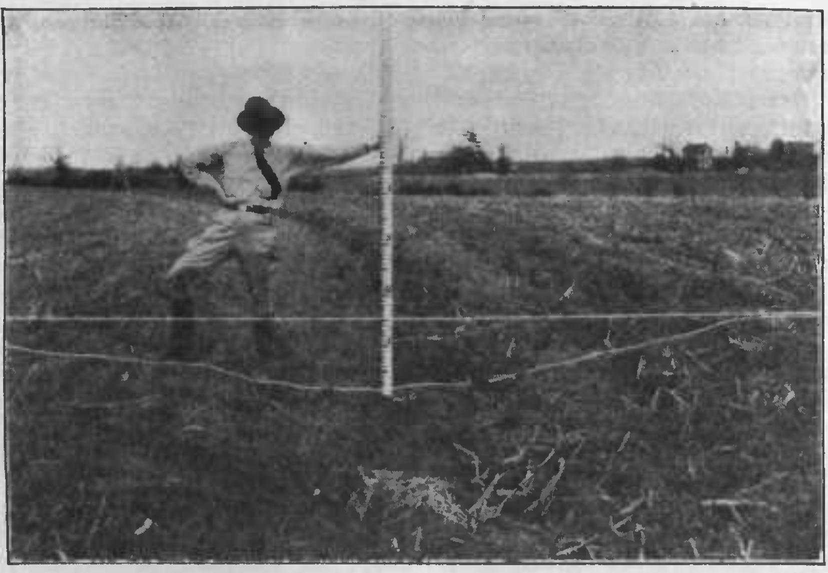

FIGURE 10.—The drainage-type terrace in the Piedmont area. It is important that a wide channel with ample capacity be provided.

erosive velocities. Since low-velocity surface drainage is required, the channel and not the ridge is of primary importance. A wide, relatively shallow channel of low gradient that has gentle side slopes and ample water capacity will give the most desirable results (fig. 10). The excavated earth is used to bring the lower side of the channel to a height sufficient to provide necessary capacity. A high ridge

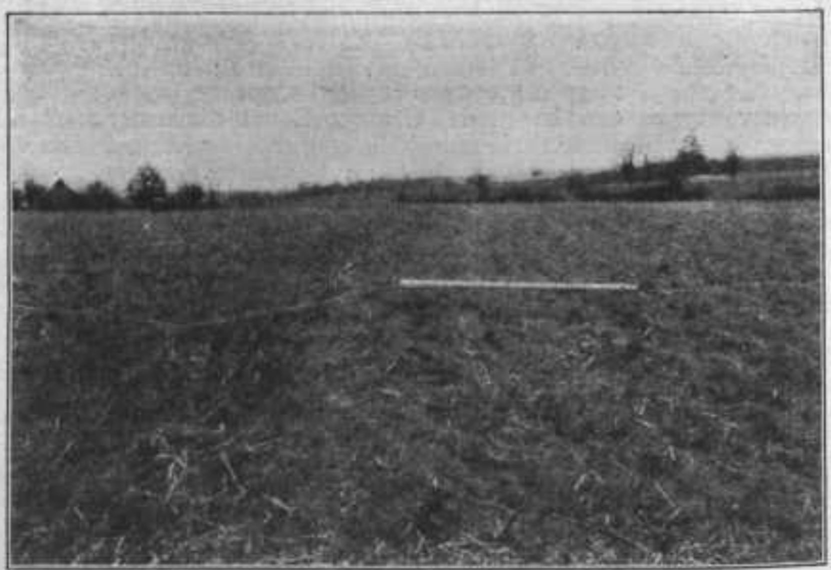

FIGURE 11.—This drainage-type terrace has been blended into the surface slopes and the channel capacity maintained by proper plowing. The terrace will offer a minimum of inconvenience to tillage operations.

is not desirable since it seriously interferes with tillage operations, increases construction costs, and frequently requires for its formation a large part of the topsoil scraped from the field. In the drainage-type terrace the ridge should be considered as supplemental to the channel and should blend gradually into the surface slopes to afford a minimum of interference with machinery operations (fig. 11).

In general, the drainage-type terrace is applicable to soil types that are relatively impervious and to conditions in the Southeast, the Middle Atlantic States, the Tennessee and Ohio Valleys, and those parts of the Mississippi Valley where there is a reasonably good distribution of rainfall throughout the growing season. In these States the amounts and rates of rainfall are relatively high, and since the retention of all the rainfall would be difficult and damaging to growing crops, the surplus rainfall must be removed through surface drainage.

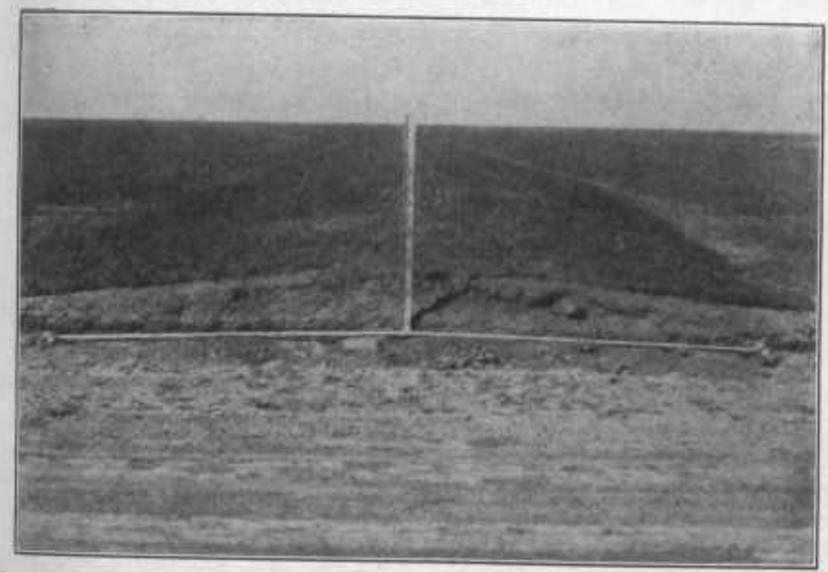

FIGURE 12.—The absorptive-type terrace is used in the Great Plains for erosion control and moisture conservation. It is important that the ridge be high enough to spread the collected run-off over a wide area and wide enough to allow satisfactory operation of tillage equipment.

ABSORPTIVE TYPE

Erosion control by the absorptive-type terrace is accomplished indirectly by water conservation. In order to increase absorption the terrace is constructed so as to flood collected run-off over as wide an area as possible. If this is to be done most effectively the surface slopes on which the terraces are built should be fairly flat, the ridge should be of sufficient height to pond water over a relatively large surface, and the earth required for the ridge so excavated as to avoid concentration of run-off on a small area (fig. 12).

The degree to which these conditions can be attained is limited by the construction methods that are necessary and the land slopes encountered. In this type of terrace the ridge is of greater importance than the excavated channel, which is more or less incidental to the construction of the ridge. When maximum absorption is desired the terraces must be designed for ample storage capacity and placed on level grades with closed ends. As a factor of safety the ends are often left open so that excess rainfall can escape before the terrace overtops. In some areas the ends of the terraces are partly blocked, depending on the necessity of safety outlets for excessive rainfalls not included in the design frequency. If the impounded water from level terraces would result in excessive crop damage, a slight channel grade, particularly near the outlet, may be necessary.

The absorptive-type terraces are adaptable to areas of low precipitation and to soil types that will absorb the accumulated run-off fast enough to prevent damage to growing crops. These areas are largely confined to absorptive soils and gentle slopes in the drought and wind-erosion areas of the central Great Plains. The absorptive-type terrace may also be used with considerable success on certain restricted areas of sandy soils and gentle slopes where the rainfall is heavier, such as the sandy coastal plains of the Southeast. Thorough examination of the soil absorption and rainfall rates should always be made before this type of terrace is used. The absorptive-type terrace, on a Texas field, is shown in figure 13.

FIGURE 13.—Conserving moisture by terracing. These terraces are on too steep a slope for most effective distribution of the moisture.

BENCH TYPE

Terracing as now practiced in many foreign countries consists of building relatively steep land into a series of level or nearly level strips running across the slope. The strips are separated by almost vertical risers, which are retained by rock or a heavy growth of vegetation. This type of terrace is known as the bench terrace and exemplifies the original meaning of the word "terrace." It is one of the oldest mechanical methods of erosion control, having been used for many centuries in thickly populated countries where economic conditions necessitated the cultivation of steep slopes. The use of the bench terrace on steep slopes not only retards erosion losses but also facilitates cropping operations on these slopes.

Population density and scarcity of flat lands do not as yet demand extensive cultivation of excessively steep slopes in the United States.

Some cultivation of field crops on steep, bench-terraced slopes has been practiced in sections of the Southeast for several generations (fig. 14), and the continuation of this practice may be necessary in hilly or mountainous sections. In the highly productive citrus and avocado districts of southern California bench terraces have been used to a considerable extent on steep valley side slopes. In other States there are scattered examples of their use in connection with truck farming or vineyard and orchard cultivation. Wherever the absence of adequate flat lands or the special adaptability of particular slopes to high-income crops necessitates the cultivation of steep slopes the bench terrace will probably continue to be used in the United States.

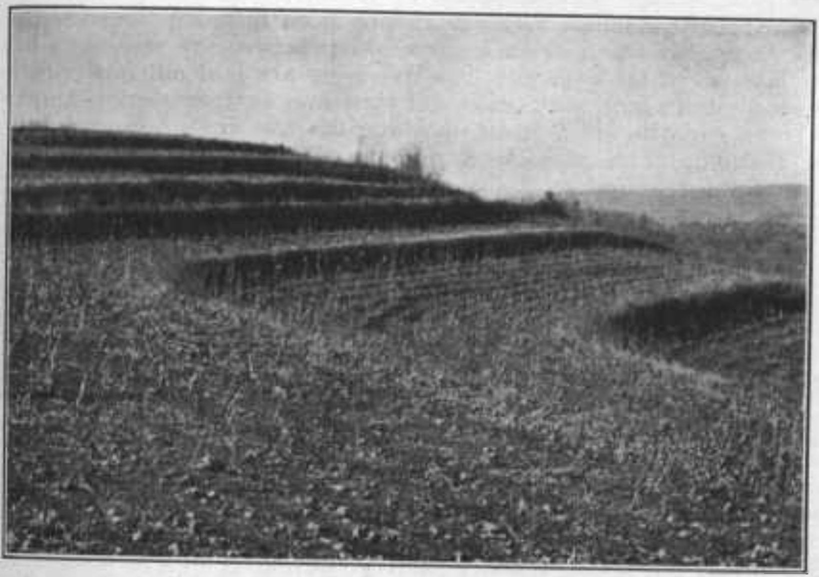

FIGURE 14.—Bench terraces on a 20-percent slope in the South. These benches have been developed over a period of years by leaving the ridges in permanent vegetation and allowing the soil to move down the slope between terraces.

Owing to its limited use, the most desirable design and construction practices have not as yet been thoroughly investigated in this country, so this discussion of the bench terrace will of necessity be limited to a brief review of past practices and recommendations based thereon.

The ordinary method of developing the bench terrace in the Southern States was to construct a series of small ridges usually at intervals and grades selected according to the judgment of the surveyor. Some of the specifications used compare favorably with our regular terrace recommendations, whereas others vary from them materially. The ridges were not cultivated and were allowed to grow to briars, weeds, or grasses. They were also frequently used as a place to pile rock and roots collected from the fields. Contour cultivation was practiced on the interval between ridges. The upper side of the interval between ridges was lowered by erosion, and the soil retained by the ridges raised the lower side. In addition to this leveling of the interval by erosion, the process was intentionally hastened by turning plow furrows downhill whenever possible during the regular cultivation operations. Several years of alternate soil transportation and deposition down the slope were usually sufficient to form a series of fairly level strips with steep, protected risers between. On some terraces the surface run-off was allowed to flow over the terraces, whereas on others an attempt was made to maintain a ridge on the crest of the riser or a water furrow just above it so that run-off could be diverted from the field and discharged at the end of each terrace.

In California a bench terrace, sometimes referred to as the Reddick-type terrace because of H. E. Reddick's efforts in adapting it to southern California orchards, is produced in much the same manner, except that irrigation grades and practices are used as a basis for laying out the system. The tree rows are laid out on irrigation grade lines (which vary with soil type and surface slope), and two or three furrows are thrown up along the tree rows before the trees are planted. This provides a ridge in which to plant the trees and a furrow for irrigating the trees during planting. Subsequent cultivation is restricted to one direction, the direction of irrigation, and a narrow belt of natural vegetation remains in the rows between trees. It has been found that if no cross cultivation is permitted a distinct bench-terrace system will develop in about 10 years. The original spacing of tree rows is arranged so that when the bench terraces have developed there will be sufficient room for cultivation and irrigation between the tree rows.

Figure 15 shows a soil profile through a bench terrace after many years of formation and use. A study of this profile not only shows what happens to the soil during the leveling process, but also reveals some of the important soil aspects that must be considered in developing satisfactory specifications for bench terracing. Bench terracing should be discouraged on soil strata subject to sliding. The depth of topsoil, the character and permeability of the subsoil, and the depth to the parent material are features that should be considered in arriving at the most satisfactory spacing specifications. If the spacing is too wide with respect to the depth of topsoil, and if the subsoil cannot be successfully cropped, too much unproductive soil will eventually be exposed over the surface and render the entire field useless for crops.

Spacing specifications also vary with surface slopes, type of equipment, and the tillage practices to be used on the land. The completion of bench terraces during the initial construction operations does not seem practical, except possibly under special conditions, because of the extensive moving of earth involved. Where this has been attempted in the past it has resulted in high construction costs and often has led to unfavorable cropping conditions owing to the abrupt disturbance and distribution of the soil.

Before the use of bench terraces in any area is considered, a thorough study should be made to determine whether there is justification for cropping the steep slopes that require this type of protection. If suitable lands with flatter slopes are available or if a profitable return cannot be expected, cropping of the steeper slopes by the use of bench terraces should be discouraged. The construction

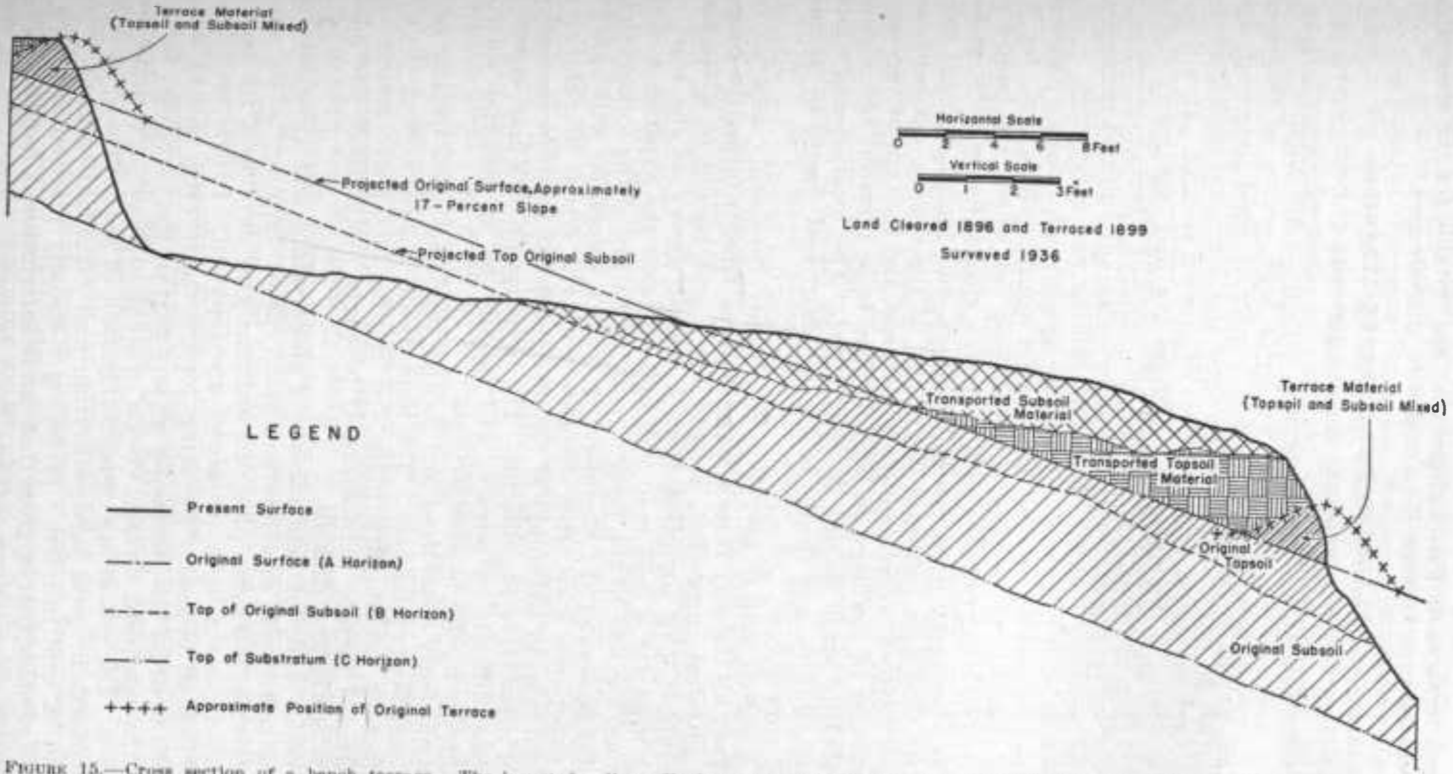

FIGURE 15.—Cross section of a bench terrace. The inverted soil profile has been developed by soil movement between terraces. Unless the topsoil is relatively deep in comparison with the vertical interval between terraces, subsoil is eventually exposed over the entire surface.

of bench terraces on flatter slopes that are suitable for the absorptive- or drainage-type terrace should also be discouraged.

PLANNING THE TERRACE SYSTEM

GENERAL CONSIDERATIONS

Certain fundamental engineering principles are involved in designing and constructing terraces, but a high degree of theoretical training is not so important as the faculty of good judgment, combined with an agricultural background and a general understanding of the various phases and measures of erosion control. It will usually be advisable for farmers who have not had training in the use of surveying equipment and in the planning of a terracing system to have the surveying and planning done by an agricultural engineer or someone who has had the necessary training and experience.

The first step in planning a terrace system is to make a thorough physical inspection of the area under consideration and, for the larger projects, to prepare a sketch map on which are located all the topographical features such as drains, ridges, slopes, hills, gullies, field and property lines, roads, buildings, and fences, and any other features that may influence the design of the system. A reconnaissance of adjacent areas should also be made, and the type of vegetation and amount of drainage on both the area to be terraced and adjacent contributing areas should be determined. The location and size of culverts, gullies, and drains below the watershed should be included in the survey.

If a sketch map is used it need be only reasonably accurate and may vary all the way from a map prepared from information secured by a physical inspection, a hand level, and pacing to a complete topographic map compiled from a transit survey of the area.

The need for a field map will depend upon the experience of the fieldman, the size of the project, and the nature of the topographical features encountered. Engineers or terrace specialists with sufficient field experience may often dispense with the actual preparation of the field map to advantage if the topographical features encountered do not make terracing difficult. The preparation of a map, especially of areas difficult to terrace, will usually be of material value to younger men who lack experience.

Insufficiently considered and hastily prepared plans usually result in unsatisfactory lay-outs. The importance of determining the most satisfactory preliminary plans lies in the fact that terraces once constructed become permanent, if properly maintained, and relocation is costly and difficult.

From a study of field notes and observations and a consideration of the soil types, precipitation, and type of farming in the area a satisfactory terracing plan can ordinarily be developed for an area, provided certain basic principles are followed. In the preliminary planning, all necessary terracing for the entire farm should be considered in order that terracing on any part of the farm may be fitted into the complete terrace system without difficulty or unnecessary expense. The possibility of rearrangement of fields, fences, and roads to conform to good land-utilization and farm-management policies should be kept in mind. Terracing is usually planned according to drainage units, that is, areas that can be satisfactorily handled through one outlet or system of outlets. Such factors as ridges, drains, roads, large gullies, abrupt changes in slopes, property or field lines, and terrace lengths are some of the main determinants of boundary or division lines between terracing units. Adjacent farms may often have fields in the same drainage unit, in which case a joint terracing system may be used to advantage for both fields provided a satisfactory agreement can be made between the two landowners for joint construction and maintenance of the terraces and outlets.

The location of the most desirable terrace outlet and determination of the necessary measures of control are the first items to be considered in making the preliminary field plans. After the outlets are located, the terracing system should be developed around them in such a way as to conform to the topography and yet use the outlets to best advantage. The simplest and most economical type of outlet is usually secured where terraces can be discharged directly onto well-established sod or other natural cover that will provide sufficient protection against the run-off from the terraces. Caution must be exercised in selecting a natural outlet, and it must be carefully watched for evidences of failure. Many terrace systems have failed just because too much dependence was placed on a natural outlet that had far too thin a cover of grasses, shrubs, or forest litter to withstand the added discharge from the terraces. The ideal natural outlet consists of a dense growth of permanent sod that is protected from grazing or other damage. On relatively flat slopes permanent woods in which there is a good undergrowth and forest litter and in which controlled grazing is practiced also make a very good outlet. If satisfactory natural outlets are not possible, it will be necessary to construct a suitable outlet to convey the run-off from the terraces to stabilized waterways.

If it is necessary to prepare special outlets, vegetated outlets are usually preferable, provided they can be satisfactorily established. It is often advisable to have the necessary vegetation established in these outlets before the terrace run-off is discharged into the channel. This can be accomplished by immediate sodding of the outlet channel, by seeding and the use of temporary outlets, or by the establishment of vegetation in the outlets before the terraces are constructed. Where special protection in the form of mulching is provided, a good vegetative cover can sometimes be secured by seeding without temporarily diverting the run-off. The mulch, which serves both as a protection against flowing water and as a conserver of moisture, is usually held in place by mechanical means until vegetation becomes established. The establishment of vegetation, particularly grasses and legumes, by seeding in prepared terrace outlets is worth considerable effort since seeding is more economical than sodding. Special channel cross sections, seedbed preparation, fertilization, and seed mixtures are usually necessary to assure satisfactory vegetated outlets.

Where it is necessary to use a combination of vegetative and mechanical protection in the outlet, the vegetation is ordinarily used in the upper part of the channel and permanent check dams in the lower part. Usually the most economical of mechanically protected outlet ditches, in relation to the area drained is one that has terraces of maximum permissible length discharging into it from both sides—provided the cost of construction and maintenance has been reduced to a minimum. All prepared outlet channels should be as straight as it is practical to make them. It is desirable, wherever convenient, to have terraces on opposite sides of the outlet discharging into the outlet directly opposite each other.

Prepared terrace outlets should be located where they can be constructed and maintained most economically and will function satisfactorily. It is preferable that they be on the gentler slopes and on field or property lines where they will interfere least with tillage practices. Large or crooked gullies should seldom be used for terrace-outlet ditches because it is difficult and expensive to protect and maintain them. It is usually advisable to divert run-off away from such locations. Diverting run-off from gully heads by means of terraces often provides the most economical gully control. As a general rule the use of road ditches as terrace outlets has not proved satisfactory except where the outlets can be economically installed and where a cooperative agreement for their construction and maintenance can be worked out between the landowner and the highway officials.

When the field to be terraced receives any appreciable amount of run-off from an adjacent area it will be necessary to divert this run-off from the terrace system by some form of diversion or interception ditch. If this is not done the added run-off will probably cause overtopping of the first terrace it encounters, which will ultimately lead to failure of each succeeding terrace down the slope. The diversion ditch must have ample capacity and nonerosive grades and must be protected from silting by erosion-control measures on the contributing drainage area.

In making estimates of rates of run-off for the purpose of determining size of ditches, outlets, or weir openings in control structures some standard procedure applicable to the area under consideration should be followed. The run-off curves and tables prepared by C. E. Ramser for small agricultural areas are as accurate as any available at the present time for the eastern United States. Ramser's reduction ratios of 0.60 for 1 acre, 0.70 for 10 acres, 0.75 for 30 acres, and 0.90 for 100 acres can be applied for rates of run-off from graded-terrace areas, and an additional reduction of about 25 percent can be made in estimating run-off rates from level-terrace areas. It is generally agreed that no reduction in run-off rate should be made for terraced areas larger than 100 acres.

In the field plan of a terrace system shown in figure 16 more difficulties than are ordinarily encountered in any one field are included in order to illustrate methods commonly used to overcome them. Note that a diversion ditch has been utilized to intercept run-off from an unterraced area above the field. This ditch is necessary to protect the terraces. Since no adequate natural waterway is available to carry run-off from the terraces to the stabilized stream below, a vegetated outlet ditch is used. Natural waterways should be utilized if available and satisfactory.

TERRACING AND SOIL TYPES

Both terrace design and construction may be influenced to a considerable extent by the characteristics of the different soil types and even by variations within a single type. For example, the erodibility or permeability of a particular soil may modify the selection of the terrace spacing, grade, and cross-sectional dimensions,

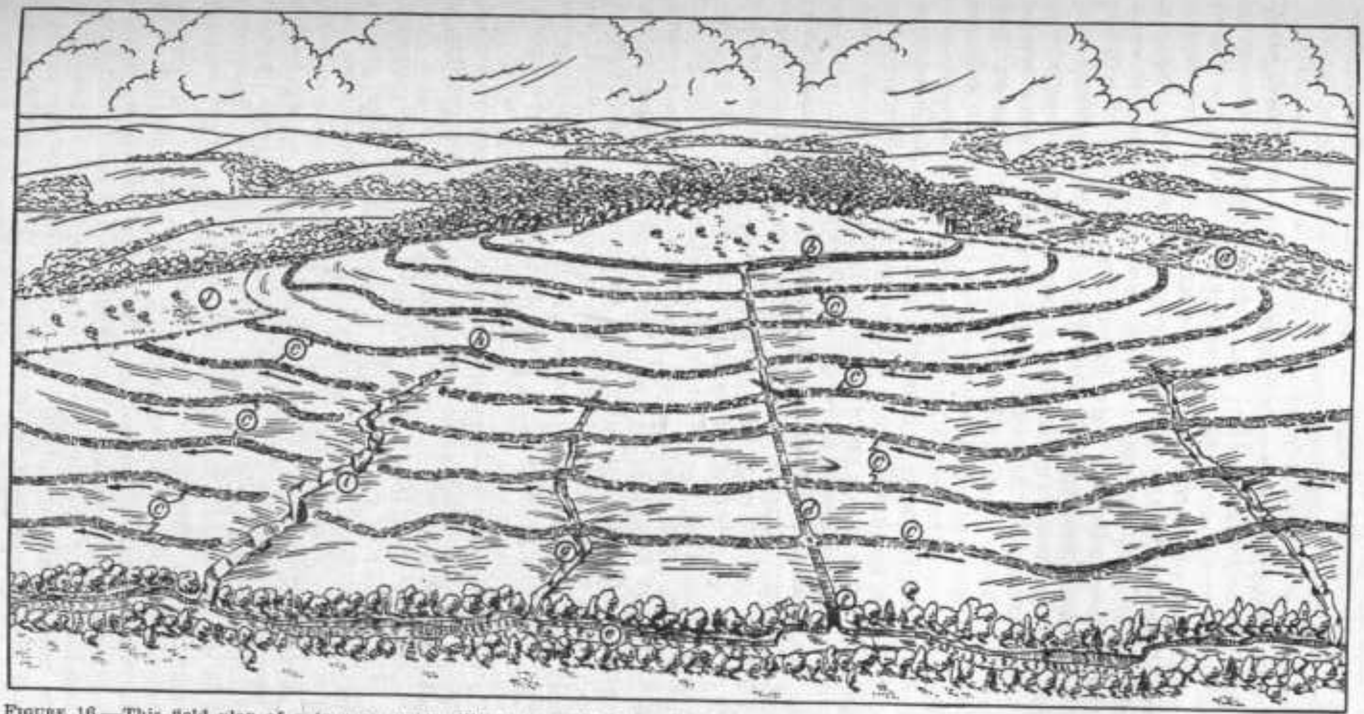

FIGURE 16.—This field plan of a terrace system illustrates methods used to overcome the many difficulties that may be encountered in terracing. The relatively flat slope at the right (*a*) is strip-cropped. Terraces may be extended across it later if necessary. The diversion ditch (*b*) carries run-off from the unterraced area above. Most of the terraces (*c*) drain into a vegetated outlet ditch (*d*). This outlet empties into a creek (*e*) that is protected by a check dam (*f*) well back from the stream bank to control the final drop into the creek. Small gullies (*g*) may be terraced across. A terrace (*h*) diverts headwater from the gully that is too large to terrace across (*i*). Terraces on the left of the large gully discharge into the pasture (*j*).

and the soil structure and its physical condition will have a marked effect on construction features such as size and type of equipment, difficulty of construction, season of construction, and time and power required.

The ease with which terraces can be constructed will be directly affected by soil characteristics. On some soils terrace construction may even be impractical owing to the unstable nature of the soil or the presence of rock or hardpan near the surface. A very wet or dry condition of the soil vitally affects terrace construction. Adverse soil conditions may greatly increase the cost of terrace construction. The Soil Conservation Service found that the cost of building terraces in the lighter Coastal Plain soils of the Southeast, which were in good workable condition, was one-third to one-half the cost of constructing similar terraces at the same time and with the same type of equipment in the nearby Piedmont soils of different inherent characteristics and in an unfavorable condition owing to prolonged drought. It has sometimes been found necessary to use supplemental machines, such as scarifiers, to loosen the soil before terracing machines could be made to penetrate it. The highly abrasive action of some soils quickly wears down points, blades, and mouldboards, necessitating frequent replacements or repairs. Sticky, gumbo soils clog up terracing machines and lower their efficiency. All these factors affect the cost of constructing terraces, and this cost in turn will partly determine whether or not any particular area can be economically retained for cultivated crops if terracing is necessary.

A soil combination that makes terrace construction difficult is a shallow silt or sandy loam surface soil over rock or hardpan. Associated with such soil combinations are low absorptive capacity and frequent high run-off rates. Under such adverse combinations terrace construction is often impractical. On a friable, fine sandy soil terracing may be unsatisfactory because of the rapidity with which impounded run-off will penetrate the terrace ridges and the ease with which the soil will slough away when saturated or when being cultivated. Soils that are only moderately friable can often be terraced satisfactorily if wider terrace ridges are provided to compensate for the increased porosity and friability of the soil.

Shallow surface soil in itself does not prohibit terrace construction unless the subsoil is very difficult to penetrate. The undesirability of exposing subsoil in the terrace channel is sometimes overemphasized. As a rule exposed subsoil gradually becomes productive and when mixed with topsoil, yields crops that are either back to normal or above normal in a few years' time. If the land has to be used for the production of farm crops, the temporary decrease in crop yields is usually small in comparison with the larger loss that would occur if the soil wastage were not checked.

Knowledge of differences in erodibility and permeability of the various soil types tends to encourage, upon first thought, material changes in terrace specifications to compensate for such differences. A closer examination of the factors involved, however, indicates that any changes made must be held within close limits or the safety of the entire terrace system may be jeopardized. Even though there is wide variation between soils in susceptibility to erosion and in absorptive capacity, the ultimate effect of these and other soil characteristics on terrace design cannot be definitely evaluated until it is ascertained how these characteristics react to the critical storms, which produce the higher rates of run-off.

Variations in soil infiltration rates have a much more direct effect on the annual or average amounts of run-off than they do on rates of run-off during rainstorms of high intensities or of very long duration. Rainfall intensities are frequently produced that are far in excess of the infiltration rates of even the most pervious soils. Storms of long duration usually produce a saturated or partially saturated soil condition, which will materially reduce infiltration rates and thus contribute a relatively high rate of run-off from a soil that under ordinary conditions would be very pervious. Once run-off is underway, some of the more permeable soils are very erodible.

Since terraces must be built to withstand the unusual storms that may occur during the design period it does not seem advisable to deviate from standard terrace specifications on account of ordinary variations in soil types. When a combination of favorable conditions is encountered, some variation from standard specifications may be made without endangering the safety of the terrace system.

TERRACING AND CULTURAL PRACTICES

TILLAGE EQUIPMENT AND TERRACE DESIGN

In the development of terracing specifications, consideration must be given to necessary tillage-machinery operations. If the terrace spacing is too close or the terrace slopes too steep, the proper operation of tillage machinery becomes impractical. The minimum terrace spacing and side slopes that permit practical machinery operation on a terraced field will vary in different regions according to the size of machinery that is customarily used for field work. In the Southeastern States, where one- and two-mule equipment is used, narrower terraces and closer spacing can be used than in the Central and Western States, where larger tillage equipment is ordinarily employed.

Major or costly adjustments in standard terrace designs or specifications to allow for better operation of tillage machinery cannot be justified because many of the initial difficulties encountered in operating machinery on terraced land can be overcome or greatly diminished by proper operation of the equipment. The operation of tillage equipment on the contour or approximately parallel to the terraces not only reduces soil movement between terraces but also aids materially in terrace maintenance and eliminates many of the difficulties encountered in operating tillage machinery. Regulating the location or position at which the various implements operate over the terraces also eliminates certain of these difficulties. Satisfactory results can be obtained in some instances merely by replacing obsolete or old-type, rigid frame machines with newer and more flexible implements. Minor changes in machinery design to facilitate operation on terraced land may be forthcoming if such changes become definitely advisable.

CROPPING PRACTICES AND TERRACE DESIGN

The development of terracing specifications at the soil and water conservation experiment stations has been largely in conjunction with contour cultivation and soil-improving rotations that include a high percentage of clean-cultivated crops (corn and cotton). Outside the experiment stations the expansion of rotations to include winter cover crops and more small-grain or forage crops, which are generally considered more resistant to erosion, and the practice of using strip cropping with terracing have introduced a temptation to disregard the terracing practice established at the stations and to deviate materially from conventional terrace design. It is assumed that the changed cropping practices will reduce the run-off and erosion sufficiently to justify a large increase in terrace spacing or a reduction in channel capacity. This tendency to depart from standard specifications is greatest in areas where terracing is new and experience lacking. Departure from established practice under the most favorable conditions and within certain limits may be justified because well-established, close-growing crops provide considerable protection against surface run-off. Experimentation and field observations indicate, however, that any such deviation from standard recommendations must be held within comparatively narrow limits and made only after full consideration of its effect on erosion and run-off during storms that produce maximum rates of run-off. The more complete protection that is provided by permanent grass covers must not be confused with the partial protection that is provided when annual farm crops are grown either in rotations or alternated in strips across the slope.

In order to determine what alteration a particular cropping practice will permit in terrace-design specifications it is necessary to consider the protection it will afford during a complete rotation and rainfall cycle. The degree to which the crop protects the soil during adverse seasons and the stage of crop growth during seasons of intense rainfalls are of particular importance. A certain cropping system may materially reduce annual or average run-off and soil loss, but if comparable reductions cannot be assured during the rains of higher intensities, which are used as a basis in establishing terrace specifications, it would be unsafe to make material changes in the terrace design to allow for this reduction. During certain periods practically all farm crops tend to lose their effectiveness in erosion control. These critical periods occur when the crop is dormant in the fall, spring, or winter; when the seedbed is being prepared or the new crop is being planted; when the crop is young and has but slight development of root and stalk; when the plants are seriously injured by frost, drought, insects, and disease; when the plant growth is arrested by harvest or maturity; and when the ground is frozen or saturated. Another factor that should not be overlooked is the probability that the rotations or cropping practices depended on to protect the soil may not be maintained, particularly during periods of crop shortages and surpluses or during high and low price cycles.

Run-off data from the soil and water conservation experiment stations indicate that fields with clean-cultivated crops experience moderately high run-off rates more frequently than do fields with close-growing crops and that the average annual soil loss from the former is usually much higher than from the latter. A study of these records, however, indicates that rates of run-off from close-growing crops are not of like degree during all storms that produce the higher rates of run-off. If these storms occur at a critical crop period the rate of run-off and soil movement may be comparatively high.

The primary purpose of using good cropping practices on terraced land is to improve the soil fertility, reduce the annual soil movements between terraces, and minimize terrace maintenance rather than to permit major adjustments in terrace specifications.

TERRACE SPECIFICATIONS

The previous discussion of slopes, rainfall and run-off rates, soil characteristics, vegetal cover, tillage, and cropping practices as related to terrace design gives some appreciation of the many factors involved in establishing terracing specifications and the relative importance of each for any particular area. It has not been found practical to assign definite values to each of these variables and to treat each as a separate item in determining final terrace specifications. For such a procedure the problem is too complex and the variables too indefinite. Standard specifications can be established by using actual field and experimental data on terracing in a certain area as a guide for terrace design in similar areas. Some deviation from standard specifications may be made to provide for the exceptional areas where favorable or unfavorable conditions may arise that have not definitely been provided for in the standard specifications. In establishing standard specifications every effort has been made to provide a terracing system that will give the most satisfactory erosion control and adequate surface drainage as well as offer a minimum of obstructions to efficient tillage operations.

LIMITING LAND SLOPES

On slopes above 10 to 12 percent, it is difficult to build and maintain terraces that have adequate capacity and can be farmed with modern machinery. These steeper slopes are ordinarily not recommended for production of the more common cultivated crops except in areas where conditions require it. In the majority of agricultural areas the drainage-type terrace is applicable to the slopes that, under a good land-use program, are generally considered suitable for the production of cultivated crops.

The upper limit of land slopes on which the absorptive-type terrace can be used most effectively for water conservation is, in general, about 3 percent. Where this terrace is used on lands having greater slopes the actual area ponded is too small to conserve much moisture unless the terrace ridge is built unreasonably high. If it is impractical to secure the desired storage capacity, a modified form of the absorptive-type terrace, providing for some drainage, may be used on slopes up to 10 or 12 percent.

Where it is necessary to use slopes above 12 percent for orchards and the production of farm crops the bench-type terrace may be applied, if terracing is required. This type of terrace may be adapted to 25- to 30-percent slopes.

SPACINGS

In the Northern States, where the ground is not subject to erosion during the several months of the year when it is frozen and where crop rotations usually include few row crops and more of the erosion-resistant forage or small-grain crops, terrace intervals may be slightly greater than is permissible in the Southern States. The rainfall intensities also are generally lower in the Northern States. It is apparent, therefore, that terrace-spacing recommendations for the Northern States should differ from those for the Southern States.

As a result of field observations and terrace-spacing studies on the soil and water conservation experiment stations[5] C. E. Ramser established some general terrace-spacing recommendations for the Southern and Northern States. The terrace spacings given in tabulated form in table 1 and in graphic form in figure 17 are based on these recommendations. The minimum and maximum values vary from the average by 15 percent. If exceptionally good cropping practices, erosion-resistant soil, and low rainfall intensities are characteristic of the area to be terraced, the terrace spacing might be increased as much as 15 percent with reasonable safety. But if the rotations include a relatively high percentage of row crops, if the soils are erodible, and if the rainfall intensities are high, terrace spacing should probably be decreased as much as 15 percent. With intermediate combinations of favorable or unfavorable factors, corresponding intermediate increases or reductions should be made in the spacing. It will often be found that a favorable factor is offset by an unfavorable one, and in such instances any deviation from recommended average spacings cannot be justified. For example, the value of a good erosion-resistant rotation may be offset by a very erodible soil type or by high rainfall intensities so that the combined results are about the same as though all factors were average.

Besides the recommended vertical interval between terraces on various slopes, table 1 gives the corresponding horizontal distance between terraces, the acreage of each terrace interval per mile or per 100 feet of terrace, and the feet of terrace required per acre of land. This information enables the reader to estimate readily the number of acres of land that a given length of terrace will serve or the amount of terracing that will be necessary for a given acreage of land. For example, if land on a 5-percent slope is to be terraced in one of the Southern States where soil and rainfall conditions permit the use of the average (mean) spacings recommended, the table shows that the proper vertical interval between terraces is 3.25 feet. The corresponding horizontal spacing will be 65 feet; each mile of terrace will serve 7.88 acres, or each 100 feet of terrace will serve 0.149 acre; and it will require 670.15 feet of terrace for each acre to be terraced.

If adverse soil and rainfall conditions are encountered and it is deemed advisable to use the minimum spacings recommended, which are 15 percent less than the average, the vertical interval will be 2.76 feet. The corresponding horizontal spacing will be 55.25 feet; each mile of terrace will serve 6.70 acres, or each 100 feet of terrace will serve 0.127 acre; and it will require 788.42 feet of terrace for each acre to be terraced. This considers only the area above terraces.

If favorable field conditions indicate that the maximum spacings recommended can be safely used the corresponding unit figures can be

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[5] At the time these studies were made these stations were known as erosion experiment stations.

TABLE 1.—*Recommended terrace spacings*[1] *and related data for drainage-type terraces*

Southern States—V I=2+S/4

Percent slope (S)	Vertical interval (V I)			Horizontal distance			Acres per mile of terrace[2]			Acres per 100 feet of terrace[2]			Feet of terrace per acre[2]		
	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Feet*	*Feet*	*Feet*
1	1.70	2.00	2.30	170.00	200.00	230.00	20.60	24.24	27.88	0.390	0.459	0.528	256.23	217.80	189.39
2	2.12	2.50	2.87	106.25	125.00	143.75	12.88	15.15	17.42	.244	.287	.330	409.98	348.48	303.03
3	2.34	2.75	3.16	77.92	91.67	105.42	9.44	11.11	12.78	.179	.210	.242	559.03	475.18	417.16
4	2.55	3.00	3.45	63.75	75.00	86.25	7.73	9.09	10.45	.169	.172	.198	683.29	580.80	505.00
5	2.76	3.25	3.74	55.25	65.00	74.75	6.70	7.88	9.06	.127	.149	.172	788.42	670.15	582.74
6	2.97	3.50	4.02	49.58	58.33	67.08	6.01	7.07	8.13	.114	.134	.154	878.58	746.79	649.37
7	3.19	3.75	4.31	45.53	53.57	61.61	5.52	6.49	7.47	.105	.123	.141	956.73	813.14	707.03
8	3.40	4.00	4.60	42.50	50.00	57.50	5.15	6.06	6.97	.098	.115	.132	1,024.94	871.20	757.56
9	3.61	4.25	4.89	40.14	47.22	54.31	4.86	5.72	6.58	.092	.108	.125	1,085.20	922.49	802.06
10	3.82	4.50	5.17	38.25	45.00	51.75	4.64	5.45	6.27	.088	.103	.119	1,138.82	968.00	841.74
11	4.04	4.75	5.46	36.70	43.18	49.66	4.45	5.23	6.02	.084	.099	.114	1,186.92	1,008.80	877.16
12	4.25	5.00	5.75	35.42	41.67	47.92	4.29	5.05	5.81	.081	.096	.110	1,229.81	1,045.36	909.01

Northern States—V I=2+S/3

Percent slope (S)	Vertical interval (V I)			Horizontal distance			Acres per mile of terrace[2]			Acres per 100 feet of terrace[2]			Feet of terrace per acre[2]		
	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]
1	1.70	2.00	2.30	170.00	200.00	230.00	20.60	24.24	27.87	0.390	0.459	0.528	256.23	217.80	189.39
2	2.27	2.67	3.07	113.47	133.50	153.52	13.75	16.18	18.61	.260	.306	.352	383.89	326.29	283.74
3	2.55	3.00	3.45	85.00	100.00	115.00	10.30	12.12	13.94	.195	.230	.264	512.47	435.60	378.78
4	2.83	3.33	3.83	70.76	83.25	95.74	8.58	10.09	11.60	.162	.191	.220	615.60	523.24	454.98
5	3.12	3.67	4.22	62.39	73.40	84.41	7.56	8.90	10.23	.143	.168	.194	698.19	593.46	516.05
6	3.40	4.00	4.60	56.67	66.67	76.67	6.87	8.08	9.29	.130	.153	.176	768.66	653.37	568.15
7	3.68	4.33	4.98	52.58	61.86	71.14	6.37	7.50	8.62	.121	.142	.163	828.45	704.17	612.31
8	3.97	4.67	5.37	49.62	58.38	67.13	6.01	7.08	8.14	.114	.134	.154	877.87	746.15	648.89
9	4.25	5.00	5.75	47.22	55.56	63.89	5.72	6.73	7.74	.108	.128	.147	922.49	784.02	681.80
10	4.53	5.33	6.13	45.30	53.30	61.29	5.49	6.46	7.43	.104	.122	.141	961.59	817.26	710.72
11	4.82	5.67	6.52	43.81	51.55	59.28	5.31	6.25	7.18	.101	.118	.136	994.29	845.00	734.82
12	5.10	6.00	6.90	42.50	50.00	57.50	5.15	6.06	6.97	.098	.115	.132	1,024.94	871.20	757.56

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[1] The spacings are based on recommendations of C. E. Ramser.
[2] Includes only the interval above each terrace.
[3] The minimum is 15 percent below the mean, and the maximum 15 percent above.

selected from the table. Values for intermediate conditions can be determined by interpolation. Similar information can be secured from the table for terracing on land slopes from 1 to 12 percent in the Northern and Southern States.

Convenient thumb rules that give the approximate vertical interval recommended for average conditions in the Northern and Southern States have been developed. In the Southern States the approximate vertical interval in feet can be determined by dividing the slope by 4 and adding 2 to the resultant quotient, $VI=2+S/4$. The vertical interval in feet recommended for Northern States can be determined by dividing the slope by 3 and adding 2 to the resultant quotient, $VI=2+S/3$. For example, the average vertical interval in feet recommended for terraces in the Northern States on a 6-percent slope is $6/3+2=2+2=4$.

Many terraces will be laid out by contractors, terrace surveyors, engineers, or even farmers who often prefer to use a chart rather than a table for determining the required vertical interval, horizontal spacing, and miles of terracing for various slopes and acreages. For their convenience figure 17 has been prepared. It is essentially a graphic presentation of the information given in table 1. The chart can be used very easily when one understands what the different lines and scales represent.

The 14 sloping straight lines on the chart represent land slopes. These lines intersect the heavy curved lines at points that give recommended spacings for terraces on slopes represented by the lines. The upper heavy line is for average field conditions in Northern States, the lower for average field conditions in Southern States. Approximately parallel to each of the heavy curved lines are two dotted lines that indicate the maximum and minimum spacings recommended. The line above the heavy curve represents the upper limit, and that below, the lower limit. The vertical scale on the left gives the vertical interval in feet, and the horizontal scales at the bottom give corresponding horizontal distance between terraces, acres per mile or per 100 feet of terrace, and feet of terrace required per acre.

To illustrate the use of the chart, suppose a 3-percent slope is to be terraced in the Northern States, and suppose the field conditions are about average. To find the spacing desired, follow the 3-percent slope line to the point where it intersects the heavy curved line for the Northern States. From this point trace a line to the vertical-interval scale on the left. The number on the scale at that point gives the vertical interval as 3 feet. To find the corresponding horizontal spacing and the miles or feet of terrace required per acre on the 3-percent slope, draw a perpendicular line downward from the point where the slope line intersects the heavy line. Readings at points where this line cuts the four scales at the bottom of the chart give a horizontal distance between terraces of approximately 100 feet, 12.0 acres per mile or 0.2 acre per 100 feet of terrace, and 436 feet of terrace for each acre of land.

If favorable field conditions justify the use of the maximum spacings recommended, the 3-percent slope line is followed to the point where it intersects the upper dotted line. The vertical interval for this point is about 3.5 feet, the horizontal distance is about 115 feet, the approximate acres per mile or per 100 feet of terrace is 13.9 and

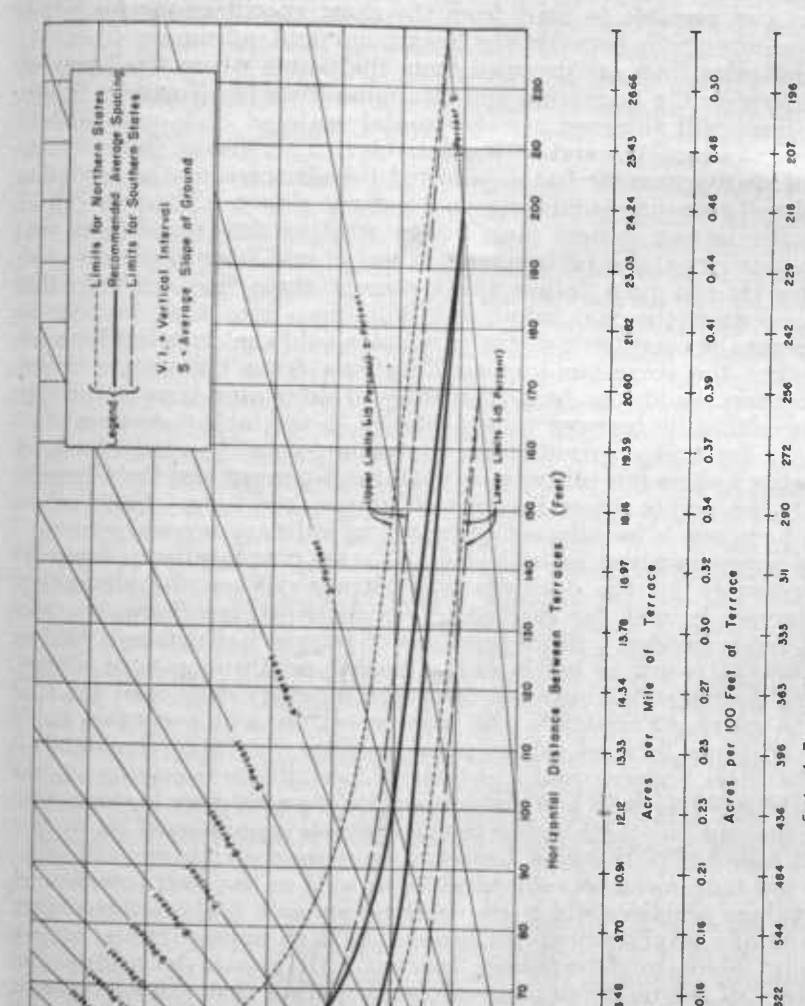


FIGURE 17.—Recommended terrace spacings and related data for drainage-type terraces.

0.26 respectively, and about 379 feet of terrace will be required for each acre to be terraced.

It is also possible to read from the chart specifications for points that lie anywhere between the maximum and minimum lines. If perpendicular lines are dropped from the points where the 3-percent line intersects the maximum and minimum lines for Northern States, these lines will intersect the horizontal scale of distances between terraces at about 115 and 85 respectively. This means that a variation of as much as 30 feet is allowed to take care of the variation in soil and cropping conditions on 3-percent slopes. The person who plans the terrace system must judge whether field conditions will allow spacings above or below the average and how much above or below. He can then follow the 3-percent slope line down to that point between the maximum and minimum lines that he believes represents the conditions of the particular field that is being terraced, and select the corresponding specifications from the proper scales.

The chart could also be used readily to determine terrace spacings on slopes that lie between those included in the table. Approximate readings for a 3½-percent slope, for example, can be easily made by following a slope line midway between the 3-percent and the 4-percent lines to the points where it intersects the curved lines. Such refinement, however, is usually not necessary in ordinary terracing work.

The spacings given in table 1 and shown graphically in figure 17 are primarily for the drainage-type terrace. When the absorptive-type terrace is used, the spacings given for Northern States are generally recommended. Since this type of terrace has not been used in experimental work as much as the graded or drainage-type terrace, spacing specifications have not been so completely developed for it as for the latter. Practically the same spacings will generally apply for both types because any material increase in the terrace interval for the level terrace would ordinarily permit more erosion on the slopes between terraces and give less uniform water distribution. The ideal spacing for the absorptive-type terrace would seem to be that which would give the most uniform moisture distribution and minimum soil movement between terraces as well as the least interference with tillage practices and a low construction cost. The water-storage capacity of a level terrace with closed ends is an important and often a limiting factor in determining spacings. It should be sufficient to take care of the maximum run-off accumulation that can be expected from the contributing drainage area during the design period. This run-off may be as high as 4 or 5 inches in the semiarid regions and 7 or 8 inches in the more humid areas.

On fairly uniform slopes the average slope of the area can be used in computing the vertical interval for the terraces. If the slopes vary considerably the weighted average of all the slopes that a terrace is to cross should be used in computing the vertical terrace interval for each terrace. On some fields it might be advisable to reduce or increase the indicated interval slightly for certain terraces in the system in order to place them advantageously. It may also be necessary to make adjustments between terrace intervals in order to get proper alinement of terraces at the outlet ditch. In order to secure these features it is usually more desirable to decrease the spacings somewhat.

GRADES

Since experimental results show that both the rate of surface run-off and the soil loss in run-off increase with steeper terrace grades, the minimum grade that will provide satisfactory drainage is desirable for the drainage-type terrace. As a variable grade retards the rate of run-off and provides drainage in a more satisfactory manner than the uniform grade, its use is generally preferable for terraces more than 300 feet in length.

In determining the final grade, the total length of the terrace should be estimated and a variable grade established that increases toward the outlet by regular increments. The grade is commonly changed every 300 to 500 feet. Wherever convenient, it is usually desirable to break grades at critical points such as gullies, fills, or low spots. Maximum grades of over 4 inches per 100 feet of length are seldom advisable since steeper channel grades usually allow excessive amounts of soil to be washed from the terrace channel. A possible exception may be found in areas with heavy clay soils or where relatively high rates of run-off are encountered. Under either of these conditions, a fall of as much as 5 inches per 100 feet of length for the last increment of a 1,600- or 1,800-foot terrace may be advisable. A common grade arrangement for areas of relatively high rainfall rates and ordinary soils is 0 to 400 feet, 1 inch per 100 feet; 400 to 800 feet, 2 inches per 100 feet; 800 to 1,200 feet, 3 inches per 100 feet; and 1,200 to 1,600 feet, 4 inches per 100 feet. Where the rainfall is high and the soil is relatively sandy a grade arrangement of 0 to 400 feet, level; 400 to 800 feet, 1 inch per 100 feet; 800 to 1,200 feet, 2 inches per 100 feet; 1,200 to 1,600 feet, 3 inches per 100 feet may be used. In areas of low rainfall and ordinary soils a grade arrangement of 0 to 500 feet, level; 500 to 1,000 feet, 1 inch per 100 feet; 1,000 to 1,500 feet, 2 inches per 100 feet may be advisable.

The absorptive-type terrace is ordinarily built with a level grade. Wherever some drainage is desired either one or both ends of the terrace can be left open or even a slight grade provided if necessary.

LENGTHS

In general, 1,600 to 1,800 feet is the maximum distance that a terrace should drain water in one direction. When properly constructed and maintained, ½-mile terraces will often give satisfactory service. In order to eliminate the need for a second outlet ditch a few terraces of this length may sometimes be used to advantage in a terrace system in which the slopes are relatively uniform. On gullied land a length of 1,500 feet should seldom be exceeded. When a few terraces in a system must exceed the maximum lengths recommended they are handled most satisfactorily by draining the excess length to a convenient natural or vegetated outlet in the direction opposite to the outlet for the main part of the terrace. Or the entire terrace may be drained in one direction, if the channel cross section is increased toward the lower end to provide additional capacity.

The maximum length of the absorptive-type terrace, particularly when the ends are left open or when a slight grade is used toward the outlet, should not exceed that recommended for the drainage type. This would mean that a maximum total length of 3,200 to 3,600 feet might be used for a level terrace if necessary. If closed ends are used, occasional blocking of the terrace channel provides a safety measure against excessive water concentration should breaks occur at any point, and if this practice is followed there appears to be no need for restrictions in permissible terrace lengths.

CROSS SECTIONS

The three main requirements of satisfactory terrace cross sections are: (1) Ample channel capacity; (2) channel and ridge side slopes flat enough to permit the operation of farm machinery along the terrace without undue breaking down of the terrace or hindrance to tillage operations; and (3) economical cost of terrace construction.

The customary cross sections for both the drainage- and absorptive-type terraces are shown in figure 9. The drainage-type terrace provides channel capacity primarily by means of a graded, excavated waterway; the absorptive-type obtains its capacity by means of a ridge that floods the excess rainfall over a wide area. The water depth of a settled terrace of either type should be from 15 to 22 inches, and the minimum water cross-sectional area of the channel of the drainage-type terrace should seldom be less than 7 to 8 square feet. Larger cross-sectional water areas are usually necessary for the absorptive-type terrace. Long terraces should have a cross-sectional area greater than 7 to 8 square feet toward the lower end because there will be a greater accumulation of water in the lower reaches of the terrace.

The side slopes of the channel or ridge should seldom be steeper than 4:1, and 5:1 is preferable Steeper side slopes may be permissible in the Southeastern States, where small equipment is generally used, but the flatter side slopes are necessary where larger machinery is used. The total width of terraces may vary from 15 to 40 feet, depending on the land slopes and the type of machinery to be provided for.

TERRACE STAKING, REALINEMENT, AND MARKING

After the preliminary plan for the terrace and outlet system has been decided upon and the final terrace spacing and grades selected, the staking of the terrace system can be begun. The person doing the field staking must understand the use of a level and how to determine grades, elevations, slopes, and vertical intervals. He must also have had sufficient experience in terrace construction to know how far it is practical to deviate from the true grade lines in the final realinement of terrace stakes.

PRELIMINARY STAKING

Random stakes should first be set to mark the location and approximate width of the outlet ditch or ditches. The upper terrace is then staked, the drainage divide being used as a starting point from which to measure the vertical interval for the first terrace. An exception to this rule may be made if it is desired to have a definite location for some particular terrace in the system. This terrace would then be located first, and a sufficient number of terraces staked between it and the drainage divide to insure that the maximum vertical interval for any one terrace would not be exceeded, and any reduction necessary in the spacing of terraces could be divided proportionately. After the upper terrace is staked, each of the succeeding terraces is staked in turn.

In order to get proper alinement of terraces at the outlet ditch it will usually be found most convenient to start staking at the outlet end of the terrace. The selected terrace-channel grades can then be used to locate all other stakes from there to the other end of the terrace. If the outlet ditch has terraces emptying into it from one side only, there is no particular advantage in starting to stake a terrace from the outlet end. Stakes should be set at 50-foot intervals except on curves and through draws, where a 25-foot spacing should be used. It is customary and usually most convenient to have the stakes indicate the location of the center line of the ultimate terrace ridge. There is not, however, any objection to setting the stakes so that they indicate the center line of the channel or a line midway between the ridge and channel if the field surveyor prefers to follow either of these practices. It is not always possible to secure the most satisfactory terrace lay-out in the first attempt. After a few lines have been staked, topographical features will sometimes be encountered that will favor changes in terrace lines. If such changes are extensive it is usually best to pull up all stakes set and start over again. Even experienced engineers cannot always select the most desirable starting point without first setting a few preliminary stakes and then making such readjustments as seem desirable.

REALINEMENT OF TERRACE LINES

After the terrace lines have been staked some realinement is usually necessary on each proposed terrace in order to eliminate undesirable sharp curves, to obtain greater ease of construction, and to secure a finished terrace that will offer a minimum of inconvenience in later tillage operations.

The realinement needed will vary with the relief of the field but will usually consist of moving certain stakes up or down the slope where there are sharp curves in terrace lines until the most desirable terrace line is secured. The general procedure is illustrated in figure 18. Good field judgment must be exercised in order to secure the most satisfactory realinement of terraces.

The movement of terrace lines up and down slopes will of necessity be restricted by the drainage and construction features encountered. Usually the straightening should be limited in upward movement so that not more than 6-inch additional cuts will be necessary in the terrace channel. An exception might be made when a wide, sweeping bow can be eliminated by a slightly deeper cut, provided the other terraces of the system will follow uniformly. The straightening of terraces through depressions should not be such as will introduce excessive ridge heights and pond areas. Usually the maximum ridge height should not exceed 3 feet. If a gully has formed, the settled height of the terrace ridge above the break or fill in the gully should seldom exceed 3 feet.

MARKING TERRACE LINES

If a final check of the terrace and outlet locations shows that the entire lay-out will be satisfactory, the terrace lines should be marked with a plow furrow since stakes are easily lost and more difficult to follow with the larger terracing equipment.

If the farmer or landowner has not assisted with the staking it is desirable that he go over the proposed terrace lay-out in detail, preferably plowing out the terrace lines himself so that he can fully visualize the complete lay-out. He should be informed of all the construction details necessary and particularly of any probable additional work such as fills across gullies or excavations in the outlet ditch.

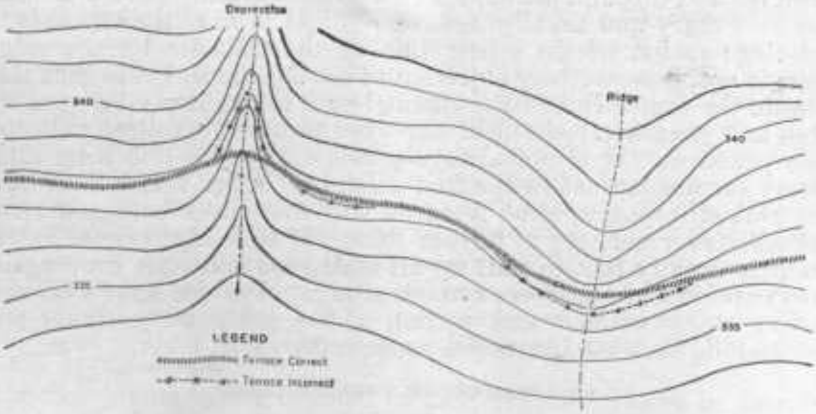


FIGURE 18.—Realining the terrace line by straightening sharp curves through depressions and over ridges facilitates both terrace construction and tillage operations.

TERRACE CONSTRUCTION

Within the last few years there has been considerable development in methods of terrace construction because the recent increase in terracing activities has directed attention to construction phases and to the improvement and development of terracing equipment. The first problem in terrace construction is that of securing the most suitable equipment and the second that of properly manipulating it. In finishing the terraces additional work is often required to fill low points on the ridge, bring high points in the channel down to grade, fill gullies, and connect the ends of terraces with outlets or complete them across fence lines.

EQUIPMENT

Machines designed especially for terrace construction give the most satisfactory results, but other equipment such as road graders, ditchers, scrapers, plows, and drags may be used if regular terracing equipment cannot be secured (fig. 19). Small blade terracers, scrapers, V-drags, and plows, pulled by farm tractors, horses, or mules, have been used for the construction of a large part of the terraces in the United States today (fig. 20). Considerable time is required to construct terraces with this type of equipment, and there is therefore a tendency to stop before an adequate cross section has been secured.

The most economical terracing can usually be done with the heavier

FIGURE 19.—Terrace construction with the plow and V-drag. It requires considerable work to develop satisfactory terraces with this type of equipment.

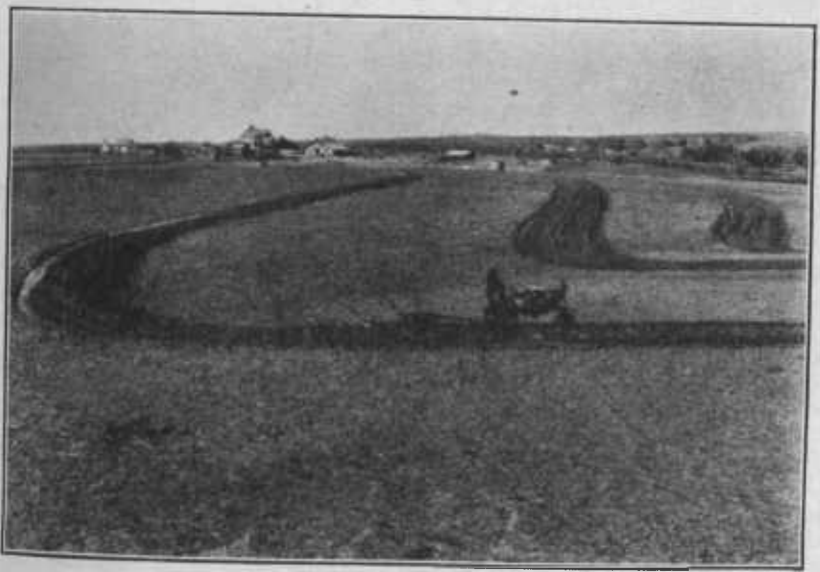


FIGURE 20.—Satisfactory terraces can be constructed with small blade terracers and the regular farm tractor, provided a sufficient number of rounds are made to develop adequate cross sections.

tractors and specially designed terracing machines (fig. 21). The 10-foot-blade terracer with the 40–50-horsepower crawler-type tractor seems to be meeting with the greatest favor at the present time. The initial cost of this equipment is comparatively high, and it is impractical for most farmers to make such an investment for their own terracing. It is therefore desirable to provide means whereby the individual landowner can take advantage of the more desirable terraces and economical construction costs resulting from the use of satisfactory terracing machinery without the necessity of making such large initial investments. An attempt is being made to accomplish this objective by several different methods, but few of these have been established for a period long enough to warrant definite recommendations as to the most desirable procedure.

FIGURE 21.—Terracing with a 10-foot blade terracer and crawler-type tractor. This type of equipment is used extensively for terrace construction.

In some States, counties are authorized to use county road equipment or to use county funds to purchase terracing equipment. Farmers usually pay the operating costs and, in some instances, small additional amounts to cover any proportionate part of the equipment charges. Where State laws do not provide for this procedure, groups of local farmers organize associations, purchase machinery, and rent it out to farmers on a cost basis. Or one or more farmers may purchase a terracing outfit and after they complete their own terracing, contract to do their neighbors'. In some areas where the demand for terracing warrants it, private contractors are entering this field and seem to be doing the work very satisfactorily.

Two new terracing machines operating on principles quite different from the blade terracers have been developed recently—the rotary type (fig. 22), at the Iowa State College, and the modified elevating grader type (fig. 23), at the University of Missouri. These machines

FIGURE 22.—The rotary-type terracer developed by the Agricultural Engineering Department of Iowa State College.

FIGURE 23.—The elevating grader-type terracer developed by the Agricultural Engineering Department of the University of Missouri.

appear to be effective for certain conditions because of their relatively low power requirements and high capacity for terrace construction. They have an advantage in the comparatively low investment required for terracer and power unit, in low operating cost, and in the ease with which they can be transported to scattered work, but they are not reversible, nor have they been extensively tested under all conditions.

CONSTRUCTION PROCEDURE

In terracing a field the uppermost terrace should be constructed first, and after it, in turn, each succeeding terrace down the slope. If the lower terraces are constructed first they are likely to be badly damaged should a rain occur before the upper ones are completed. The top terrace should not only be constructed first, but it should also be especially well constructed because the safety of the lower terraces is dependent upon it. If the top terrace fails, the other terraces down the slope are very likely to fail, owing to the overload they will receive. The delayed terracing method (extending the construction of all terraces in a field over a period of several years), which has been advocated in some areas in order to initiate terracing over a larger area without increasing the expenditure of time and funds, is a dangerous procedure and cannot be generally recommended. Usually the few rounds made on each terrace the first 1 or 2 years do not provide sufficient capacity to withstand run-off, and much overtopping and damage to the field results. Terraces are sometimes not completed to sufficient size, and they remain a source of trouble thereafter. It is desirable to complete the construction of terraces in as short a time as possible, but when the work must be distributed over a period of years the practice of constructing a few of the upper terraces the first year and building additional terraces each succeeding year is to be preferred to the practice of starting all the terraces at one time and doing only a little work on each terrace every year until all are completed.

The practice of doing only the main excavating and earth moving with the terracing equipment reduces initial construction costs and, if necessary, can be recommended provided the terraces are watched carefully during the first year or two. Sufficient work should be done with the terracing equipment, however, to obtain minimum channel requirements for the area. Later, if the field is properly plowed and disked, these operations will smooth down the terrace slopes and enlarge the channel so as to provide the recommended factor of safety.

It requires considerable experience and perseverance to develop proficiency in terrace construction. The following are a few of the more important principles to be observed in the operation of terracing equipment:

1. Unless necessary, never remove soil from areas that later will require filling.
2. Move the soil as few times as possible.

3. It is generally easier to move soil down the slope.
4. It is difficult to move loose earth over loose earth with a blade terracer.
5. Earth can be moved most efficiently if the blade is cutting some undisturbed earth at all times.
6. Move as much earth each trip as the power will permit.
7. Regulate the blade so that uniform cuts will be secured. This is particularly important on curves.
8. Do not disturb the topsoil from a wider area than is necessary.
9. It is usually desirable to secure the necessary terrace height as early during construction as possible.
10. Under varying soil conditions adjust the angle of the blade so that satisfactory scouring will be secured.

In building terraces all the earth may be moved from the upper side or a part from each side. Heretofore the practice of moving the earth from both sides was common, but the trend now is toward constructing more and more of the terrace from the upper side. This is particularly true of the drainage-type terrace, which is used where a definite channel above the terrace is desired (figs. 24 and 25). In areas where a comparatively narrow drainage-type terrace is suitable, it has been found most economical to construct all of the terrace from the upper side. In other areas, particularly on the slopes above 3 or 4 percent, only a small portion of the terrace is constructed from the lower side. This construction necessitates reversible-type machines if the most efficient use of equipment is to be obtained.

In areas where water conservation is desired and the absorptive-type terrace is used, construction from both sides is advisable because this type of construction gives a wide, high ridge with a minimum depression above or below the terrace and is suited to the relatively flat slopes in these areas (fig. 26). When some construction is done from the lower side of a terrace, care should be exercised not to leave a distinct channel below the terrace ridge in which run-off may accumulate and possibly break over at low points. Such concentration usually leads to undesirable washing between terraces.

When it is necessary to construct terraces with horse- or mule-drawn equipment, the small blade terracers, the wooden V-drag, the plow, or the scraper can be used. It has often been found desirable to use the plow in combination with one of the other implements for most satisfactory results. The terrace is usually started by backfurrowing to the terrace ridge for several rounds with the plow, and then sufficient trips are made with the small blade terracer or the V-drag to complete the terrace section. In some soils it is necessary to plow ahead of the small terracers each trip in order to obtain sufficient penetration to throw up earth enough to form a terrace. When the fresno or slip scrapers are used, the team is usually driven in a circular path over the terrace, the scraper being filled above and below the terrace and dumped along the ridge as it crosses each time. When small equipment is used, farmers should be prepared to spend considerable time in constructing their terraces in order that they may be developed to a cross section of sufficient size before being put to use (fig. 27).

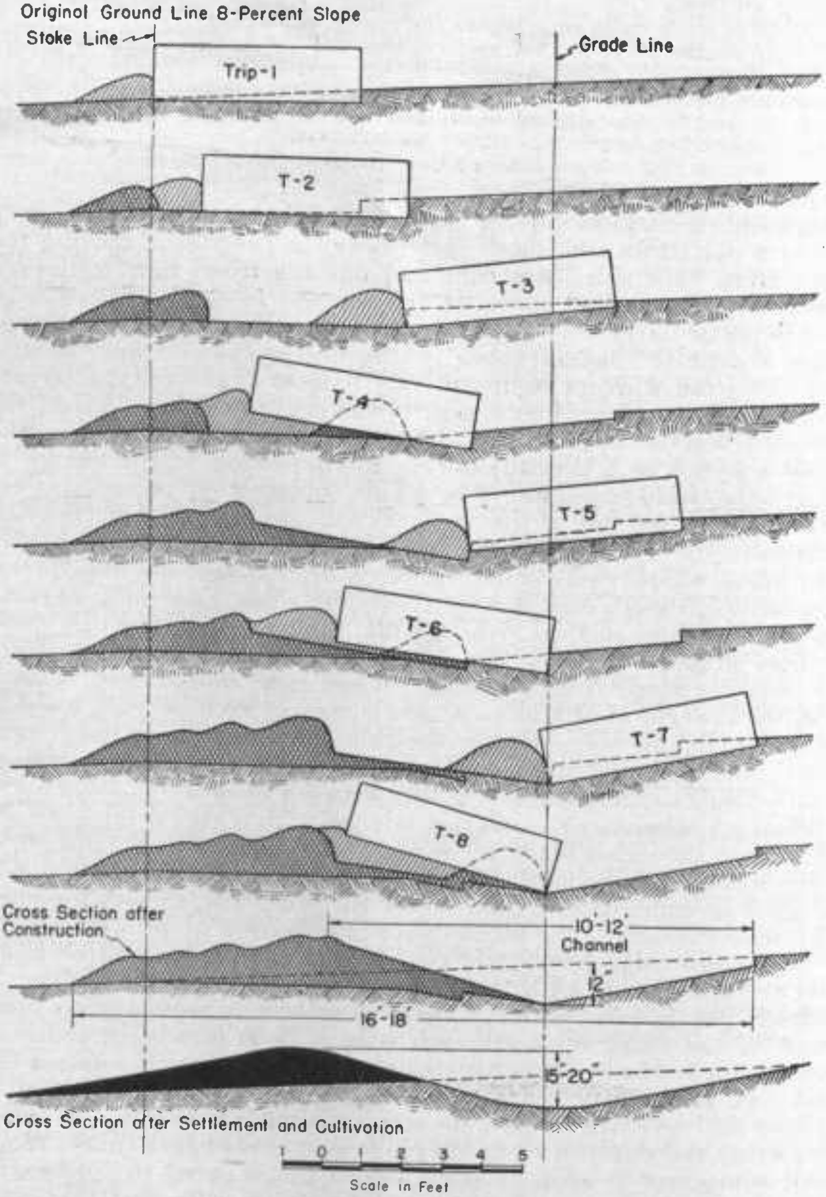


FIGURE 24.—Progressive steps in constructing a drainage-type terrace in the Southeast with a 10-foot blade terracer. The terrace is constructed from the upper side only.

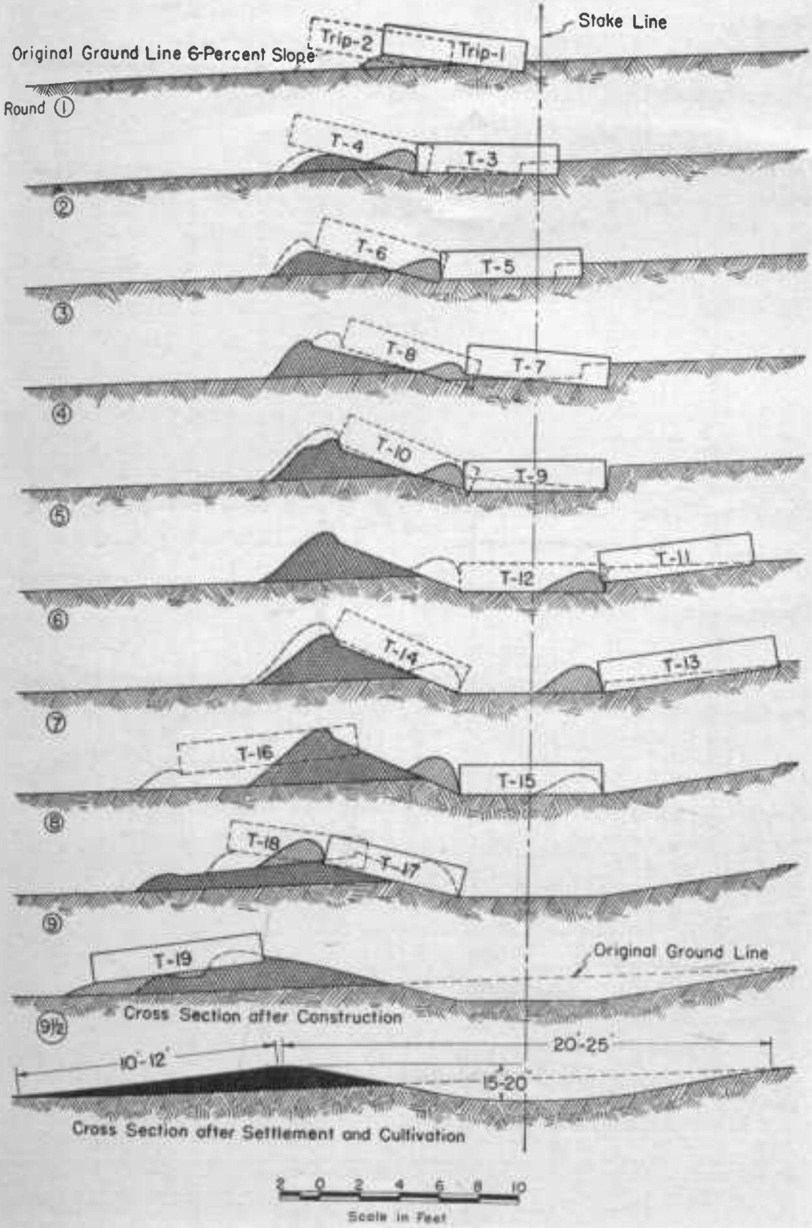


FIGURE 25.—Progressive steps in constructing a drainage-type terrace in the Midwest with a 10-foot blade terracer. The terrace is constructed from the upper side only.

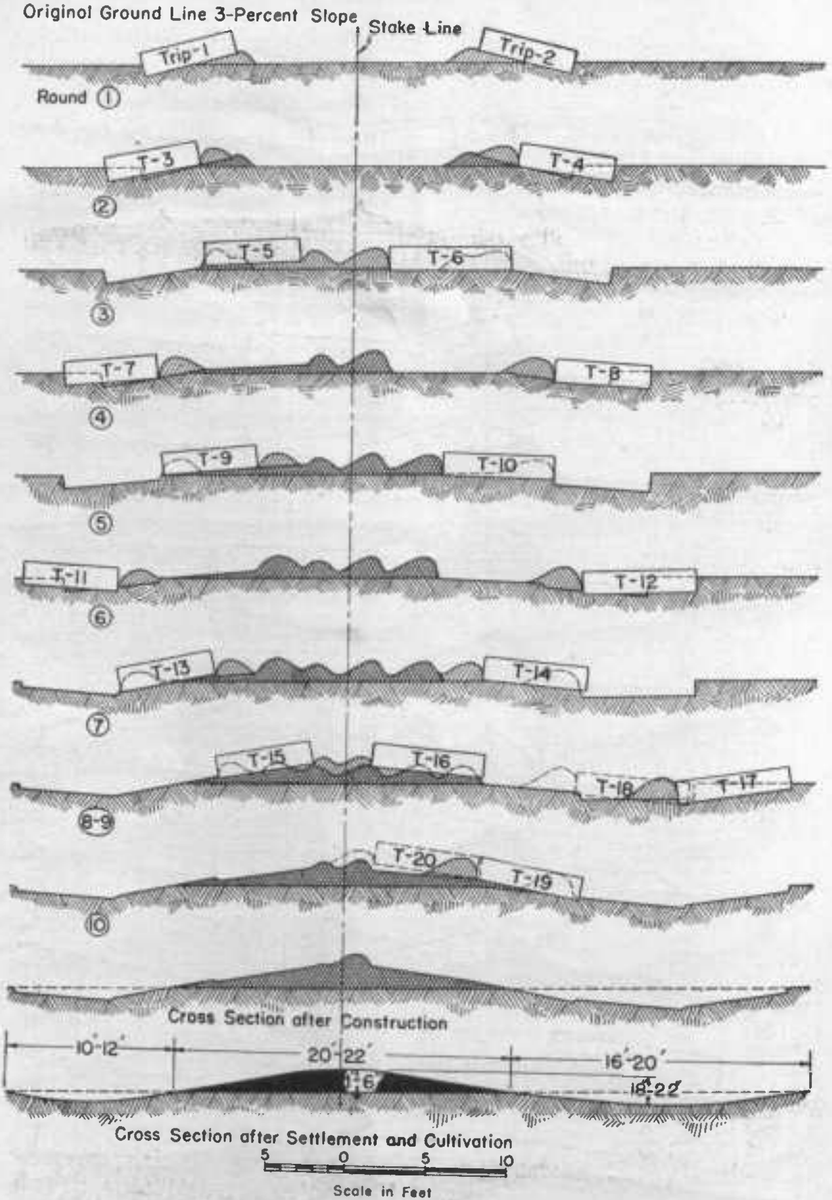


FIGURE 26.—Progressive steps in constructing an absorptive-type terrace in the Great Plains with a 10-foot blade terracer. The terrace is constructed from both sides. With inexperienced operators and on certain soil types it may be desirable to secure the necessary center height during the first few rounds.

SUPPLEMENTAL WORK

Where terraces cross gullies or even slight depressions it is necessary to do some extra fill work in order to maintain the proper terrace location and ridge elevation. A slip scraper, fresno, or rotary scraper is usually used for this work (fig. 28). Failure to build fills properly

FIGURE 27.—Partly constructed terraces in the Great Plains, where slopes are relatively flat and uniform.

FIGURE 28.—Making use of a slip scraper and team to fill low places in a terrace ridge.

is a common cause of trouble in terracing. Where an appreciable gully has developed, the fill should be made somewhat in the manner required for earth dams. It must be well compacted and impervious. A substantial bond should be provided between the fill and the gully sides. The fill must be made high and wide enough to prevent overtopping or wash-outs. Usually the height of the terrace at points where fills are made should be increased 15 to 20 percent to compensate for the extra settlement that will occur in the filled portion.

If terraces are to be continued from one field to another, it will be necessary to build the intervening section by hand if a hedge or fence that cannot be removed prevents construction of this part of the terrace with the regular terracing equipment. It also is frequently necessary to do some hand work on terraces where outlet ditches or field fences prevent the regular equipment from going the full length of the terrace. It is important that all such parts be completed to full channel capacity as one weak place in a terrace is sufficient to cause its failure.

A terrace cannot be considered complete until it has been carefully checked for correct grade and height. To assure proper channel capacity and the flow of water in the direction desired, low places on the ridge and high spots in the terrace channel should be marked and corrected before the equipment leaves the field. On the level terrace it is usually necessary to determine only the low points in the ridge. The level and rod are used in checking, and sufficient readings are taken to determine accurately where corrections are necessary. Elevations and grades should be checked very carefully around bends and across gullies and at terrace outlets. A common fault in terrace construction is to provide too much grade near the terrace outlet. If correctional work is required over an appreciable length of the terrace, it can usually be done most satisfactorily by using the regular terracing equipment.

COSTS

So many variables affect the cost of terracing that it is difficult to find two jobs that cost exactly the same per linear foot of terrace. The most important variables are the nature and condition of the soil; the length of terrace; the topography, size, and condition of the field; vegetal cover; kind of equipment used; and the experience and skill of the terrace operator and the vigor with which he pushes the work. Wet or heavy soils are more difficult to terrace than sandy or moderately dry soils. Other conditions being equal, short terraces cost more per unit of length than long terraces, owing to the time lost in more frequent turning. A heavy covering of long grass or weeds interferes with the progress of the construction work, as do gullies, rocks, sprouts, or stumps.

The difference in cost of identical terraces constructed by two different operators may be as much as 50 percent because of the difference in the skill of the operators. Farmers ordinarily do not have sufficient terracing to do on their own farms to become proficient in the operation of terracing equipment, and until an operator develops sufficient skill the cost of construction will always be high. This is one of the chief reasons why county terracing associations or terracing contractors employing skilled operators can usually build terraces more cheaply than can farmers who operate their own equipment.

When soil conditions are favorable, slopes uniform, and efficient terracing equipment available it is often considered that the cost of terracing a field is about the same per acre as the cost of plowing that same field. When conditions are unfavorable (heavy soil, frequent rocks, stumps, or gullies, and irregular topography), terracing may run as high as $10 or more per acre. It is to be noted that the terracing costs mentioned here do not include the cost of outlets, but cover only the actual cost of constructing the terraces.

Since there are so many variables affecting the cost of terrace construction it is very difficult to compare costs from different areas. Table 2 gives terracing costs at a number of the Soil Conservation Service demonstration projects. Costs on performance of different types of terracing equipment after as many of the variables as possible have been eliminated are given for individual States and groups of States. The equipment rates were determined by using the average costs submitted by the projects for the various types of equipment. An operator's average wage of 37 cents per hour was used, and only the time and cost actually necessary to construct the terrace were included. No lost time, supplemental fill work, or outlet work was considered. The costs shown for these States indicate the cost of terracing with equipment that is representative within the several States. The table also shows the terracing cost in four regions of the Soil Conservation Service. The types of equipment used were somewhat similar to the types used in the States. These costs include the actual rates submitted from the field, lost time, and repairs. Staking, supervision, fill work, outlet work, and overhead are not included.

TABLE 2.—*Average cost of terrace construction on Soil Conservation Service demonstration projects*[1]

State or region[2]	Power of tractor	Terracer	Average slope	Terraces constructed	Earth per mile	Time worked	Total cost per mile	Cost per cubic yard
	Plow		*Per cent*	*Miles*	*Cubic yards*	*Hours*	*Dollars*	*Dollars*
Illinois, Iowa, Missouri	3–4	Rotary	3–8	19.2	1,984	615.6	32.06	0.016
Iowa, Missouri	3–4	Elevator grader	5–7	5.7	2,000	168.0	29.02	.015
	Horsepower							
North Carolina, Illinois	20–25	2-wheel, 8-foot blade	6–7	24.7	1,113	702.0	38.08	.034
Oklahoma	35–40	4-wheel, 9-foot blade	3	60.3	2,351	1,172.0	31.04	.013
Do	40	4-wheel, 10-foot blade	3	32.3	2,119	533.0	26.49	.013
Alabama, South Carolina, Virginia, Louisiana, Missouri, Oklahoma.	35–40	2-wheel, 10-foot blade	4–9	378.8	1,417	6,186.0	24.33	.017
Georgia	55	do	8	102.3	1,020	1,352.0	21.65	.021
Oklahoma	50	4-wheel, 10-foot blade	3	23.8	2,599	454.0	35.14	.014
Texas	50	4-wheel, 12-foot blade	2	86.0	1,961	1,380.0	33.00	.017
Region 2	40	10-foot blade	3–8	5,017.0	1,331	77,741.0	22.39	.017
Region 4	40–50	10- to 12-foot blade	3–5	1,059.2	2,599	25,247.0	38.19	.015
Region 5	30–40	8- to 10-foot blade	6–8	230.5	2,138	8,498.0	[3]54.04	.025
Region 7	40–50	10- to 12-foot blade	3–5	1,212.0	2,352	29,320.0	33.85	.014

[1] Cost of outlets is not included.
[2] The States that compose these regions are indicated in fig. 1.
[3] Higher costs are in part due to the newness of the work and to inexperienced operators.

The following figures give costs of terrace construction with small-blade equipment and animal power. The rates used are arbitrary and are applied for purposes of comparison only. That these terraces have small cross sections is evidenced by the low earth yardage per mile of terrace. It will be necessary to rework many of the terraces, particularly those reported from South Carolina and Georgia, in order to obtain the necessary cross-sectional area.

State: South Carolina. (Average slope 6 percent; data from one-half mile terrace construction.)

Equipment: Six mules on 8-foot blade terracer; three mules on terracing plow; and two mules on turn plow.

Total mule cost per mile of terrace, 105 hours at 15 cents per hour	$15.75
Total equipment cost per mile of terrace, 33 hours at 2 cents per hour	.66
Total labor cost per mile of terrace, 49 hours at 30 cents per hour	14.70
Total cost per mile of terrace	31.11
Cubic yards fill per mile of terrace	620
Total cost per cubic yard of fill	$0.050

State: Georgia. (Average slope 4 percent; data from 1.19 miles terrace construction.)

Equipment: Four mules on 8-foot blade terracer and terracing plow.

Total mule cost per mile of terrace, 112.4 hours at 15 cents per hour	$16.86
Total equipment cost per mile of terrace, 28.1 hours at 2 cents per hour	.56
Total labor cost per mile of terrace, 56.3 hours at 30 cents per hour	16.89
Total cost per mile of terrace	34.31
Cubic yards fill per mile of terrace	465
Total cost per cubic yard of fill	$0.074

State: Texas. (Average slope 3 percent; data from 1 mile terrace construction.)

Equipment: Six oxen on terrace grader.

Total oxen cost per mile of terrace, 660 hours at 5 cents per hour	$33.00
Total equipment cost per mile of terrace, 110 hours at 3 cents per hour	3.30
Total labor cost per mile of terrace, 110 hours at 30 cents per hour	33.00
Total cost per mile of terrace	69.30
Cubic yards fill per mile of terrace (estimate)	1,466
Total cost per cubic yard of fill	$0.047

FARMING TERRACED LAND

The construction of a well-designed system of terraces does not in itself stop erosion. Construction is only the initial stage, and the success of the terraces depends on whether they are properly maintained and farmed after construction. Too often erosion-control efforts cease with the construction of the terraces, and the expenditure for construction is wasted because of subsequent faulty cropping and tillage practices. A surprisingly large percentage of the terraces that have been in use for 5 years or more are no longer effective because the continued practice of one-crop farming and tillage up and down the slopes have reduced the capacity of the terrace channels to such an extent that frequent overtopping has resulted. Such terraces have aggravated rather than alleviated erosion. This is true of both the old terracing areas, in the South, and the newer ones, in the Central States.

Terraces must be supported by adequate tillage and cropping practices in order to maintain them, to minimize erosion between them, and to improve the soil.

One of the most desirable tillage practices for terraced land is contour farming—the plowing and planting of crops parallel to the terraces. This produces a series of miniature depressions and ridges between terraces, and these aid in moisture conservation and erosion control. Operating tillage equipment parallel to the terraces, particularly equipment that penetrates the soil, also results in minimum damage to the terrace ridge and channel (fig. 29). By plowing parallel to the terrace and regulating the location of dead furrows and backfurrows, terraces can be maintained and their cross sections changed so as to provide the most desirable slopes for any particular field (figs. 30 and 31). The method of locating dead furrows and backfurrows to enlarge or maintain the channel of the drainage-type terrace and the ridge of the absorptive-type terrace is illustrated in figure 32. The location of the other backfurrows and dead furrows may be varied from year to year according to the surface condition of the field and the most convenient manner of finishing irregular strips or short rows. It is desirable to turn uphill as many of the furrows between terraces as possible.

FIGURE 29.—Contour plowing the interval between terraces aids in moisture conservation and erosion control and facilitates proper terrace maintenance.

The irregularity of surface slopes and the differences in terrace sections and types of equipment used make it difficult to establish definite rules for plowing terraced land so as to maintain the terraces properly and adjust surface slopes. Considerable ingenuity must be exercised by the plowman since the starting and finishing points will vary not only from field to field but from year to year on the same field. He must keep in mind the most desirable terrace cross section

FIGURE 30.—A terrace ridge can be made wider and the side slopes reduced by backfurrowing toward the ridge.

FIGURE 31.—Plowing a drainage-type terrace in order to maintain proper cross section. Note how the channel is being plowed out and how the terrace has been blended into the lower slope.

and the principle of maintaining and developing the channel by plowing it out, of maintaining the ridge by backfurrowing to it, and of varying the other dead furrows and backfurrows over the field so as to develop the most desirable surface slopes between terraces.

The two-way plow is not commonly used for plowing unterraced fields, but it appears to have some distinct advantages for plowing terraced fields. It will eliminate the necessity of backfurrows or dead furrows in undesirable locations. A further advantage is that the furrows between terraces can be turned up the slope. This will give the soil an upward movement that will partly offset the natural downhill movement caused by erosion and tillage. This type of plow has been used in plowing terraced land on several of the experimental farms of the Soil Conservation Service and has shown good results.

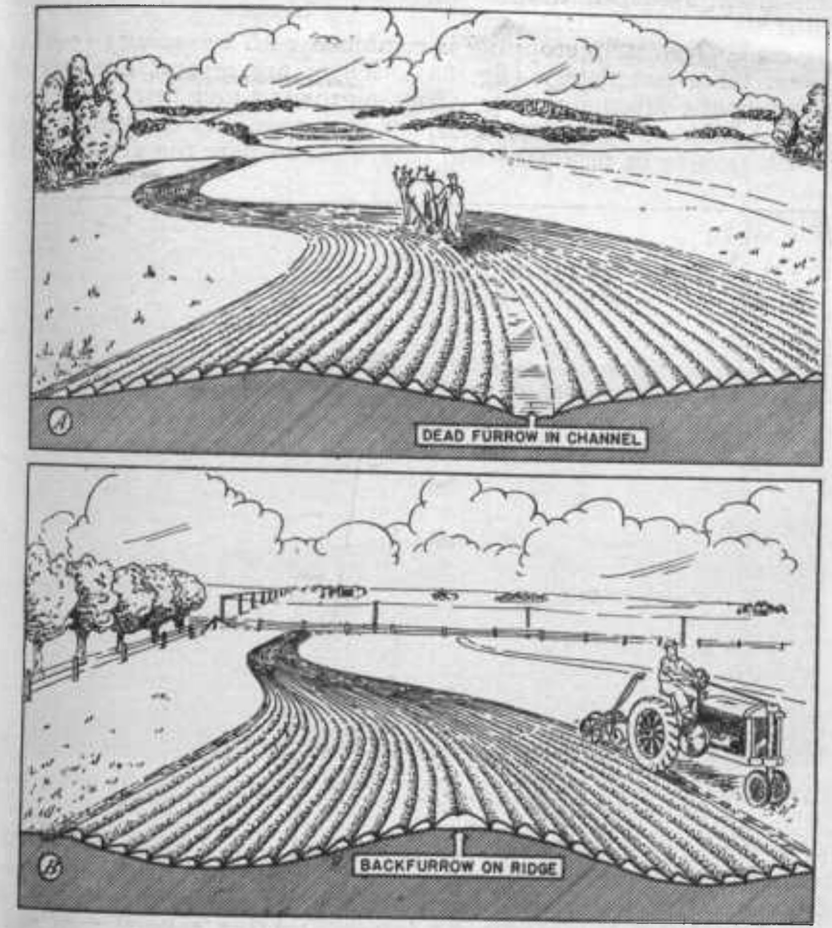


FIGURE 32.—Maintaining terraces by plowing: *A*, The channel of the drainage-type terrace can be enlarged by plowing it out. Between channels turn as many of the furrows uphill as possible to offset the natural soil movement down the slope. *B*, The ridge of the absorptive-type terrace can be enlarged by backfurrowing to it. The location of the dead furrow should be varied from year to year to avoid excessive depression at any one point.

Good terrace sections can usually be maintained with little or no additional maintenance work if contour tillage and proper methods of plowing are practiced. Under exceptional conditions, where it may not be possible to maintain proper cross sections by the regular plowing operations, it will be necessary to use the blade or scraper on the terraces at regular intervals. The lighter terracing machines or home-made V-shaped drags with ordinary farm power units can ordinarily be used satisfactorily.

In some areas strip cropping is combined with terracing to control erosion more completely (fig. 33). There are several methods of arranging the alternate strips of close-growing and row crops on a terraced field. The type of rotations, the crops, and the proportions of each crop to be produced will determine in part the arrangement and width of strips. In combining the two control measures (1) use strips as nearly uniform in width as possible in order that rotation of crops may be practiced, (2) have at least one boundary line of each strip fall between adjacent terraces so that a portion of each terrace interval will be protected by a close-growing crop, (3) eliminate point rows insofar as possible by absorbing irregular areas in strips of close-growing crops, and (4) use the minimum number of strips that will provide effective erosion control in order that the necessary tillage operations may not become unduly complicated or burdensome.

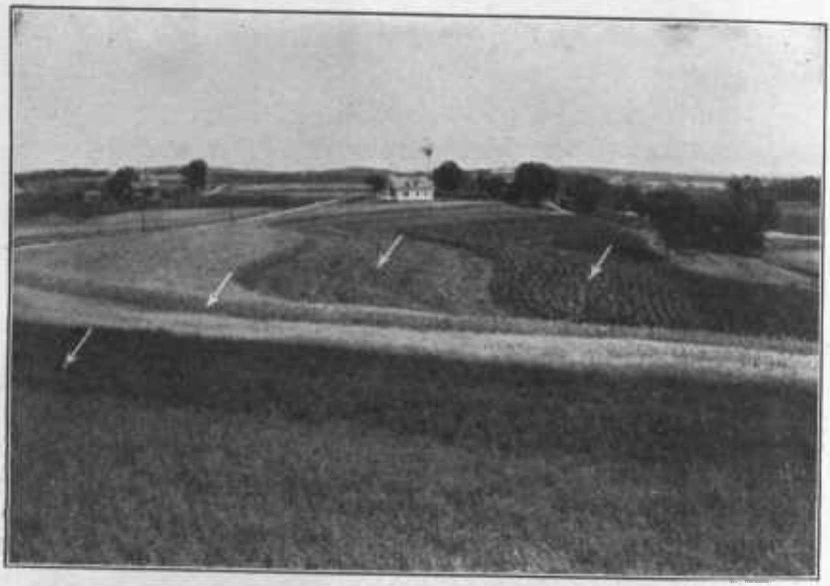
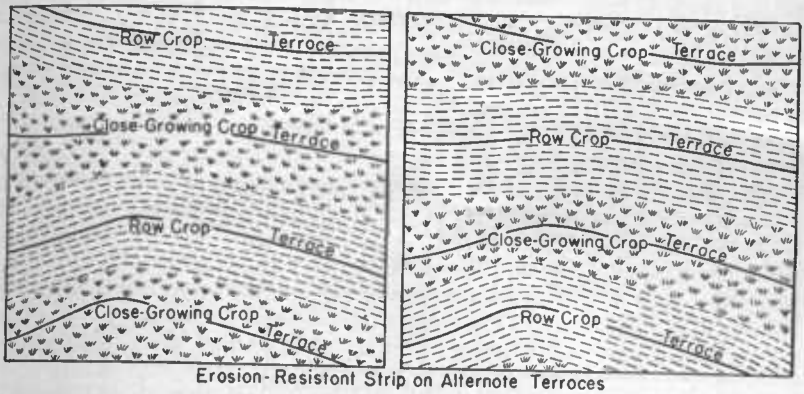
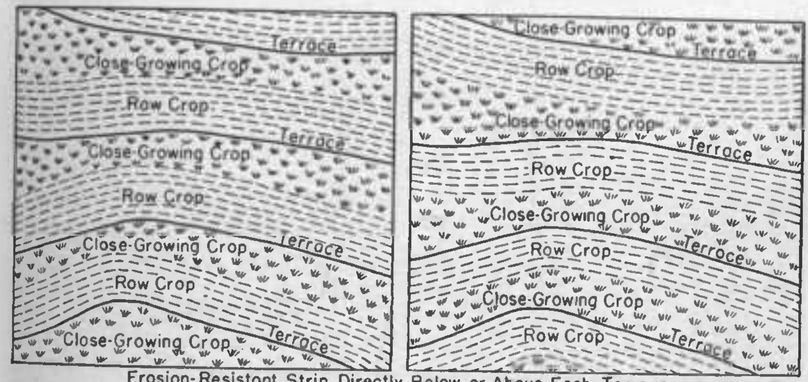


FIGURE 33.—Strip cropping combined with terracing. Adjacent strips are centered on consecutive terraces. The arrows indicate terrace locations.

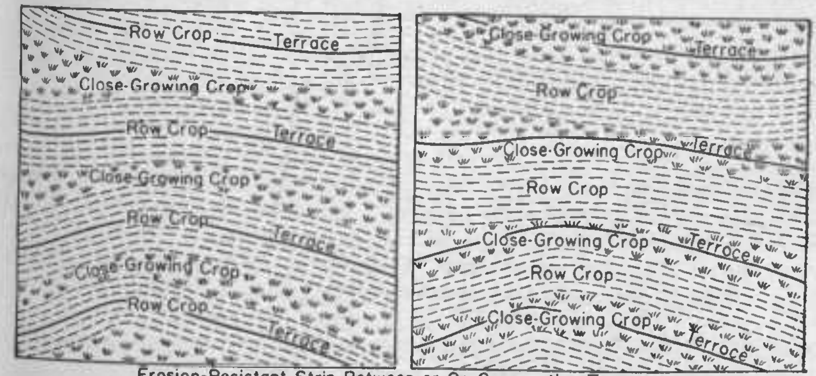
A combination of strip cropping and terracing that provides for close-growing crops on alternate terrace intervals and for row crops on the intervening one merely complicates the tillage and harvesting operations and does not provide any better erosion control than would be effected by terracing and by rotating the same crops in the usual method. The most effective methods of combining terracing and strip cropping are illustrated in figure 34.



Erosion-Resistant Strip on Alternate Terraces



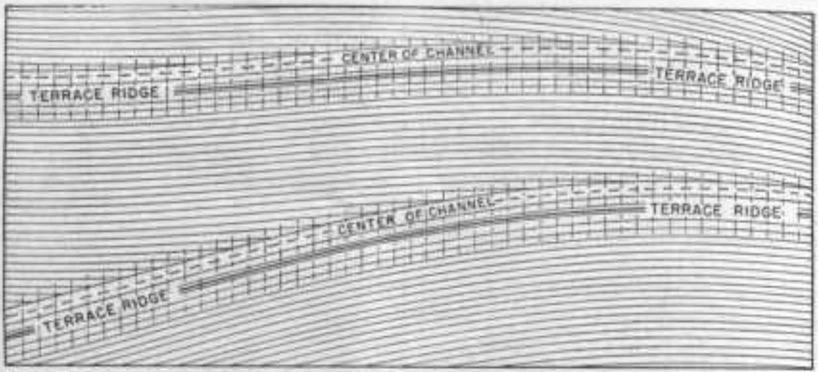
Erosion-Resistant Strip Directly Below or Above Each Terrace



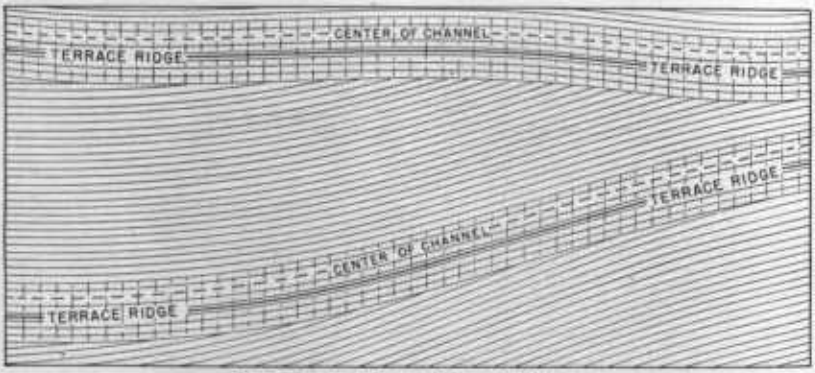
Erosion-Resistant Strip Between or On Consecutive Terraces

FIGURE 34.—Three suggested methods of combining strip cropping and terracing.

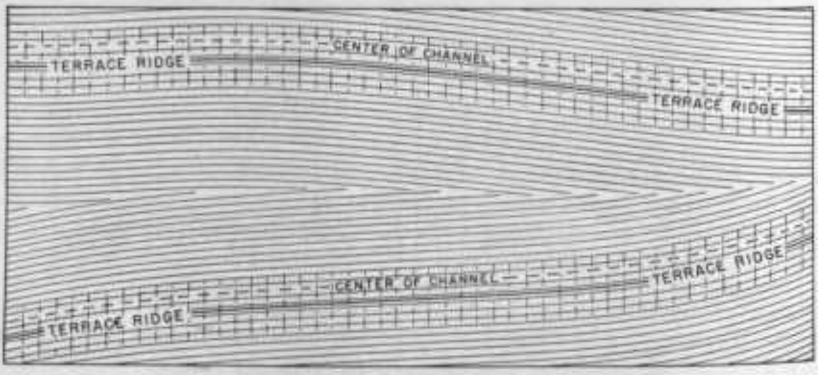
When a field is in contoured row crops it is impossible to avoid short or point rows unless the land slope happens to be very uniform. These point rows may be arranged in many different ways, and the arrangement selected depends largely on the preference of the land operator. His choice may be influenced by such factors as past practice or the type of tillage equipment he uses. Figure 35 indicates three of the more common row arrangements, showing point rows in



Point Rows in Terrace Channel



Point Rows at Base of Terrace Ridge



Point Rows Between Terraces

FIGURE 35.—Three suggested arrangements of point rows in relation to terraces.

the terrace channel, at the base of the terrace ridge, and between terraces.

Many combinations of these arrangements are possible. The relative merits of each will depend largely upon local conditions and individual choice. A combination that appears to have some merit is to run the long rows parallel along alternate terraces and allow the short or point rows to terminate along the intervening terrace. By this method only every other terrace will receive point rows and these will terminate both in the channel and against the ridge. It is contended by some that terminating point rows on the terraces is conducive to erosion because these rows are slightly off the contour and they also tend to concentrate the turning of cultivating machinery on the terraces. This objection can be offset to some extent by always using parallel rows on the area occupied by the terrace and by ending the point rows just above or below this area. The third arrangement suggested in figure 35 throws point rows between terraces and more nearly equalizes the digression of the point rows from the contour.

The Soil Conservation Service demonstration project at Meridian, Miss., has developed a row arrangement (fig. 36) that reduces even more the variation of the point rows from the true contour. One or more master rows are equally spaced between terraces, and the point rows are allowed to fall between the master rows or between the master row and the terrace, according to the row arrangement used. This arrangement of rows requires more field work than any other discussed in this bulletin.

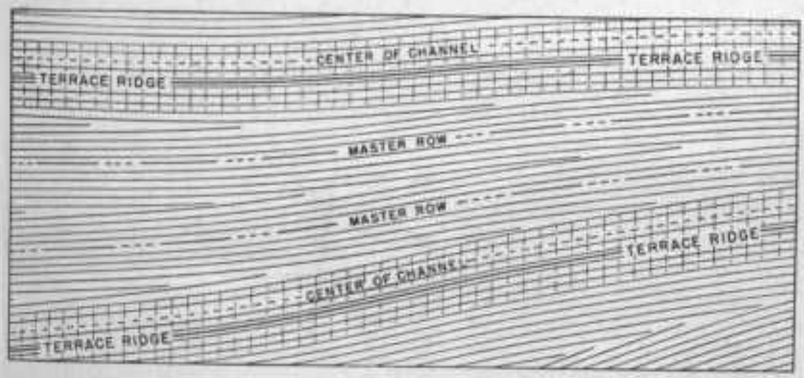


FIGURE 36.—Arranging point rows between master rows on terraced land places all the rows more nearly on the contour than does any of the methods shown in figure 35. This is the most intricate of the four suggested arrangements.

It should again be emphasized that terraces require frequent inspection, particularly during the first year after construction, when the ridges and fills are settling. During this period they should be inspected after each heavy rain. If breaks in the terrace are discovered they should be repaired as soon as possible. If the run-off has concentrated between terraces and washed silt barriers into the channel these should be removed so that the channel will be clear for the next rain. This work can usually be done most conveniently with a shovel at the time of inspection. Ordinarily the most careful inspection is required where the terrace crosses gullies, where bends occur, and at the outlet end.

Some farmers object to terracing because they believe that it will interfere with their regular farming operations. At the same time they usually fail to appreciate the fact that the gullies that are gradually developing on their farms will eventually cause more serious in-

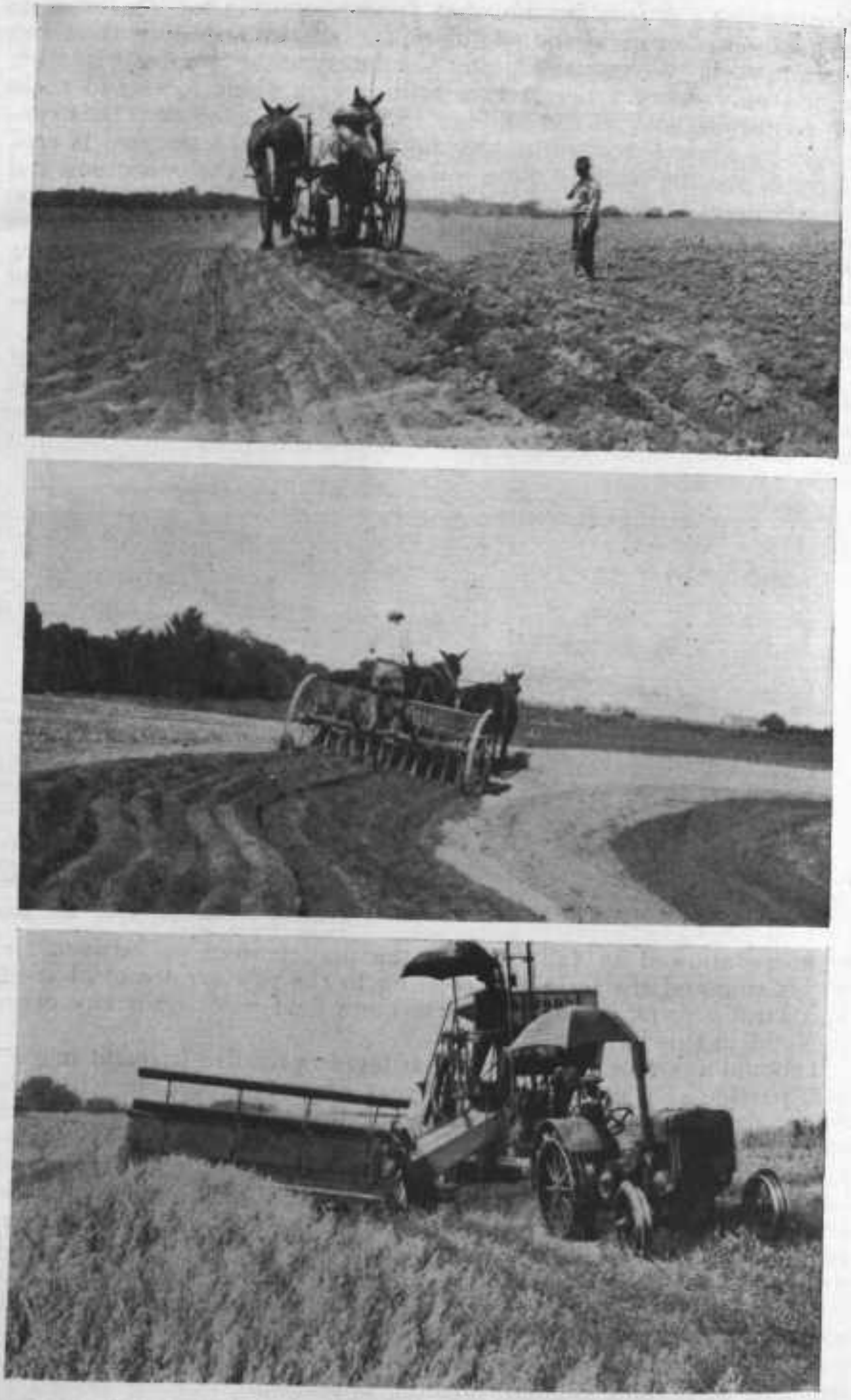


FIGURE 37.—Farm machinery can be satisfactorily operated over terraces if they are properly constructed and if contour tillage is practiced, as shown in the three pictures.

terference with their farming operations than terracing possibly could and that the continual loss of topsoil will eventually make their entire farming operations futile. Farming terraced land is not unduly difficult if the farmer is willing to give up straight rows and try contour farming (fig. 37). Although contour farming introduces minor inconveniences it is usually found that the advantages far outweigh the disadvantages. Farmers have found that even the turning of equipment necessitated by short rows is not nearly as difficult as was anticipated. After the operator becomes accustomed to point rows he can carry on his regular farming operations with very little damage to crops. It has also been found much easier to operate machinery on the contour than up and down hill.

Much more satisfactory results from terracing will be secured if farmers will adopt with regard to their terraces a policy similar to that followed by State highway departments with regard to their highways. Both highways and terraces must have good design and construction features and should be used and maintained according to recommended practices. With proper use and care terraces will ordinarily function for many years.

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