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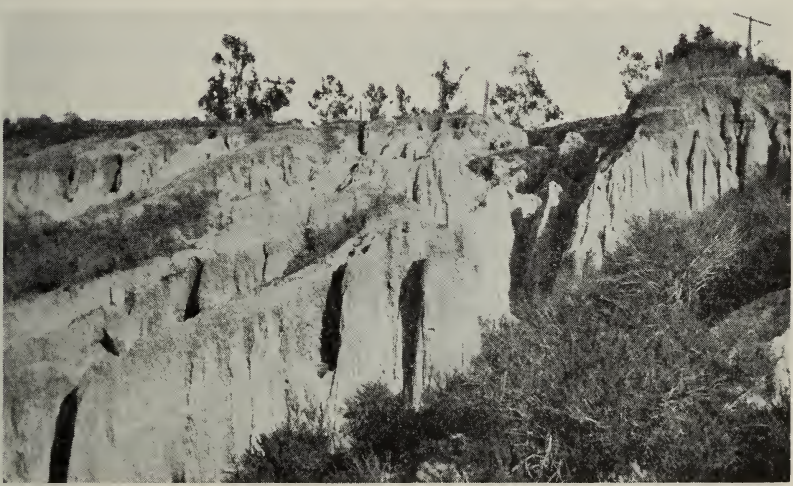
SOIL EROSION IN CALIFORNIA: ITS PREVENTION AND CONTROL

WALTER W. WEIR



The ''bad-land'' type of erosion in Tierra fine sandy loam.

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WALTER W. WEIR[2]

INTRODUCTION

Soil erosion is an active and important agency in the destruction and the depletion of one of the most valuable natural resources. It has, within the last decade, become recognized in America as a problem of national importance and is now attracting the attention of soil scientists and agricultural engineers, as well as the farmers in many sections of the country. The earlier studies on erosion and erosion control in this country were made along the Atlantic coastal plain and Piedmont section of the Appalachian states, but in more recent years this work has extended westward to include most of the Mississippi Valley states, Texas, and Oklahoma.

The 1930 Agricultural Appropriation Bill carried an item of $160,000 for the study of soil erosion problems by the United States Department of Agriculture, either independently or in cooperation with state, county, or farm organizations.[3] To facilitate the carrying out of this project, the country was divided into nineteen regional soil-erosion areas, in each of which may eventually be established a soil-erosion experimental station. Several of these have already been established and are in operation. Southern California is included as one of these regions, but no station has, as yet, been established in this state.

There is an inclination to take a narrow view of the damage done by erosion and to consider only the most obvious results, such as those shown in the frontispiece. The formation of gullies and the damage caused by the deposition of eroded material on cultivated fields (fig. 1), highways, or drainage ways, are truly visible and often spectacular, but may be of less economic importance than some other damages such as those caused by sheet erosion, loss of moisture, loss of fertility, decrease in yield and nutritive value of crops, excessive cost of cultivation, and many other less tangible results (fig. 2).

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[1] Received for publication May 13, 1932.

[2] Associate Drainage Engineer in the Experiment Station.

[3] Ramser, C. E. The federal soil erosion projects. Agr. Engin. 10(9):277–281. 1929.

Fig. 1.—A lemon grove in southern California buried in the debris eroded from a mountain canyon in which the brush cover had been recently destroyed by fire. (Photograph courtesy of W. Metcalf.)

Fig. 2.—The light-colored patches on these hills near Salinas are the result of sheet erosion, the surface soil having been washed away and the infertile subsoil exposed. This soil, the Docas clay loam, does not erode into gullies, but the effects of erosion are shown in decreased yields.

SCOPE AND EXTENT OF EROSION

Bennett and Chapline[4] estimate that each year the streams of the United States carry one and one-half billion tons of solid material into the ocean, and that contained in this is more than 126 billion pounds of plant food material, valued at over two billion dollars. This is more than twenty-six times the amount of plant food used by plants in the

[4] Bennett, H. H., and W. R. Chapline. Soil erosion a national menace. U. S. Dept. Agr. Cir. 33:1–36. 1928.

same period. A very considerable portion of this loss of soil and plant food comes from cultivated lands and pastures. That this loss has been accelerated by the activities of man and his animals on these lands cannot be denied. Although it has long been recognized that such streams as the Mississippi, and especially the Missouri (Big Muddy), carry enormous amounts of silt, and in more recent years that erosion has developed to such a degree in many of the states east of the Mississippi River as to be obvious to the most casual observer, it has not been generally recognized that these conditions exist to a considerable extent

Fig. 3.—Erosion of a freshly plowed field with gentle slopes. This field can be saved if proper measures are taken while the gullies are still small. Note that the first evidences of erosion occurred along the furrows left by a harrow, but as the volume of water increased, it broke out of these furrows and followed a more direct line down the steeper slopes.

over practically the whole country, and that California is in no wise exempt from such destructive agencies.

In its effects upon agricultural and pastoral lands, erosion does not stop with merely removing the upper soil layers and exposing the subsoils over millions of acres, changing vast areas from productive loams and sandy loams to unweathered and unproductive clays (figs. 2 and 3), but goes on to the point of actually destroying these lands by deep channels or gullies (figs. 4 and 5); it wastes not only soil but also water; it not only destroys the land eroded but may also greatly reduce the agricultural value of the land on which the eroded material is deposited; it not only reduces the size and number of plants that can be grown but also diminishes the nutritive value of those which are grown, and at the same time increases the cost of producing them (fig. 6). Investigations indicate that erosion, as accelerated by man's activities, is affecting not less than 75 per cent of all of the cultivated land in the United States and from 75 to 90 per cent of all western range lands.[5]

Fig. 4.—After being cleared of its native brush cover, this hillside produced three or four crops of beans before it became unusable.

Fig. 5.—Before the World War this Ventura County slope produced lima beans. In 1915 the author designed a system of terraces to protect it from erosion, which had then just started, but the terraces were not constructed. The field is now so badly gullied that it can no longer be used for any purpose. The gully running from right to left across the center of the picture is 60 feet deep and 40 feet wide (see fig. 10). The soil is Rincon loam.

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[5] Bennett, H. H. The national program of soil and water conservation. Jour. Amer. Soc. Agron. 23(5):357–371. 1931.

The following editorial in Agricultural Engineering ably expresses the seriousness of erosion:

Erosion is gradually dawning upon the agricultural consciousness of America as one of the major problems. Like a mighty octopus a gully will reach out its tentacles and swallow whole farms with insatiable appetite. Less ostentatious, leech-like, sheet erosion sucks the life blood of agriculture—the top 6 inches of soil. [That these are

Fig. 6.—The dead furrows between tree rows served as collectors of runoff and were washed into deep gullies. Contour cultivation would probably have saved this orchard. The soil is Hames gravelly sandy loam.

Fig. 7.—Uncontrolled erosion has rendered this fertile little Orange County valley unfit for any type of agriculture which requires tillage.

not idle words is well illustrated by the two California scenes shown in figures 6 and 7.] So insidious is its attack that its importance seems to have been discovered only recently by students of erosion. Many a farm has washed and is washing out from under the owner's feet without his being aware of it. Erosion is a world problem, few soils are immune or even highly resistant to it; cultivation stimulates it; even slight slopes encourage it. We might have learned to appreciate and guard against the depredations of erosion from the history of former civilizations. The fact that we have not exemplifies adages to the effect that experience teaches a dear school and that a student for it is born every minute.

Erosion is farm relief with a vengeance. It is rapidly reducing the surplus production capacity of American agriculture. But while it is throwing marginal farms hopelessly below the margin, it is likewise taking its toll from good farms; and when agriculture needs more production capacity it will not be able to bring back the soil and plant food which is now slipping away to the sea.

If the chief capital of its agriculture is only 6 inches thick and is being washed away more than twenty times as fast as it can be renewed by Nature, how long will it take America to wake up and do something about it? Any institution or individual guilty of such gross neglect in the handling of other forms of public trust would be prosecuted. But soil erosion is allowed to continue as if it were strictly a personal matter to each individual landowner.

If a great fire were sweeping the country, doing damage at the rate it is being done by erosion, an army of fighters would be mustered to combat it. But for soil erosion a few scattered sentinels are posted to observe the destruction and give the alarm. . . .[6]

Fig. 8.—It will require heroic measures to bring this once-productive pea land at Arroyo Grande back into tillable condition. Unfortunately, there are many farms in this vicinity which are being destroyed by erosion, and no effort is being made for their protection. The Arnold and Tierra soils in this region have a tendency to erode in this manner.

Soil erosion occurs throughout the entire state of California and can be observed under almost all conditions of rainfall, slope, and soils. Certain areas, however, are more susceptible to erosion than others, and in these areas it has become a problem of major importance. Such an area lies in a strip 20 to 25 miles wide extending along the coast from the vicinity of Paso Robles southward to the International Border. There are many fields in these regions which have become so badly gullied that

[6] Agr. Engin. **10**(9):304. 1929.

they have been abandoned (figs. 4, 5, and 8). Other fields are being cultivated or pastured with ever-decreasing yields, and no doubt will soon be abandoned; still other fields are as yet showing but slight effect from erosion and may, if properly handled, continue to produce satisfactorily. Large areas of grazing land throughout the hill lands of eastern San Luis Obispo County and in the Sierra foothills of the upper San Joaquin Valley also show many evidences of erosion. Certain soils of the coast valleys north of San Francisco Bay are badly eroded (fig. 9) and undoubtedly many areas in the more hilly sections of the state would become seriously eroded if they were cleared and put under cultivation.

Fig. 9.—A terraced prune orchard in Sonoma County badly damaged by erosion because the area above the top terrace was too large. Proper design and adequate maintenance are required by all erosion-control works.

Most of the photographs shown in this paper were taken in cultivated areas and show in a striking manner the way in which erosion is taking its toll of natural resources.

CAUSES OF EROSION

Soil erosion is caused by the action of water moving over the surface of the soil, thereby transporting particles of soil which have been loosened from one place and depositing them in another. The point of deposition, however, may be many miles from the point of acquisition.

The power of moving water to scour or loosen soil particles varies as the square of the velocity, and the power to transport this material varies as the sixth power of the velocity. It is therefore obvious that anything which influences the velocity of moving water also influences its erosive power.

Not all soil erosion is man-induced, nor can that which is so induced be entirely prevented. There is no doubt that the influences of man have very largely contributed to the acceleration of erosion, but his influences may also be profitably directed toward both remedy and prevention. Wherever water runs down hill there will be erosion; otherwise, there would be no alluvial or water-transported soils filling the valleys and providing the most valuable agricultural lands.

Curiously enough, greater effort is made to prevent the deposition of eroded material on other lands than to prevent the erosion itself. It is not an uncommon sight to see levees, dikes, or ditches constructed to prevent overflow on flat lands and for the diversion of silt-laden waters into creeks and rivers. Much less often are measures taken to prevent runoff and its accompanying erosion on the lands which are being depleted of both water and soil. At the present time, therefore, very little benefit can be said to accrue to farmed lands by the building up or accumulation of soil from eroded areas.

Normal erosion may be described as that which takes place under natural undisturbed conditions of soil, rainfall, slope, and vegetative cover, and although certain combinations of these factors may occur which will for a time greatly accelerate this action, it is usually slower and less destructive than erosion to which man's activities have been a contributing factor. As variable as the rate of normal erosion may have been in the past ages, there is ample evidence to show that at the present time erosion has been greatly accelerated through man's influence. Only that erosion for which man is either directly or indirectly responsible need be discussed here, and for only such erosion need remedial or preventive measures be applied.

Vegetative cover is probably the most important factor of all those influencing erosion. The amount and type of vegetative cover is influenced by the amount and distribution of rainfall and by temperature, and this relation is so adjusted that for any particular condition the destructive forces of erosion are balanced by the reconstructive forces which govern the regrowth of vegetation, formation of new soil, etc.

Vegetative cover is susceptible of important modification by man in his attempts to gain a livelihood by tilling the soil or by grazing his flocks. Its removal or alteration by man, or his influences, may be placed in four general categories:

1. Cultivation and preparation of land for agricultural purposes.
2. Pasturing of stock.
3. Lumbering and other nonagricultural land-clearing operations.
4. Fire.

It is obvious that native vegetation cannot be maintained intact on cultivated fields, and that the planted crops must be tilled in order to produce the maximum yield. There may be occasions where the growing crops, as, for instance, hay and grain, are as great a protection to the soil against erosion as the native vegetation, but many times these are not at a growth stage which will afford much relief when most needed. Even with such crops as grain, it is necessary to plow, cultivate, and otherwise disturb the soil so that the previous crop residue is of less value in reducing erosion than it would be on undisturbed soil. Row crops, both annual and perennial, usually require that the soil between rows be free from vegetation and therefore more subject to erosion.

Plants have a three-fold influence as a protection to the soil against the destructive action of running water. The stems, leaves, and branches intercept the rainfall before it touches the soil, thus breaking up the force of its fall and the resulting pounding action which always takes place on bare hard surfaces. Raindrops, therefore, reach the surface of the soil at greatly reduced velocities. Vegetation tends to minimize the concentration of rain water on the surface and its collection into small streams or rivulets. The roots of vegetation hold the soil particles together.

Both living and decaying roots open up the soil and form small passageways into the deeper layers whereby water is more readily absorbed by the soil and allowed to pass into the subsoil. Water which has penetrated into the soil seldom aids in erosion. Therefore, the more water that a soil can absorb and the more rapidly this takes place, the less will be the eroding power of that which remains. If all rain water was absorbed as fast as it falls, there would be no erosion.

The remains of vegetation are in themselves highly absorptive and retain, for a period at least, a considerable part of the water which falls as rain. Cultivation disturbs the natural soil and the interlacing effect of growing and decaying roots, often materially changing the soil structure and very frequently leaving the surface not only without any protection but also actually leaving it in a condition that promotes erosion rather than retards it. When the last cultivation takes place up and down the slope, small channels are left in which water may accumulate and start its eroding action.

When grazing lands are properly pastured, there will always remain sufficient cover to protect the soil from excessive erosion, but when too heavily stocked, the cover is so completely removed that adequate protection no longer exists. When food is scarce, grazing animals are forced to search repeatedly over the same ground for food, thereby not only disturbing the surface soil but also actually cutting up and destroying the roots of grass and other herbage. The action is very similar to cultivation, with the result that erosion may take place before another crop has been established.

Land clearing and lumbering removes the protecting cover from large areas and in some cases may result in serious erosion. This is particularly true where the slopes are steep and where clearing is complete.

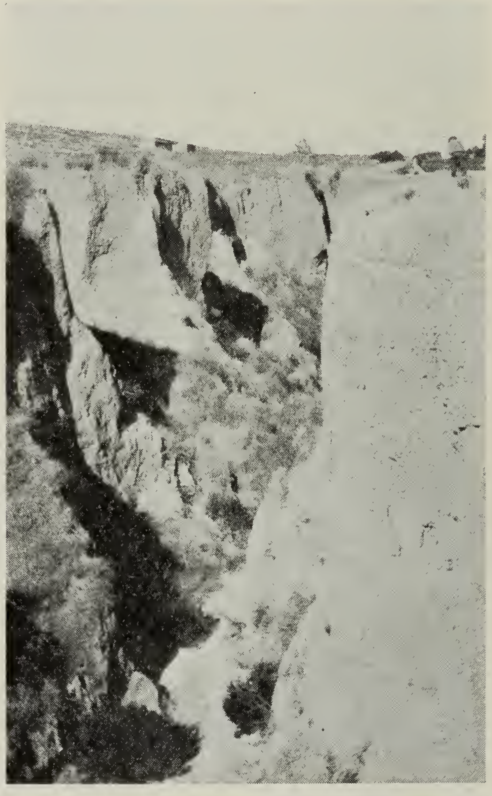

Fig. 10.—This deep gully (note its depth by comparing it with the men on the right bank) was a shallow waste ditch that could be stepped across in 1915 (see fig. 5).

Some hillside residential property has been seriously damaged because the brush and timber have been removed and erosion has been uncontrolled.

Very striking and spectacular examples of erosion often follow fire. Reservoirs have been filled with debris from burned hillsides; roads, bridges, and growing crops have been destroyed by floods coming from burned areas; and the burned lands are often so badly gullied and denuded of surface soil that they remain bare for years as a constant reminder of their destruction and a constant menace to mankind.

EFFECTS OF EROSION

The most obvious effect of erosion is the formation of gullies. The photographs accompanying this paper show many examples of gullying. Some of these are so deep and wide that the destruction of the land is complete, and nothing can be done to restore it to productiveness (see frontispiece and figs. 5 and 10).

Fig. 11.—Less than half an hour's rain on August 29, 1931, caused this wash through a citrus grove at Riverside. The damage was repaired, but it might have been prevented. The soil, Ramona loam, is subject to this type of washing under conditions such as existed here.

Fig. 12.—Close-up view of the effects of erosion on newly plowed orchard land at Paso Robles. About one-third of the surface 3 inches was removed by a single rain in February, 1931. Contour planting or terracing would have prevented this loss. The Linne soils erode in this manner on unprotected steep slopes.

In other places the gullies are smaller and may be in part restored by check dams and settling basins. Few of these gullies have been formed for long periods, and most of them are of comparatively recent origin (figs. 5, 11, and 15).

There is no fixed difference between what is termed "sheet erosion" and "gullying." It is rather a matter of degree of destruction or the size of the gullies. Usually when the gullies are shallow enough to be

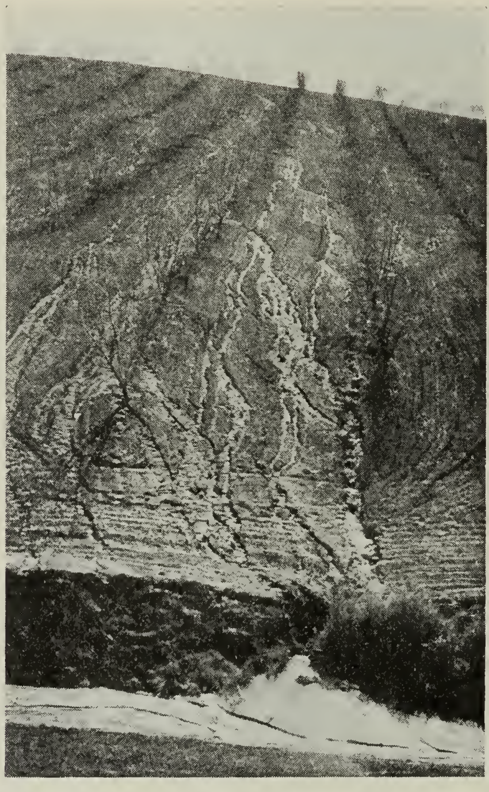

Fig. 13.—This almond orchard on Linne soils near Paso Robles was cultivated up and down the slope with the result that it was an easy victim to erosion when a severe rain occurred. About one-fourth of the surface soil to the full depth of plowing was lost in one storm. (Picture taken in 1926 by C. F. Shaw.)

crossed by cultivating tools and can be filled in by cultivation, the erosion is considered as sheet erosion (fig. 12). This type may be almost, if not entirely, as destructive as the former, and when fields become so poor as to be abandoned or neglected, deep gullying usually follows. Figures 13 and 14 illustrate this point. The cultivation of fields cut up into irregular shapes, as illustrated by figure 15, is difficult and expensive, and in such a condition protection will probably cost more than the land is worth.

Fields from which as much as an inch of soil is washed away annually are not uncommon in some of the pea-growing areas of San Luis Obispo County. This condition is readily observed during the early

Fig. 14.—This photograph of the same orchard as shown in figure 13 was taken in 1931. The land has been entirely abandoned, for the gullies are now 4 to 6 feet in depth.

Fig. 15.—The winter-pea industry around Arroyo Grande is threatened with serious losses unless some measures are taken to prevent soil erosion. This field, although not yet totally destroyed, has been badly damaged by gullying. This has all occurred within the present decade. Because of the meandering gullies, the remaining areas are difficult to cultivate, and reclamation will be costly.

spring and has resulted in a material reduction in yield. Abandoned fields are numerous (figs. 4, 8, and 14). During the rainy season, the fields and orchards of this section are cultivated after each storm and the small gullies which have been formed are filled in with loose material only to be washed away again by the next rain. Frequently the material eroded from one field is deposited on another, thus spreading the destruction to two areas (figs. 1 and 16). It usually takes considerable time for newly deposited soil material to become sufficiently incorporated with the underlying soil and to become good fertile land.

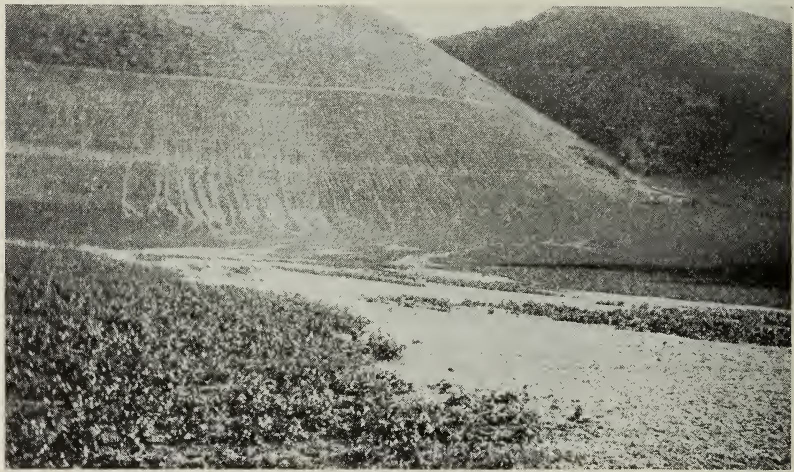

Fig. 16.—The cultivation of very steep slopes is always followed by some loss in surface soil and in cases such as this one at Pismo Beach should not have been attempted. The steep hill has been destroyed by gullying and the flat land seriously damaged by the debris. The soil in the foreground is Lockwood gravelly sandy loam, dark-colored phase, and the eroded hillside is Zaca gravelly clay adobe.

Overgrazing of pasture lands is an important factor in the erosion of untilled areas (fig. 17). As has already been stated, the relation of cover to rainfall is very delicately adjusted and even in those areas where the rainfall is scanty the grass cover is sufficient to protect the lands on which it grows from excessive erosion. Any major disturbance in one factor of this relation is likely to increase the influence of the other factor to the point where it may become destructive. Obviously, the amount and distribution of rainfall or the topography of the landscape is not altered by the presence of foraging animals, but the amount of grass and brush which is permitted to grow and protect these areas from erosion can be very materially affected. After the removal of the surface soil by erosion, it has been shown that the ability of the soil to restore vegetative cover is greatly reduced and that frequently undesirable species of grass or brush are allowed to become dominant.[7]

Fig. 17.—The removal of all vegetation by overgrazing is causing thousands of acres of pasture land to be destroyed by erosion in the foothills of the southern San Joaquin Valley.

Fig. 18.—Gully erosion resulting from fire which destroyed the soil-holding vegetation. (Photograph courtesy of United States Forest Service.)

[7] Sampson, A. W. Relation of erosion to soil productivity. Agr. Engin. 12(4): 114–116. 1931.

Sinclair, J. D., and A. W. Sampson. Establishment and succession of vegetation on different soil horizons. Hilgardia 5:155–175. 1931.

The type of cover which follows the erosion of pasture lands may be of such low nutritive value as to be reflected in the stock grazing on these lands; symptoms of malnutrition can be directly traced to erosion caused by uncontrolled grazing.[8] That the products from eroded lands used for human consumption may be lacking in essential elements for normal growth and development may not be beyond a reasonable possibility.

Fire, especially that for which man is responsible, is probably the most inexcusable of the vegetation-destroying elements. Improper cultivation, overgrazing, and similar activities may in part be justified, at least temporarily, by economic considerations, but seldom can this be said of fire. Fire may so completely destroy the cover that disastrous erosion immediately follows (figs. 18 and 19). A very striking example

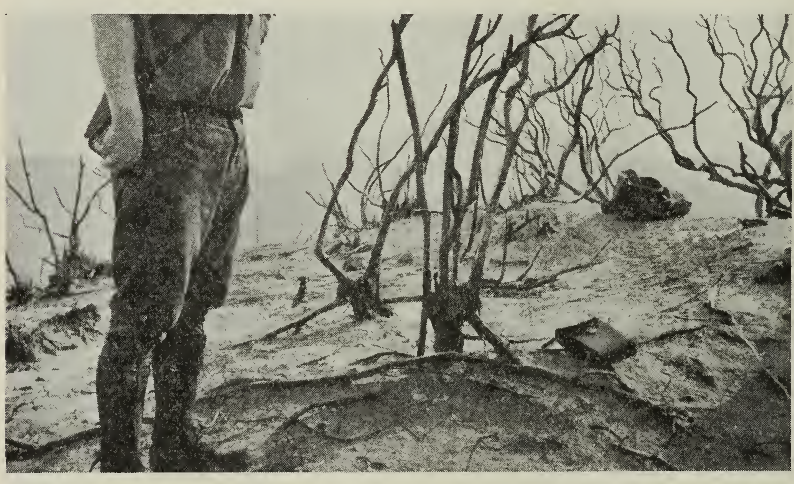

Fig. 19.—Water and wind erosion has removed all the humus-bearing surface soil from this burned-over brush area, as shown by the exposed roots and crowns. (Photograph courtesy of United States Forest Service.)

of erosion after fire occurred during the early spring of 1931 in the vicinity of Moorpark in Ventura County. Portions of this tract were so badly dissected by deep gullies that it has no further use as either pasture or timber land, and the damage caused by the deposit of eroded material on highways and cultivated fields amounted to several thousand dollars.

The serious erosion which usually follows the denudation of large areas by smelter fumes is well known. The vegetation, consisting largely of timber, was destroyed from about 100 square miles of mountain land in Shasta County as the result of fumes from the smelter at Kennett

[8] Hart, G. H., and H. R. Guilbert. Factors influencing percentage calf crop in range herds. California Agr. Exp. Sta. Bul. 458:1–43. 1928.

(fig. 20). Vegetation is so completely destroyed by this chemical action that many years elapse before it is restored. During the time when the area is without protection, erosion may be very serious and result in so depleting the fertility that only inferior types of cover succeed in establishing themselves.

The increase in surface runoff as the result of surface erosion is a serious matter in California, where the conservation of water is so essential to crop production. On irrigated areas the deficiencies in moisture may be supplemented by artificial applications of water, but in many sections irrigation is not available. In these sections water lost by surface runoff represents a positive decrease in the amount of moisture later available for plant growth. The season of available soil moisture

Fig. 20.—About 100 square miles of timber-covered mountains in Shasta County were completely denuded of cover by smelter fumes. These areas are now badly eroded and most of the surface soil has been lost.

may therefore be lengthened in direct proportion to the amount of water that can be saved from runoff. If there were no other reason for the prevention of soil erosion than moisture conservation, the effort would be fully justified in this state. A single example will indicate the benefits of the additional moisture. At the Spur Erosion Experiment Station in Texas[9] a field which was terraced so as to retain the entire rainfall produced on two successive years 169 pounds and 233 pounds of seed cotton per acre (28 and 66 per cent respectively) more than the average of four similar fields which although terraced, lost a portion of the rainfall by runoff.

[9] Conner, A. B., R. E. Dickson, and D. Scoates. Factors influencing runoff and soil erosion. Texas Agr. Exp. Sta. Bul. 411:1–50. 1930.

At Riverside in 1930 the season's rainfall was 12.69 inches, and 28 per cent of it was lost by surface runoff. When one takes into consideration that rainfalls of less than 0.2 inch in any storm are usually lost by evaporation and are therefore practically negligible in supplying moisture for plant growth, the amount of water lost by runoff from heavier storms is even more significant. In some seasons as much as 30 to 40 per cent of the rainfall occurs in such relatively ineffective light showers. Fifty per cent or more of the rainfall in some heavy storms is lost in runoff. In August, 1931, 1.37 inches of rain fell in less than half an hour at the Citrus Experiment Station in Riverside and, although the soil was dry at the beginning of the rain, the runoff probably greatly exceeded 50 per cent except in places where there was a heavy growth of covercrop. No serious damage resulted from this storm except on bare cultivated fields, where erosion was very destructive (see fig. 11).

Although no measurements have been made in San Luis Obispo and Santa Barbara counties, it is evident from the amount of soil which is lost that the runoff must be a large proportion of the rainfall for storms exceeding 1 inch in 24 hours. The retention of this water in the soil would in itself add materially to the crop growth and yields in this region. Precipitations in excess of 2½ inches in 24 hours occur on an average of about once a year at San Luis Obispo, and downpours exceeding 7 inches in 24 hours have been recorded there. It is not expected that all of the rainfall can be retained or that erosion can be entirely prevented on steep cultivated fields during such excessive storms as have just been mentioned. It is, however, highly desirable that such protection as is economically feasible be undertaken.

EXPERIMENTS RELATING TO EROSION

The amount, distribution, and intensity of rainfall vary greatly from place to place, and there is probably no part of the country in which so great a variation occurs as in California. McGee[10] estimates that about one-third of the total rainfall flows from the surface of the earth as surface runoff and the remainder enters the soil, replenishing that which has previously evaporated or been transpired through plants. It has already been shown that these figures may be greatly exceeded in many instances. Veihmeyer[11] has shown that the losses by evaporation are insignificant when compared with transpiration, and that except for the immediate surface, evaporation losses are exceedingly

[10] McGee, W. J. Soil erosion. U. S. Dept. Agr. Bur. Soils Bul. 71:1–60. 1911.

[11] Veihmeyer, F. J. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia 2(6):125–291. 1927.

small even where there is no vegetative cover. This means then that vegetation must be depended upon as the principal agency in reducing the moisture content of soils to such a point that they will absorb rainfall. Without vegetative cover a much greater portion of the rainfall will be lost by surface runoff than would normally occur. That such a condition actually occurs is readily observable from even a superficial comparison of forested or brush-covered areas with bare areas.

The most important function of plants in relation to erosion control is not the drying out of the soil through transpiration, important as that is, but rather it is the mechanical obstructions which plants and plant remains offer to the free movement of water over the surface of the soil. Lowdermilk[12] has found that the humus resulting from plant remains is also effective in keeping the soil open and receptive of moisture by preventing the coating or sealing of the surface with fine-grained particles. By retarding the velocity of moving water and preventing or hindering its concentration, plants make it possible for more water to be absorbed by the soil. Recent unpublished work by the Bureau of Agricultural Engineering, United States Department of Agriculture, has shown that more than twice as much water will be absorbed by soils covered with undisturbed native vegetation as by soils which have been disturbed by cultivation and are bare of growing crops.

Erosion, or the carrying away of material by moving water, is governed by the amount of water, the slope of the land, and the obstacles which are placed in the way of its free movement. These three factors are interdependent and the control of any one of them affects the other two.

As rain falls upon the surface of a field the moisture is absorbed by the soil and penetrates below the surface. If the moisture falls slowly, this process may continue for considerable time, but if the rain falls more rapidly than it can be absorbed, the surface soil quickly becomes saturated, and the excess remains on the surface as free water. If the surface is level or is roughened by cultivation or organic debris, this water lies more or less stationary until it has had time to be absorbed, but if the sufrace is smooth and sloping, it begins to move down the slope. At first this movement is slight, but with increasing supply of water it soon gathers into tiny streams. Once this is started, the coalescing streams grow in magnitude and swiftness and eroding power as they proceed down hill.

As soon as these streams become large enough to pick up and carry soil particles of any considerable size, they begin to entrench themselves

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[12] Lowdermilk, W. C. Unpublished work on factors affecting surficial runoff of rainfall and surface erosion of soil profiles.

in the spaces from which the soil they carry was just removed. Entrenchment means further concentration and increased destructive power, which continues until some intervening factor develops. The intervening factor may be a change in slope which will decrease velocity, a natural or artificial obstruction or barrier which will break up the stream, or a cessation in the rain or water supply. The erosive power of clear, moving water varies as the square of the velocity, but the power to transport eroded material is much greater; furthermore, the erosive power of water carrying suspended material is directly in proportion to the amount of suspended material. It is obvious that the carrying capacity and the size of particles which may be carried is a function of the volume of the water as well as its velocity.

According to Bennett and Chapline[13] soils high in silt, light-textured soils overlying less-absorptive heavier types, clays that undergo marked granulation and fragmentation on drying, and those low in organic matter are most susceptible to rapid denudation by sheet erosion. Soils having unstable subsoils of sandy material are more subject to gully erosion than those having permeable subsoils of silty clay or clay loam. Soils with impervious sublayers are far more erosive than those with permeable substrata unless the substrata are very unstable. Studies on soils subject to severe erosion in California bear out these conclusions and indicate that light-textured sandy soils having relatively impervious heavy clay subsoils are most easily eroded, especially when the surface soils are of shallow depth. On the other hand, soils having uniform textures throughout a considerable depth of profile are, other things such as slope, rainfall, cover, and tilth being similar, less subject to erosion than those having a dissimilar surface and subsoil. Soils which are heavy textured are generally least subject to erosion, except where their heavy texture is due to the fact that a lighter-textured surface soil has already been eroded away and the present uppermost layers are in reality exposed subsoils. In the latter case the chemical composition, lack of humus, and the structure and consistence of the clay may be such as to offer little resistance to erosion.

Every soil so far examined in this state that is subject to severe erosion has been found to have surface soils ranging from decidedly acid to neutral and in many cases the subsoils are acid. Apparently those which are most acid in both surface and subsoil are most severely eroded. This is probably due to the fact that soils containing lime (basic) are flocculated, while those lacking in lime (acid) are deflocculated, and the degree of deflocculation is a measure of the acidity of

[13] Bennett, H. H., and W. R. Chapline. Soil erosion a national menace. U. S. Dept. Agr. Cir. 33:1–36 1928.

the soil. Just what practical value these findings may have and how this information may be used in connection with plans for relief from erosion have not yet been determined.

Middleton[14] has done some work in an attempt to determine wherein those soils which most easily erode differ both chemically and physically from others which do not, but his work has not yet been carried far enough to establish an altogether satisfactory method of measuring the relation between these factors and susceptibility to erosion. Several of the more erosive soils in California are mentioned in the captions to the illustrations in this paper.

EROSION PREVENTION AND CONTROL

So much has been said regarding the importance of cover as a protection against erosion that the impression may be gained that the maintenance of cover is the only remedy. Although cover is Nature's way of preventing excessive erosion, and it might be wise for man to follow this lead wherever practical, it cannot always be done. Many crops require that all vegetation except the crop itself be removed. It is therefore necessary to resort to other methods of prevention.

Only those remedial measures applicable to agricultural land and the production of crops will be discussed. Although it is true that most of the means of erosion prevention discussed herein have not been extensively employed in California, there is ample reason to believe that they are suited to California conditions. The practical treatment of soil erosion involves prevention, control, and remedy, and, like the treatment of disease in the animal and vegetable kingdom, an ounce of prevention is worth a pound of cure. The key to the treatment, whether prevention or cure, is the same, namely, the maintenance of a proper balance between slope, cover, soil, and water.

Erosion prevention and control is a new undertaking for most California farmers; however, the fundamental principles involved are not new, and for many it will be only a new application of these principles.

Erosion prevention and control will be discussed briefly under three general topics—tillage, both as a separate means of control and in conjunction with other methods; terracing; and check or soil-saving dams. The various steps to be taken in each case will not be described in great detail for much must necessarily be left to the judgment of the farmer as to what will be best for his particular needs. It is hoped that those who are interested in erosion control will consult the references listed at the end of this paper for greater detail than is given here.

[14] Middleton, H. E. Properties of soils which influence soil erosion. U. S. Dept. Agr. Tech. Bul. 178:1–16. 1930.

Contour Cultivation for Annual Crops.—Modifications in tillage practice appear to offer the greatest benefit for the least expenditure, and regardless of whatever else might be done to prevent erosion, tillage must be made a part of the scheme. One of the simplest preventives is contour cultivation, but when used as the only means of erosion prevention should be confined to slopes of less than 20 feet per hundred. Many hillsides are plowed and harrowed with the furrow running up and down hill, leaving the surface in a condition most susceptible to erosion. Figures 3, 6, 12, and 13 show in a striking way the result of this type of improper cultivation. Sloping land, which is subject to erosion, should never be cultivated *with* the slope but always *across* it. Simply cultivating at approximately right angles to the greatest slope is not sufficient, because there are very few slopes so uniform that there will be no places unprotected if cultivation is done in this way. In figure 3 may be seen the effect of cultivation of this type.

With contour cultivation, strip planting, or terracing, the first step is to lay out the lines in the field and the procedure is similar in each case. The contour interval or vertical distance between lines is determined by observing the distance below the highest point of the field at which erosion becomes apparent. This indicates the distance through which water must travel under the conditions of slope, rainfall, and soil at hand before it has attained sufficient velocity and volume to erode, and can be used as a safe approximation of the proper interval. For steep slopes the vertical distance between contours can be somewhat greater than on flat slopes because for a given vertical distance there is less horizontal distance and less area on which to accumulate water. For example, on slopes of 15 to 20 feet per 100 the contour interval may be as great as 10 to 12 feet, while on slopes of 5 to 10 feet per 100 the interval should be 4 to 6 feet. These figures should not be taken as definite recommendations for all conditions and types of soil and climate; they may require material modification to meet the needs of any particular tract of land.

When the proper contour or terrace interval (vertical distance between succeeding lines) has been determined, lines this distance apart should be surveyed and staked out. For example, if 5 feet has been determined as the proper interval between contours or terraces, as the case may be, in a certain field, then lines should be staked out having 5 feet as the difference in elevation between them. These should not be level lines, but should be given a slight fall toward one or both sides of the field. For lines 1,000 feet or more in length the fall at the upper end should be about 2 inches per 100 feet, increasing gradually to about

5 inches per 100 feet. For lines less than 500 feet in length, the fall may be uniform at about 3 or 4 inches per 100 feet. Short distances are more desirable; long runs should be avoided whenever outlets are available for shorter ones.

After the line is staked out, a plow furrow should follow the line of stakes, throwing the furrow slice up against the stakes. The return furrow should be thrown against the stakes on the next lower line. The plowing then continues between these two lines until the entire strip is plowed. The dead furrow in the center should be opened at the ends to permit free drainage. This strip is thereafter a unit for all field operations such as plowing, cultivation, planting, irrigation, and harvesting, all of which should be done parallel to the contour. If this is done and no cross cultivation permitted, it will not be necessary to resurvey the area each year; the old furrows can be followed instead. After two or three cultivations these furrows can be followed without difficulty.

Row crops should be planted in strips with the first row on the ridge or back-furrow and the succeeding rows, as far as the dead-furrow, parallel to it. This results in a field of crooked rows and usually either short or stub rows near the center of the strip, but since slopes are seldom uniform and therefore contour lines are not parallel, this objection cannot be avoided. Long rows should be avoided. About 1,500 feet should be the maximum length of row and there will be much less danger of water breaking away and running down the steepest slope if rows are restricted to 1,000 feet or less.

Provision must be made for removing excess water from the ends of the rows. This can be done by ending the rows along some predetermined line where the water is collected in a ditch or pipe line and carried down the slope. Considerable care must be used in providing outlets for this water because it may cause serious damage if left uncontrolled. Only a few suggestions can be given as to how this should be done; other methods may need to be devised if none of these may seem to fit the particular needs at hand. The water may be turned into a gully, if one is available, lined with rock (see fig. 21) or concrete, or thickly grown up to weeds and grass; or it may be turned into an adjoining uncultivated field and allowed to spread out over a large area. Usually such areas are themselves already saturated and incapable of absorbing additional water so that gullying may occur there. Another method is to collect the excess water in tile lines which run directly down the slope, the water being admitted to the line through a riser located in each dead-furrow or terrace end. Figure 30 shows such a riser used in connection with an orchard terrace outlet.

Contour cultivation such as has been described, as well as that in connection with terracing, to be described later, may mean a very decided change in cultural procedure from that in common use in the region. It may preclude the use of certain heavy machinery which cannot be readily turned in short rows and narrow strips, but modifications in farm equipment and even major changes in cultural procedure can be made and are of minor importance when compared with the saving of the soil from possible permanent injury.

Strip Cropping.—Another device sometimes used in connection with contour cultivation is "strip cropping."[15] Strip cropping consists of planting strips of densely growing or fibrous-rooted crops between strips or rows of clean-tilled crops. This method, although often highly

Fig. 21.—A slight depression which was deepened and lined with rock is here used as an outlet for terraced land. The terraces slope toward this outlet from both sides.

effective in preventing erosion, should be considered as a temporary relief until means are provided for installing more permanent protection such as terraces.

The methods of laying out the strips is similar in every essential to that of laying out fields for contour planting or terracing. A strip 10 to 20 feet wide of some densely growing crop is planted on the site of the proposed terrace or along the contour line. In California, where the damage from erosion occurs during the winter, the crop must be one which can be planted late in the fall and which will grow rapidly into a dense mass. Some of the vetches that are extensively used for cover-crops in various parts of the state should prove satisfactory. In irrigated

[15] Geib, H. V. Strip cropping to prevent erosion. U. S. Dept. Agr. Leaflet 85:1–6. 1931.

areas alfalfa would be an excellent crop for the strips. Figure 22 shows an attempt to overcome erosion by allowing strips of grass to remain in the tree row.

Erosion Protection in Established Orchards.—Contour tillage on established hillside orchards which have been planted on the square or triangular system offers a rather difficult problem. If the trees are small, far apart, and trimmed so that cultivation can be carried on close to the trunks, it is possible to lay out contours which can be fairly closely followed by crossing from one tree row to another, and after two or three repetitions a sort of low terrace will be built up which can be easily followed in future operations; but if the trees are large or closely planted, contour cultivation may not be feasible.

Fig. 22.—Strips of untilled grass-covered areas in the tree rows are sometimes effective in preventing erosion where terraces are not used. Continued use of this method with no cross cultivation will result in the formation of terraces. From the standpoint of conserving moisture for the use of the trees, it probably would have been better if the grass strips had been left between the tree rows rather than in them.

If particular care is used in providing outlets for water which concentrates in low places cultivation in the tree rows most nearly at right angles to the greatest slope will often aid materially in erosion control. If such cultivation is accompanied by a modified strip cropping even greater benefit will be derived.

Probably the best type of erosion protection for a square or triangular-planted hillside orchard is a dense covercrop. To be most efficient, it should be planted early and not plowed under until after the heavy rains are past. It is, of course, impossible to determine in advance when the rainy season will be over, and many farmers are unwilling to take chances on allowing the covercrop to remain too late.

On land which can be irrigated, it is not a serious matter to leave cover-crops standing until after the major part of the rainy season is past, but in nonirrigated areas this cannot be done without the sacrifice of considerable moisture which should be reserved for tree growth. Loss of moisture, however, even where there is no irrigation, is far less serious than loss of soil by erosion, for the soil cannot be replaced.

Table 1 indicates that considerable rain can be expected during March, and therefore plowing under a covercrop in February or early March may be too early to prevent erosion.

TABLE 1

AVERAGE MONTHLY RAINFALL IN INCHES FOR THE SIX WETTEST MONTHS, AT VARIOUS POINTS IN CALIFORNIA

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total for Year
San Luis Obispo	1.67	3.68	4.99	3.66	3.78	1.52	20.92
Los Angeles	1.19	2.66	3.00	3.02	2.75	1.05	16.00
Santa Barbara	1.48	3.25	4.18	3.35	2.98	1.18	18.23
Santa Maria	1.35	2.08	3.10	2.50	2.89	0.86	14.54
Ventura	1.28	2.37	4.03	3.36	2.86	0.73	16.02
Eureka	5.80	6.89	7.89	7.52	6.93	3.58	46.24
Santa Rosa	3.26	5.61	6.85	5.22	5.11	1.64	32.08
Napa	2.49	4.15	5.14	3.98	3.70	1.91	24.32
Poway	1.22	1.88	3.19	2.64	2.65	1.13	13.79

Tile Underdrainage.—Tile underdrainage has been effectively used to prevent erosion on certain types of soil. Soils with pervious, easily, penetrated surfaces, underlain at a few feet in depth by impervious subsoils, respond to tile drainage better than soils having more impervious surfaces. Tile are laid just above the impervious layer in lines running across the slope. The drains intercept the water as it moves along the impervious layer and carry it away before it has accumulated in sufficient quantity to cause the whole area to slide. The principles of this type of drainage are the same as those ordinarily used for intercepting drains, and the same care should be used in their design and installation. Tile drains in combination with terraces are frequently used.

There are undoubtedly some places where the methods so far suggested are not feasible with the crops that are now being grown. In such cases it might be better to change the agriculture of the section entirely by growing new and different crops which can be grown in such a way as to save the soil. To use a single example as illustrative of this point—and there are many similar examples in California—unless some method of tillage or some soil-saving device not now used is put into common practice to lessen the erosion on the garden-pea lands around Arroyo Grande, it will not be long before these hills are so seriously depleted of surface soil and fertility and so badly gullied as to be useless for any tilled crop.

It would be better to restore these areas to native brush and grass than to continue present methods of cultivation. The idea of restoring land to its native cover is not entirely new; there are a few places, particularly in Ventura County, where land that has been in beans or other annual crop has been restored to pasture with no cultivation other than that which is occasionally necessary to destroy obnoxious weeds. Unfortunately, cultivated crops were not given up on these areas until a part of their usefulness had been destroyed by erosion, so that the restoration of a desirable type of native cover may be rather slow. It is not safe to assume that land which has become unproductive for cultivated crops can be easily and rapidly restored to a pasture crop equal in value to the original native cover.

Terraces.—The terrace offers the best type of erosion protection yet devised for use on tilled land. It provides more complete protection than other methods and is adaptable to a wide range in slope, type of soil, and rainfall.

Terraces may be separated into two general groups, the bench terrace and the ridge terrace, and although there are some terraces which have characteristics common to both groups, each has a particular field for which it is best suited. The bench terrace, or as it is often called, the "true" terrace, is best adapted to steep slopes and produces a field resembling a series of stairsteps. All terraces may either be level or slope in the direction of the terrace. The sloping terrace is the more common and where irrigation is practiced is a necessity.

Bench Terraces.—The bench terrace has been highly developed in portions of central and southern Europe and in the Orient, and in southern California it is popular for steep hillside orange, lemon, and avocado groves.

As used in this state, the flat or tillable part of the terrace may slope with the general trend of the field (fig. 23) or be level (fig. 24) in the direction at right angles to its length. Trees are usually planted near the outer edge and cultivation takes place only on the upper side of the tree. The outer slope or riser is often allowed to grow up with grass or weeds during most of the season as shown in figure 26. Sometimes during the dry season this cover is removed by hoeing. There are some bench terraces in Ventura County in which the riser is planted to ice plant

(*Mesembryanthemum roseum*). This makes an excellent cover, prevents the growth of undesirable weeds, and renders the bank practically immune from washing (fig. 24).

Fig. 23.—Young avocados in San Diego County planted on a modified bench terrace. Only a portion of the inter-row space is cultivated, there being a long sloping riser between terraces. Note that the trees are planted near the edge of the terrace. As they become larger they will probably receive no cultivation other than that which can be done by hand and is required for the distribution of irrigation water.

Fig. 24.—Lemons on bench terraces in Ventura County. Note the short steep risers and flat treads in contrast with those shown in figure 23. The risers are permanently covered with ice plant and the treads are producing a green-manure covercrop.

A good contour map of the area to be terraced, although not absolutely essential, is a great aid in planning both bench and ridge terraces, especially if the area is to be planted to orchards. Although it is not always possible to lay out terraces on a map and later accurately follow this location in the field, the map gives one a bird's-eye view of the entire scheme such as is often very difficult to obtain otherwise.

The vertical distance between terraces in orchard land is determined more by the desired horizontal spacing between tree rows than by slope of the land. Each tree row is on a separate terrace. About 20 feet is considered the most ideal row spacing for citrus trees in southern California, but of course uniform spacing is impossible when contour or terrace planting is used. Terraces, measured between outside edges, may be spaced 20 feet apart along some line having the average slope of the field. Where the slope is steeper the terraces become closer together, and where it is flatter the terraces are farther apart. Only one row of trees is planted on a terrace. When terraces get closer together than

Fig. 25.—Young avocado grove in San Diego planted by the contour method. It is not terraced and has received some cross cultivation.

about 12 or 14 feet, they are usually discontinued, forming stub rows, and when they become farther apart than about 33 to 35 feet another terrace is inserted, called a fill row. In irrigated orchards it is considered more difficult to irrigate added or fill rows (rows which "point in") than to irrigate stub rows (rows which "point out"). For this reason the best practice is to locate the pipeline carrying the irrigation supply up the center of the flattest slope, using this line also as the center or beginning of the terraces. The terraces usually slope both ways from this point. This then makes it possible to have the greatest number of terraces starting at the point where they can be most easily irrigated. This type of planting causes the lower ends of the terraces to be in the hollows rather than on the ridges.

In contour-planted orchards, with or without terraces, the common practice is to so space the trees in the rows that the cross rows are straight. The only advantage of this is to give such orchards the appearance of being planted in straight rows when viewed from the roads and highways.

Huberty and Brown[16] have described in considerable detail methods of laying out orchards for irrigation by contour furrows, and the reader is referred to their circular for this information. Figure 25 shows an avocado grove which is contour-planted without the use of terraces. This type of planting is suitable only to relatively flat slopes.

Fig. 26.—Bench terraces near Greenfield. No erosion has occurred on this rather steep slope since the construction of these terraces. Note that the native grasses are allowed to grow undisturbed on the risers.

After the bench terrace has been staked out, with the proper slope, terrace interval, and other details, a strip of land, from 8 to 15 feet wide, according to the slope, lying immediately above the line stakes, is plowed. The loosened soil is then pushed over along the line of stakes with a scraper, or preferably, a tool of the road-grader type. This process is repeated until the terrace has assumed the desired form. It is not necessary to provide a level tread of cross-section to bench terraces, but the nearer this is approached the better they function as a means of erosion control.

The risers are usually left undisturbed and uncultivated. When the land is not very steep, no attempt is made to move soil out toward the edge of the terrace before planting, the actual soil movement being

[16] Huberty, M. R., and J. B. Brown. Irrigation of orchards by contour furrows. California Agr. Ext. Cir. **16**:1–16. 1928.

confined to that which takes place under normal cultivation. Cultivation should always be such that it will throw the soil outward, tending to flatten the tread and steepen the riser.

With few exceptions, most of which are devoted to ornamental landscaping, bench terraces in California are used for orchards. Figure 26, showing a field on which beans are grown, is an exception, and is used here because it clearly illustrates both the construction of the terrace and methods of tillage.

Ridge Terraces.—The ridge terrace, although not yet extensively used in this state, has a much wider field of adaptation than the bench terrace and should become a common sight on more gently sloping hill-

Fig. 27.—Terraced and contour-planted cotton field in Oklahoma showing that erosion may be prevented without the loss of the land occupied by the terrace. The best cotton is on top of the terrace. Similar methods are applicable to California conditions.

sides. There are two types of ridge terrace, the broad-base and the narrow-base, and these may be either sloping in the direction of the terrace or level. The broad-base *level* ridge terrace is considered the most ideal of all terraces: it is intended to conserve all of the water, is readily crossed with tillage tools, and is the most easily constructed; but it has been found to be less well adapted to areas of heavy rainfall than the broad-base *sloping* ridge terrace. This terrace (figs. 27 and 28) is often referred to in literature[17] as the Mangum terrace, having been named after its originator. It may be used on slopes up to about 20 per cent but is best adapted to slopes under 10 per cent.

[17] Ramser, C. E. Prevention of erosion of farm lands by terracing. U. S. Dept. Agr. Bul. 512:1–40. 1917.

Ramser, C. E. Farm terracing. U. S. Dept. Agr. Farmers' Bul. 1669:1–22. 1931.

There is no great difference, except that of width of base, between broad-base and the narrow-base terraces, and to avoid unnecessary repetition the following description will be confined largely to the broad-base sloping terrace. The ridge is from 18 inches to 24 inches high and the base from 30 to 40 feet wide. The narrow-base terrace is about the same height, but has a base 15 feet or less in width.

Under average conditions, the sloping terrace should have a fall in the direction of the terrace of about 4 inches in the first 200 feet of its length and 1 inch additional for each 200 feet of length. These figures may be modified somewhat by the nature of the soil, the steepness of the cross slope, and the amount of rainfall. Experience in any particular locality will be the best guide in regard to these features. The vertical

Fig. 28.—Putting the finishing touches on a broad-base terrace. Such a terrace is very little obstruction to cultivation.

interval between terraces will vary also with the slope, rainfall, and soils. Probably the best way to determine this is to observe the distance both vertical and horizontal through which water must travel, under the conditions at hand, before it begins to erode seriously. Observations should be made just below the crest of the hill to be terraced. For example, let us assume that at 5 feet (vertically) below the crest of the hill, erosion is readily apparent. This then should constitute a working figure, and the terraces should be about 5 feet apart vertically. (Under some conditions this interval may be as low as 3 feet or as high as 10 feet.)

The high, or starting, point in the terraces for any given field should be along some line, either one edge of the field, a ridge or a hollow near the center of the field, or some other feature which will govern the location of the terrace outlets. On land which is irrigated it would be convenient to have the high point of terraces located on ridges as is done with bench terraces in some localities. For fields up to 800 or 1,200 feet in width one edge of the field is a good starting point provided there is an outlet available at the other edge. If there is a hollow or depression near the center of the field, then the terraces should begin on either side sloping toward the depression, or if there is a ridge in the center of the field, the terraces may slope both ways toward the sides of the field. Short terraces 600 feet or less in length are better than long ones, and only on rare occasions should they exceed 1,500 feet in length.

Assuming that the terrace interval is 5 feet and that the starting or high-point line has been determined, the next thing to do is to set a stake marking the point at which the topmost terrace begins. Each terrace should be staked for its entire length, one or both ways from the starting point as the case may be, by setting pegs at intervals of 50 feet. A ''round-trip'' furrow should then be plowed following the line of pegs and the earth should be thrown up against the pegs from both sides. This forms the center line of the terrace. Sharp bends and unusually crooked terraces should be avoided, if possible, by rounding off the corners at the time the first furrow is plowed. The next step is to drop down 5 feet below the starting point and set the second line of stakes in the same manner as the first. This line is also established by plowing a furrow around the stakes. This process is repeated step by step to the bottom of the hill.

The top terrace should always be laid out and also constructed first, since it is this one that, to a large degree, determines the success of the entire project. If for any reason the top terrace fails, the lower terraces are almost certain to fail also.

The reason for staking out and plowing around the pegs for each terrace before the next lower one is located is that often some condition may be discovered along the line which will make it advisable to increase or decrease the interval or the grade in one or more of the succeeding terraces. Under such circumstances, if the beginning point of each terrace had been located before fully staking out any of them the work on all succeeding locations would have to be done over.

When the terraces are all located, the construction of the top one is begun by plowing a strip about 8 or 10 feet wide on either side of the center line. The plowed soil is then scraped toward the center with a terrace machine, road grader, or similar tool. This procedure is repeated, with each successive plowing extending a little farther from the center line of the terrace, until a ridge 20 to 24 inches in height with a base 30 to 40 feet wide is formed (fig. 28). Not infrequently most of the soil making up the terrace is taken from the upper side with the result that the uphill side of the terrace has a somewhat flatter slope than the downhill side. On steep slopes this is unavoidable.

It is better not to plow too deeply in loosening up soil for the terrace so that the terrace channel, or area from which the soil is taken, will be broad and shallow rather than narrow and deep.

Care should be taken to see that there are no low places in the terrace which are likely to be overtopped when the channel contains water. Such places should be filled in with a shovel, if necessary.

Fig. 29.—The orange grove on the left is protected, by means of terraces, against erosion, but a satisfactory terrace outlet has not been provided, with the result that a shallow drain along the driveway has become a gully.

Where a terrace crosses a gully particular attention should be given not only the height of the terrace but also to its strength and compactness, because these places are likely to be points of weakness. The completed Mangum or broad-base terrace should be an embankment high enough to prevent water from flowing over the top, have a broad shallow channel immediately above it on a grade which will carry away any water which collects at a velocity which will not erode, and yet the whole area should be available for cropping without undue interference with cultural operations.

Narrow-base terraces are laid out and constructed in a manner similar to the type just described. The rice check border as used in the Sacramento Valley and elsewhere is virtually a narrow-base ridge terrace. Although well adapted to flat slopes, the narrow-base terrace has been used on slopes as great as 60 per cent.

The cultivation and planting of terraced land may be carried on as if the terrace were not there; in other words, crops may be planted in straight rows running in any direction that the planter desires. It is becoming more and more the custom, however, to consider the strips between contours as farm units and to plant, cultivate, and harvest each strip separately. For row crops the first row follows the top of a terrace and the return row follows the top of the next terrace, with succeeding rows parallel until the center of the terrace unit is reached. Figure 27 illustrates this point for cotton. If any additional space remains it is filled in with ''stub'' or ''fill'' rows as the case may be. As in the case of contour planting, this results in crooked rows and occasional short or stub rows, but it cannot be avoided.

Fig. 30.—Well-constructed wooden check dam with tile underdrain and riser being used to prevent a gully from forming at the end of terrace runs. Steep hillsides can be planted safely in this way.

Terrace Outlets.—The terrace outlet is almost as important as the terrace itself; for it must be capable of discharging all of the water which drains from the terrace channel without creating a gully or otherwise becoming a nuisance. Figure 29 shows the results of failure to provide an outlet, and figure 21 is an example of a well-planned outlet.

The outlet may be an open channel or a closed drain leading down the slope, or it may simply be a means of spreading the water on to adjoining land in such a way that no damage will result. The open channel should be lined with concrete, stones, or other material to prevent washing, or, if the slope is not too steep, may be planted to some dense-growing permanent vegetation. The covered or tile drain is the safest outlet. A line of tile is laid directly down the slope through the low point of the terraces or at their end, and an inlet is provided at each terrace channel through which water may enter the line. A well-constructed inlet or riser of this type is shown in figure 30. The outlet, whether tile or open drain, must have sufficient capacity to carry the discharge from any rain which is likely to occur.

Where terraced fields or orchards occupy only the lower slopes of hillsides, and the upper slopes are either uncultivated or are owned by persons not interested in erosion control, some provision must be made to care for surface runoff from this area. A cutoff ditch will be satisfactory if it is properly constructed, but it must be of sufficient size to

Fig. 31.—Brush soil-saving dams are used not only to prevent gullies from becoming larger but also to collect and retain the soil so that they are gradually eliminated. After the brush becomes firmly imbedded in silt, the accumulation behind the dam becomes very rapid.

carry all of the water which will drain into it and must not have a slope so great that it will erode. The gully shown in figure 10 was once an intercepting ditch intended for the protection of the land below it, but owing to neglect it has become a source of destruction and ever-present danger.

Soil-saving Dams.—Considerable attention has been given to the control of gullies, and various devices have been employed both to prevent further erosion and to reclaim them. Several of the Agricultural Experiment Station, as well as the United States Department of Agriculture, have publications on this subject. Some of these are mentioned in the ''List of References for Further Reading'' at the end of this article.

Fig. 32.—Cobble check dams in a roadside ditch which threatened to become a serious menace. This is a more permanent check than the one shown in the preceding picture.

Fig. 33.—A soil-saving dam of small poles firmly bound together with wire cable. Note the notch left for the passage of water so as to prevent its cutting around the ends of the dam. Photograph taken July 5, 1929. (See fig. 34.)

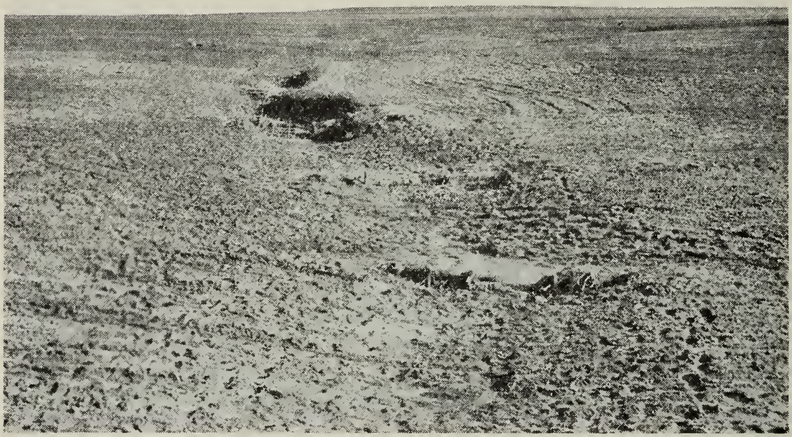

Fig. 34.—These pole soil-saving dams have nearly accomplished their purpose. This is a view of the same place as that shown in figure 33. Photograph taken December 23, 1929. (Photograph courtesy of United States Bureau of Agricultural Engineering.)

Fig. 35.—These concrete soil-saving dams in Ventura County will prevent this gully from becoming deeper, and although the channel may continue to carry storm water there will be no further loss of land.

A dam placed across a gully will cause a deposition of the larger and heavier particles of transported matter. Often when there is a large amount of this material the area behind the dam, to the elevation of its crest, will be filled very rapidly. This will usually be sufficient to prevent further washing, but if it is desired to fill the gully, the dam must be gradually raised until its crest is even with the ground surface. Earth, brush, lumber, stones, poles, or concrete may be used for the construction of these dams. A few of these are shown in figures 31 to 35.

Fig. 36.—A gully in the early stages of formation was prevented from getting beyond control by the construction of rock check dams and seeding the sides to native grasses. (Photograph courtesy A. W. Sampson.)

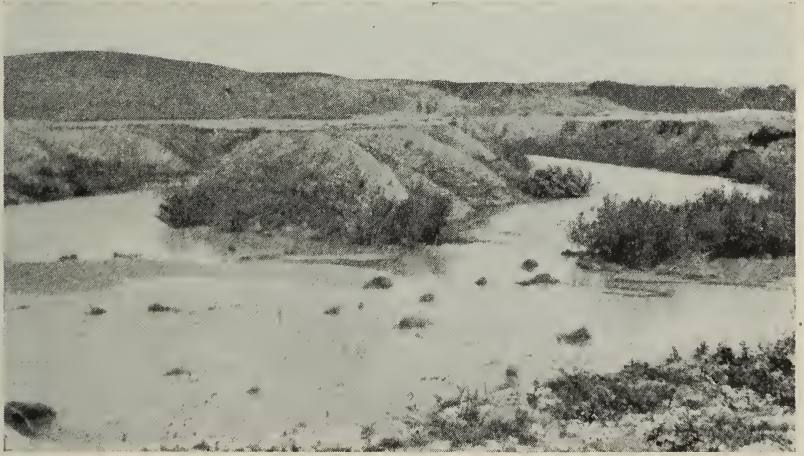

Fig. 37.—An earth dam, a portion of which shows in the lower right-hand corner of the photograph, was constructed across this deep forked gully. The gully is now being gradually silted up and may sometime be tillable land. How much easier it would have been to have taken similar precautions when the gully was only a foot or two deep!

With earth dams the water, after it has dropped its load of sediment, must be diverted around or through the dam in such a way that it will not wash it out. With brush dams the water passes through, while with dams of stone or concrete the water may be allowed to pass over. Sometimes the bottom and sides of a gully may be planted to trees or even grasses, which will hold the soil against further washing. A combination of check dams and planting has proved successful in retarding erosion in gullies, as illustrated in figure 36.

Fig. 38.—A deep barranca in Ventura County is being reclaimed by this concrete check dam. Such structures are expensive and require considerable engineering ability to design. Should such a structure fail it might endanger both life and property.

Soil-saving dams in large or deep gullies should be considered as engineering structures, and farmers without engineering knowledge should not attempt their construction without assistance (figs. 37 and 38).

EQUIPMENT AND MAINTENANCE

The development of machinery for terrace construction has kept pace with the increased use of this form of land protection so that now graders or terracers have been designed which are very satisfactory for the purpose (fig. 39). Although none of these are handled by the implement dealers of California, there is no doubt that they will be as soon as there is a demand for them. In this state machinery for grading land and constructing ditches and checks for irrigation and similar purposes has long been in use and is familiar to most farmers, so that little difficulty will be experienced in finding tools for the construction of terraces.

Fig. 39.—A type of grader in common use for constructing broad-base terraces. These are made in sizes suitable for team or tractor operation.

No mechanical means of erosion prevention or control will remain effective without constant maintenance. Check dams must be raised or strengthened at intervals, terraces must be maintained intact (see fig. 9), and outlets protected against washing if they are to continue to serve their purpose. Even such preventive measures as sodding or grass cover need careful watching to avoid their destruction by overgrazing or fire. A sensible program of farm management must accompany any attempts at erosion control and, as has already been mentioned, this may mean a material change from existing practices. Some farms should change from cultivated crops to grass or pasture land, and others should be restored to brush or timber cover.

New lands in areas subject to erosion should be farmed only after careful consideration is given to their management, and it seems very doubtful whether farmers should be permitted to farm lands which are certain to be destroyed after a few years of cropping. The engineering features of erosion prevention and control on farm lands are not difficult. Many county agents without any engineering training have become expert in terrace construction and have advised and trained farmers so that they do not hesitate to continue the work without further assistance. Throughout Texas and Oklahoma high school boys who have received instruction from their agricultural teachers or the county agents have been very proficient in this type of work.

COSTS

There are no data available on which to base the cost of erosion control in California. The statement is frequently made that terracing will be so expensive and that California farmers cannot afford to protect their land by this means. It should be remembered, however, that the most expensive type of erosion control used in this country, namely, the bench terrace, is common practice in irrigated citrus orchards of southern California and is increasing in favor, and that the ridge terrace has been introduced into the wheat-growing regions of eastern Washington and is proving a feasible means of protection against erosion for this comparatively low-priced crop. The ridge terrace is now considered almost a necessary part of the farm operation cost in the low-priced cotton and corn lands of Texas, Oklahoma, and Missouri; and contour checks for rice and strip checks for alfalfa are not considered too expensive in California. In view of these facts, it does not appear to be a logical conclusion that the ridge terrace, contour cultivation, and soil-saving dams will prove uneconomical on the relatively high-priced lands of this state.

LIST OF REFERENCES FOR FURTHER READING

For the information of those who desire to pursue this subject farther, the bulletins and papers given in the following list will be found to contain useful and practical information.

In addition to these more formal papers, there have appeared during the past five or six years a number of trade papers dealing with the design and construction of terraces, soil-saving dams, and the use of certain machinery or materials for the purpose. These papers contain some valuable practical information. Agricultural Engineering, the monthly journal of the American Society of Agricultural Engineers, contains interesting and valuable articles by writers of authority on erosion and related subjects.

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