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SOIL EROSION

CAUSES AND METHODS OF CONTROL

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A terraced field near Caledonia showing water from heavy rain held on slopes until absorbed by the soil.

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SUMMARY

Soil erosion is almost universally present in agricultural regions.

Sheet erosion is by far the more harmful and insidious type, carrying away the top soil at a steady but almost imperceptible rate.

The rate of erosion tends to increase many fold after cultivation of the land is started.

Therefore, the contributing causes of soil erosion are largely certain current farming practices—denuding steep slopes of forest or sod cover; shallow tillage; cultivation with the slope; unwise location of dead furrows, cattle runs and field roads; and crop rotations that fail to maintain a high organic content in the soil.

Prevention is largely possible by avoiding these practices.

Soil erosion cannot be entirely stopped but it can be controlled and very largely checked.

Control, in considerable measure, may be effected by the same means as prevention; but

Ultimate control of gullies must be by well established engineering methods for checking head erosion, by systematic planting of willows and other fast-growing trees, by the use of series of check dams, and particularly by the installation of soil-saving dams.

The ultimate method of **sheet erosion** control is that of terracing practically all cropped slopes subject to erosion, coupled with cover-cropping and contour cultivation.

Terraces preserve the top soil and prevent drouth by conserving the moisture.

The best type of terrace for general use is the standard graded Mangum terrace.

Crop rows may be run diagonally across the terraces but contour planting and cultivation approximately parallel to the terraces is an effective aid in controlling sheet erosion and is recommended.

One-eighth inch of depth of soil removed in a single year seems negligible; but one-eighth inch each year for forty years is, in many cases, all the top soil.

NATURAL CAUSES OF SOIL EROSION

The problem of soil erosion is an important one in Minnesota, and no farmer should ignore it who cultivates land with sufficient slope to cause water from rainfall to move over it. It is a natural process that is generally present and that will be so as long as wind and water are free to move over the surface of the earth. However, the idea generally prevalent that, on account of its natural character and general occurrence, nothing can be done successfully to control it, is wholly erroneous.

The primary causes of soil erosion are the direct action of rain beating upon the bare soil and the rapid movement of the water down the slope. The intensity of soil erosion is emphasized in the heavier and more uniform soils and on steep slopes. It is increased by freezing and thawing action in the spring, as then the top soil is usually saturated, has little coherence, and contains fewer roots, tending to prevent washing.

The steeper the slope the faster the water runs. Its eroding power always increases many times faster than does its velocity of flow. For example, if the velocity is doubled the eroding power is increased in some cases as much as sixty-four times. Gullies are caused, primarily, by water collecting in channels or shallow depressions down which it flows with a velocity sufficient to move and carry away soil particles rapidly. Burrows of gophers and other rodents are a fruitful cause of gullies because they furnish, on steep and unprotected slopes, convenient smooth channels for flowing water.

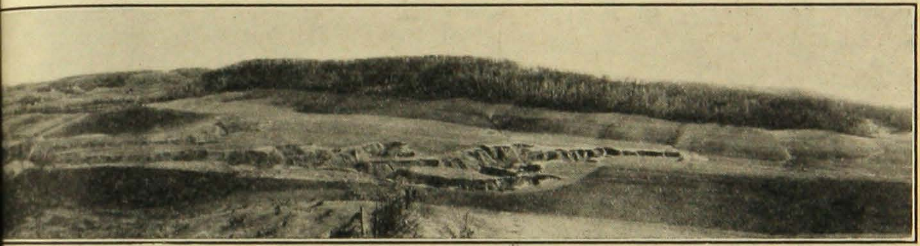


Fig. 1. A gully 20 feet deep and 150 feet wide with several branches, that, through 40 years, has [e]en its way across an 80-acre unit of a rich valley farm in Goodhue County.

Altho it is by no means the most serious phase, gullying is the more widely recognized type of erosion, owing to the evidences of its destructive character so visible to the eye. (See Figs. 1 to 4.) There are, however, phases of its destructive activity not so visible and, on this account, of a more insidious and harmful character, to which especial attention should be directed. Prominent among them is the endangering of the lives of stock. In their early stages gullies are comparatively easy to eliminate, but many farmers pay little attention to them until they have reached a size that makes them obstacles to farming operations almost impossible to overcome. (For example, see Fig 1.) Gullies frequently appear as the more advanced stage following or accompanying heavy, uncontrolled sheet erosion.

Surface washing, more exactly called sheet erosion, is much more serious than gullying, as it is general on all areas of sufficient slope to cause free water to flow over the surface, wherever the top soil has been disturbed by cultivation, or where it is not protected by some sort of natural cover as timber or permanent sod. As its name indicates, sheet erosion is the removal of a thin sheet of the top soil by water from rainfall moving over the surface as a continuous blanket and with a velocity

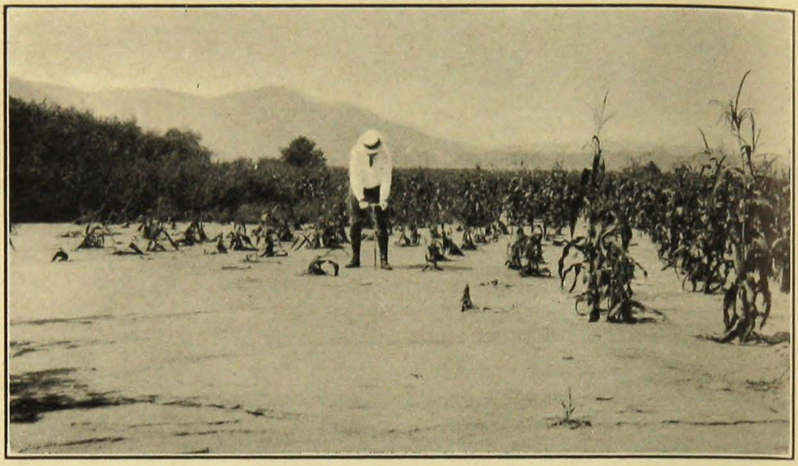
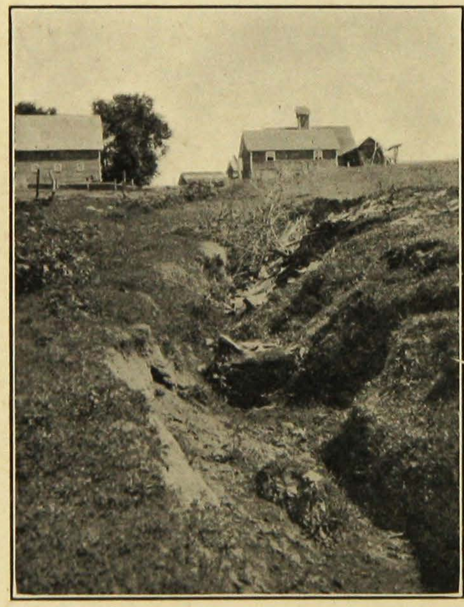


Fig. 2. Rich black loam in the Root River Valley, Houston County, buried 4 feet deep by sand washed in a single season from a large gully through the higher land.



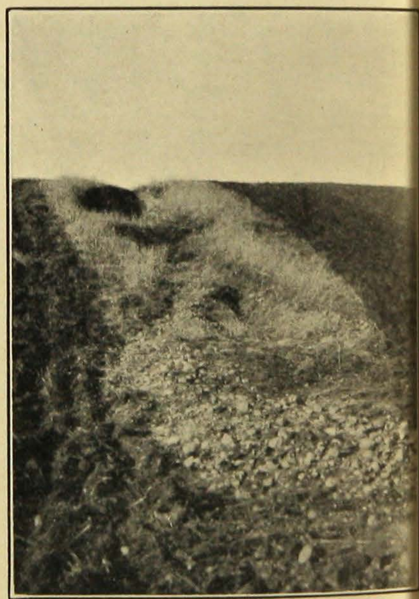


Fig. 3. Left. A gully on a central Winona County farm making its way steadily toward the buildings on the farmstead.

Fig. 4. Right. A gully 100 feet long, 10 feet wide, and 6 feet deep, developed during a single heavy rainstorm from a dead furrow plowed in the direction of the slope. The quality of the land below it is impaired for years to come by the coarse sand and gravel from the gully.

sufficient to carry soil particles with it. So gradual and insidious is this action that it is often unsuspected until the owner finds almost barren spots appearing in his richest fields. (See Fig. 5.) Yet, to the experienced eye, spots of gravel and yellow clay, and stunted and sparse vege-

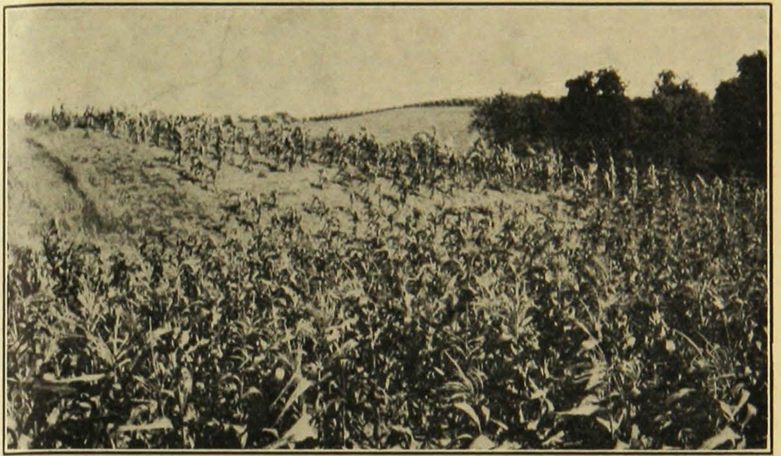


Fig. 5. Stunted corn on Dakota County slopes in 1930 caused by uncontrolled sheet erosion during sixty years of cultivation.

tation on the knolls, are unmistakable evidences of its destructive presence. (See Figs. 5 to 10.) Even if they recognize it, farmers generally look upon it as an unavoidable result of cultivation. However, researches of both federal and state agencies have shown that most of the loss of fertility commonly attributed to continuous cropping is due, instead, to the many times more rapid action of sheet erosion which removes not only the fertile elements but the very soil itself.

Altho sheet erosion itself creates no ditches, if it could be stopped or very materially checked there would be relatively little trouble from gullying, for, in most cases, gullying is the ultimate outgrowth of sheet erosion. (See Fig. 6.)

Fig. 6. A comparatively new field in southwestern Itasca County, badly scored by sheet erosion which is developing a gully near the base of the slope. A large gully farther down the hill has already been formed as a result of this wash.

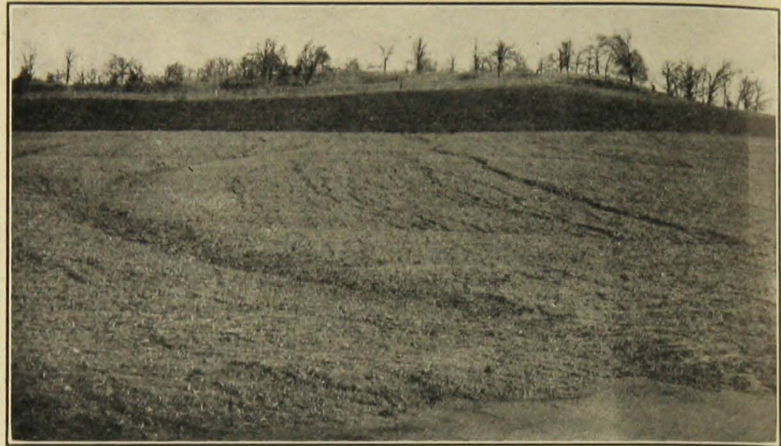


Fig. 7. A 20 per cent slope on a young grain field adjacent to the gully shown in Fig. 1, following a 5-inch rain late in April, 1930. Note the heavy scores 3 to 8 inches deep, out of which all the soil has been washed clear to the plow sole.

Soil erosion is aggravated by anything that tends to decrease a pervious condition of the soil, by denuding steep slopes of their vegetative cover, by shallow inadequate tillage, by impoverishment of the organic content of the soil, by tillage and planting operations up and down instead of across the slope, by overpasturage of hilly or rolling land, and by the growing of cultivated crops on slopes too steep for profitable tillage. In southeastern Minnesota many slopes with a fall of 10 to 15 feet to 100 are now being farmed in row crops, and others as steep as 30 per cent are in hay and small grain crops. None of these farms is terraced and little or nothing is being done to check erosion. In some

Fig. 8. What became of part of the silt washed from the slopes shown in Fig. 7. A large diversion ditch was completely filled and rendered ineffective by the single storm because there were no other protection works on the slopes above it.

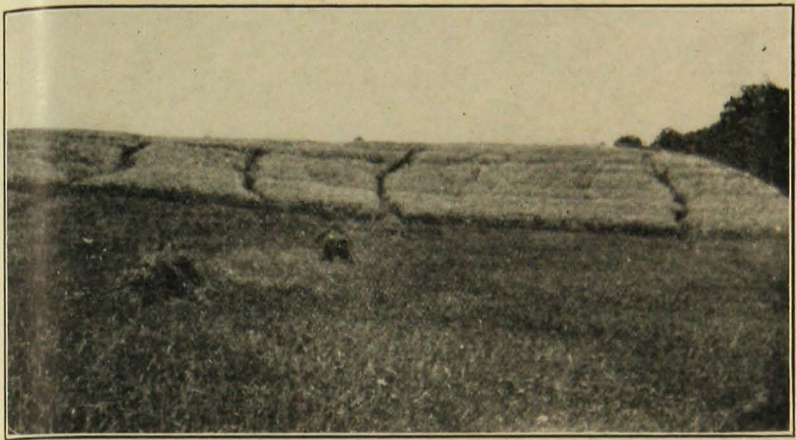


Fig. 9. This Rice County slope was once like that to the right where virgin woods is growing in 30 inches of rich black loam. Through 50 years of tillage of the open field, uncontrolled sheet erosion has removed all the loam and most of the subsoil down to the parent limestone ledge.

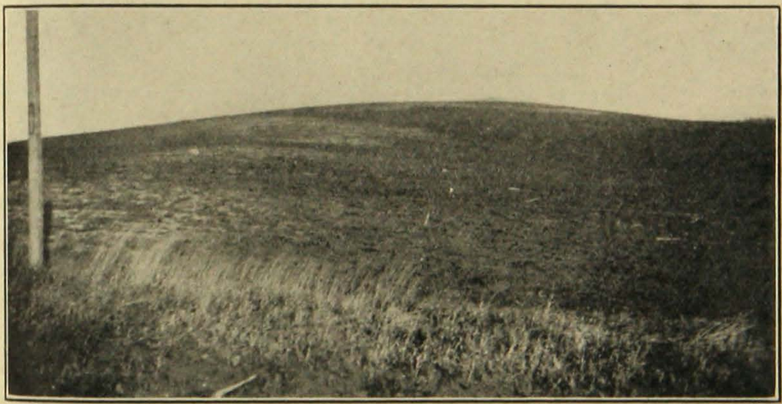


Fig. 10. A badly eroded slope in western Jackson County, near trunk highway No. 9. Note the yellow clay entirely robbed of its virgin covering of 6 to 12 inches of black loam.

cases the entire surface of the field has been washed off by a single rainstorm clear to the plow sole. (See Figs. 7 and 8.) In another generation many fields in this region will have to be abandoned unless steps are taken promptly to check erosion. A dead furrow extending up and down a slope often develops rapidly into a deep gully. (See Fig. 4.) The same thing often results from wagon tracks or cattle paths running up and down the slope.

VITAL NEED OF PRESERVING THE TOP SOIL

The damage to farms has been greatly aggravated because the washing away of the open top soil has destroyed nature's agency for catching reserve moisture that would normally be absorbed more quickly by it, and held until it could be taken up much more slowly by the less pervious subsoil. Nearly all the nitrogen and organic matter is in the upper foot of soil, which has an absorptive capacity for water about twice as great as that of the subsoil. It will absorb water much more quickly. Most of the rainfall would be absorbed by the surface soil if it could be held there for a time, but, on the steeper slopes, the water runs off before it has had a chance to be absorbed. It, therefore, is important to save the surface soil, on account both of its natural fertility and its capacity to absorb moisture. "The plant food removed from the soil by crops can be restored in fertilizers, but the soil itself, washed from the fields, can be replaced only by those exceedingly slow processes of soil formation requiring ages to build up a thin layer, only, out of the underlying parent rock."[1]

OUTCOME OF UNCONTROLLED EROSION

In many cases the depth of soil removed yearly, by sheet erosion, from Minnesota fields has not exceeded one-eighth of an inch; in others it has been as much as one-half of an inch, and in a few cases, in seasons of unusual rainfall, the rate has exceeded two inches in a year. On at least one field observed, the rich top soil has been removed to a depth in excess of 30 inches in less than 60 years of cultivation, leaving only a thin layer of sandy and unproductive subsoil over the parent rock. (See Fig. 9.) The removal of one-eighth of an inch of soil in a year, which is probably the more common experience in the southeastern and other more rolling parts of Minnesota, may seem negligible but even one-eighth of an inch a year, extending through the active life period of the average farmer, is sufficient to remove all or nearly all of the virgin top soil.

SOME SIMPLE METHODS FOR CONTROL

Soil erosion can be greatly checked by increasing the absorptive capacity of the soil. This may be accomplished by deep tillage, by tile drainage, and by increasing the organic matter through abundant use of barnyard manure and of frequently recurring cover crops in rotation. Other field practices that aid greatly in controlling erosion are: Avoiding of overpasturage, preserving and stimulating forest and other permanent cover-crop growth on steep slopes (a good stand of alfalfa is one of the best means of checking or preventing erosion) and contour plowing, planting, and cultivation. Contour farming has sometimes been objected to by those who have not tried it on the ground that it is unprofitable and that standard tillage machinery is not suited to it. In reply it is pointed out that the practice of contour cultivation is being

[1] Jones, Lewis A., U.S.D.A., B.A.E.

more and more widely followed with satisfactory results in the south and southwest in areas subject to sheet erosion. Further, some enterprising farmers in southeastern Minnesota have been using, for several years, a close approximation to this practice. In cornfields on heavily rolling and hilly land these men change the direction of the corn rows to run more nearly across the slope, at each point where the slope, in the preceding direction of the rows, begins to show a marked tendency to cause erosion. In some cases at least five such changes of direction occurred in crossing a single field. The practice probably would not have been continued from year to year if it had proved either impractical or unprofitable. No aggravated case of erosion occurred in these fields.

Very steep slopes should not be cultivated.—In general, in Minnesota, slopes with a fall of over 10 or 12 feet in 100 should never be plowed. If, however, a shortage of plow land seems to make it imperative to plant part of the steep slopes to cultivated crops, **strip farming** should be employed; that is, strips of cover crops should be alternated with strips of cultivated crops, the strips running along the contour.

Sod strips in natural water courses.—In natural field depressions where considerable water flows during rains, it is a good plan to leave a strip of bluegrass or timothy sod, one to two rods wide, in the bottom of the depression and extending the whole length of the slope. (See Fig. 11.) It is much easier to lift the plow or other tillage implement while crossing this sod strip than it is to have to make frequent turns at the edge of the gully, which is very likely to occur eventually at such a location if no preventive measure is taken. The practice of leaving a sod strip in the natural water courses is increasing in the corn-belt states

Fig. 11. This strip of sod left in a natural depression where flood water collects and flows with high velocity during rainy periods prevented serious erosion in a Winona County cornfield.

with good results. However, these sod strips tend, in time, to build up until they cause the water to flow on either side of them instead of over them. When this occurs the old sod should be plowed out and a new strip seeded in.

Sod barriers.—In small depressions where there is a tendency to wash, **cross barriers** of sod have been found effective. Strips of bluegrass sod may be put in old burlap feed or fertilizer bags and tamped in tight, end to end, at intervals across the bed of the wash. By the time the bags have rotted away the sod is well set. Another effective method is to fill the depression with straw and then lay woven wire over it, fastening it securely to stakes driven almost flush with the surface of the ground. One should be sure that the center is left lower than the edges. Such a barrier practically stops erosion and it has the added advantage that it can be crossed with any implement, whereas it is necessary to drive around a dam.

Checking the velocity of the water.—It is impossible to make any soil absorb all the water that falls during the heaviest rains; hence, in order to prevent erosion, the velocity of the water must be checked as it flows over the surface of the field. This may be done in several ways, notably by the use of check dams in natural channels, as in the road ditches along the newer highways, and by terracing. (See pages 17 to 22 and following.)

Diversion ditches.—Gullies are frequently started by allowing water from higher land to collect at the top of a field and flow freely across it without control. A diversion ditch at the upper side of the field will prevent the formation of a gully in such a case. A proper diversion ditch 2 to 3 feet deep can be constructed very cheaply by using a plow and scraper, altho a small road grader is better. Such a ditch should have a fall of not more than 6 inches in 100 feet. It should be laid out with a level in order to be sure of securing a proper rate of fall.

GULLY CONTROL AND ELIMINATION

Straw in gully control.—Very small gullies in open fields may be checked and eliminated by filling them with straw and then plowing in dirt from the sides on the straw.

Sod in gully control.—Coarse, fast-growing grass, such as brome grass, red top, or even quack grass, and a little sweet clover to supply nitrogen for the grasses, sown in gullies is effective in checking erosion, caving of slopes, and deeper scouring of the gully floor. **This practice is recommended.**

Tree planting and gully control.—Where there is an abundance of natural soil moisture, willows and other fast-growing trees, planted across the floor and along the slopes of gullies, are an effective agency in the control and elimination of gullies. When set in dense rows across the gully floor at regular intervals, they act much as a series of check dams in retaining eroded material, and when they grow sturdily they also make good anchors for brush dams. When used on the slopes to prevent side erosion and caving, it is best to plant them deep and close together in rows following the contour.

Stopping head erosion.—After a gully is once started its growth is apt to be very rapid, owing to the undermining action of the falling water at its head and the freezing and thawing action along its walls in the spring. In reclaiming a gully of appreciable size, the first need is to stop this head erosion; that is, to prevent the gully from advancing. To do this the scouring and undermining action of the water, and, if possible, its overfall, must be stopped. Wherever possible the best way is to divert the water into some nearby water course before it enters the head of the gully. If this is not possible, in the case of small gullies up

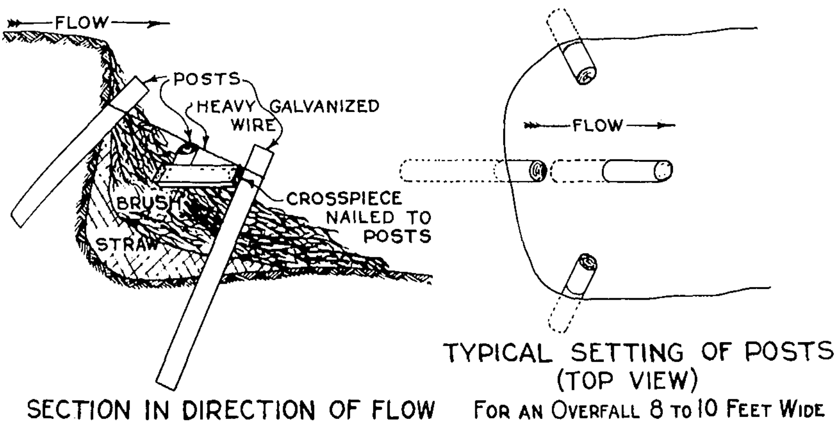


Fig. 12. Method of checking erosion and undermining at head of gully by brush and straw held firmly in place. (From Agr. Ext. Bull. 74, Iowa State College.)

to about 4 feet in depth, the headwash may be stopped by a low dam, or obstruction, built of posts, wire, and brush, close to the head, with a mat of straw and brush fastened securely underneath to break the fall of the water and prevent undermining. (See Fig 12.) The gap behind the dam will quickly fill with soil and the caving away of the headwall will be stopped. In large and deep gullies it is difficult to drop the water to the lower level without serious undermining. In such a case it is usually necessary to construct a flume, or a vertical drop, with a base and apron to check and spread the water. (See Fig. 13.) Such works may be constructed of any durable building material, as concrete, lumber, galvanized sheet iron, or corrugated iron culverts. They may cost from $100 to $1,000 or more depending upon the size of the gully and the quantity of water to be carried.

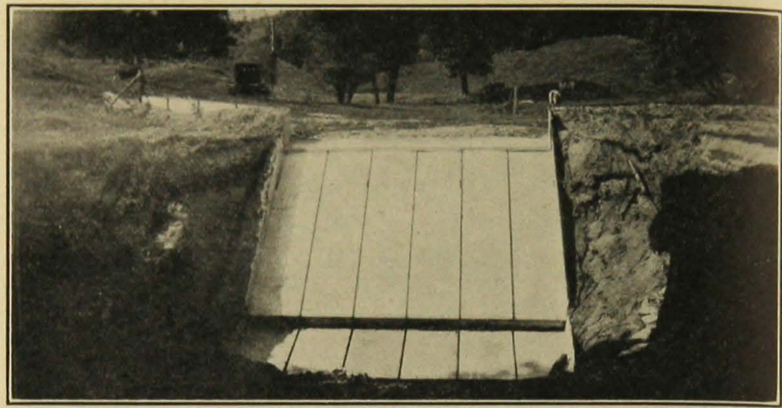


Fig. 13. Head flume of galvanized iron. Note the metal and earth wing dams at the sides that force approaching water to enter the flume, thus preventing undercutting, and the adjustable apron at the base that spreads out the falling water and checks its force. (Courtesy of Gottlieb Muhheisen, Manufacturer, Alma, Wis.)

Brush dams and check dams of other types.—Once the head erosion is cared for, check dams should be built across the floor of the gully at frequent intervals (usually 100 to 200 feet) throughout its entire length. Except at the outlet of the gully, it is usually sufficient to construct these dams of loose rock, woven wire, or posts and brush. They are cheap and easily built. (See Figs. 14 and 15.) As soon as the first dams are filled to the top with eroded material, new ones should be built. Any ordinary gully can be quickly filled in this manner. (See Fig. 16.) Check dams should always be made lower at the center than at the edges so the water will not cut around them. Frequent low dams are more economical and less apt to wash out than a few high ones. The dams should be so spaced that the bottom of one is not more than six inches above the top of the one next below. Brush dams give the best satisfaction when built of green brush with the leaves still on and the butts extending up stream. The butts should be well choked with old straw or hay. A loose brush pile in a gully is useless as the silt-laden flood will pass right through it without depositing any appreciable amount of its earthy burden. It is not advisable to put a straw stack in a gully, as the water is likely to cut around the stack and enlarge the gully.

Soil-saving dams.—In any gully of appreciable size there should be one or more soil-saving dams of masonry or earth so constructed as to retain the silt burden but let the water by. At least one such dam at or near the mouth of the gully is necessary to its control and elimination. Soil-saving dams should always be provided with a concrete or willow mat spillway and apron to prevent washing and undermining. In case of a high dam, a culvert with a vertical drop inlet is required to conduct the water under the dam, which should be at least three feet higher than

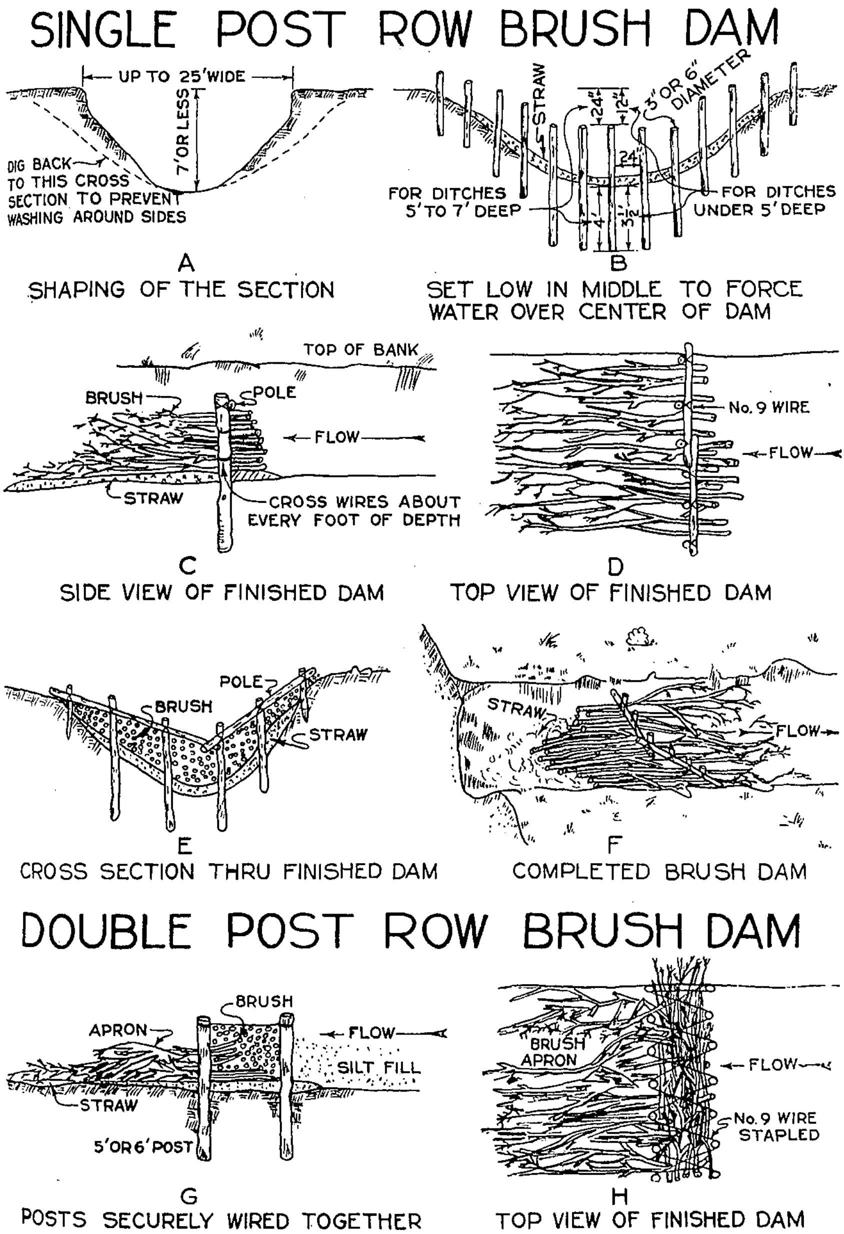


Fig. 14. How to build brush dams. *Note:* The brush must be laid methodically with butts upstream, and be packed by tramping as laid. (Adapted from Univ. of Neb. extension material by I. D. Wood.)

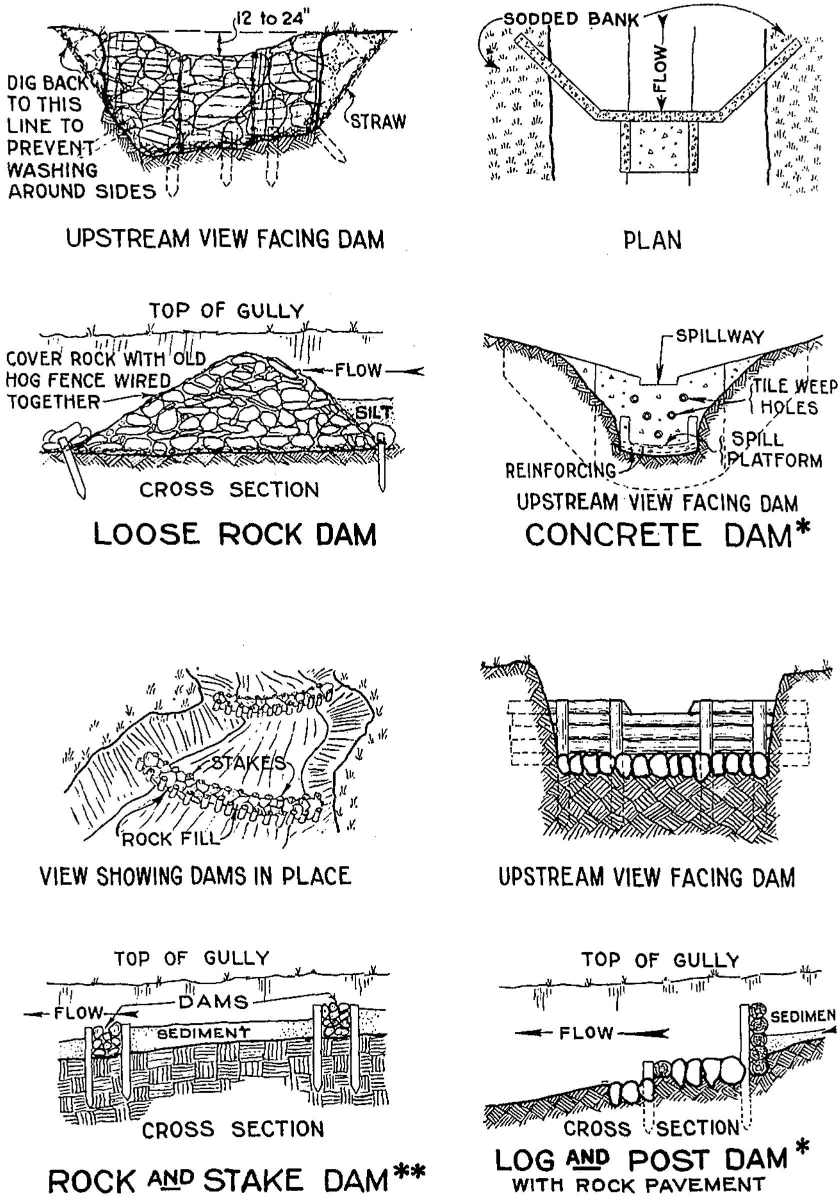


Fig. 15. Various effective types of check dams in common use.

* Adapted from U.S.D.A. Farmers Bull. 1234.

** Adapted from Univ. of Neb. Ext. Circular No. 123.

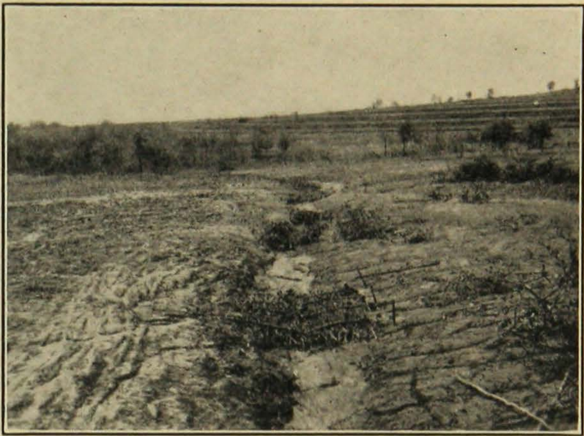


Fig. 16. A series of properly spaced brush dams that have caused a gully originally about 6 feet deep to fill up. Note the silt deposited behind each dam extending from the top of one to the base of the next one upstream. (Courtesy of C. E. Ramser, U.S.D.A. Bur. of Agr. Engr.)

the inlet to the culvert. (See Fig. 17.) Ordinarily the culvert should be designed with sufficient capacity to carry with safety the largest amount of water that was ever known to discharge through the gully. However, even when a culvert is used, a spillway should be provided as an emergency measure to take care of exceptional rainstorms. Tables 1 and 2 serve for approximate design of culverts. For large installations and for steep, narrow watersheds, it will be the part of wisdom to have a careful design worked out for the particular case by a competent

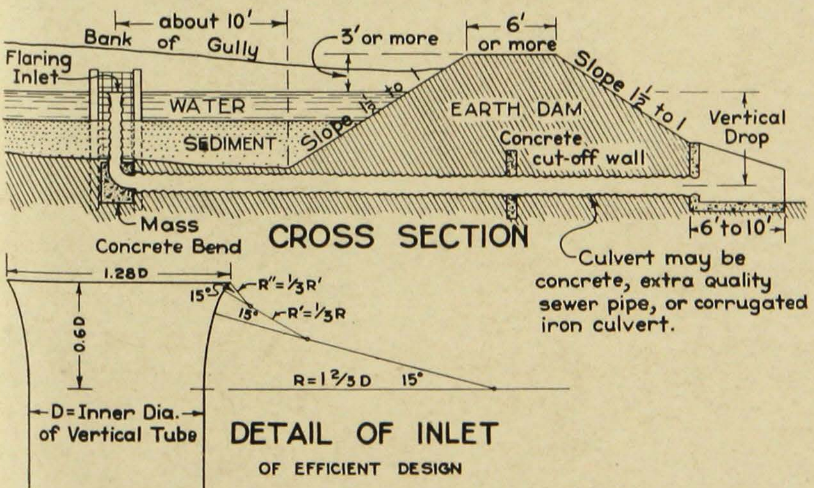


Fig. 17. Earth soil-saving dam and culvert with vertical drop inlet. (Adapted from U.S.D.A. Farmers' Bull. 1234.)

Table 1*

Cross-Sectional Areas of Pipe or Conduit for Drop-Inlet, Soil-Saving Dams for Rolling Watersheds with Length Equal to About Twice the Width

Drainage area	With no spillway around or over dam				With spillway having capacity about half that of pipe in column 2; storage, ¼ acre at level of top of inlet pipe	
	Very little storage above dam		Storage above dam, surface area, ½ acre, at level of top of inlet pipe			
	4-foot drop	8-foot drop	4-foot drop	8-foot drop	4-foot drop	8-foot drop
Acres	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.
1	0.4	0.3	0.2	0.1	0.05	0.0
2	.7	.5	.35	.2	.1	.0
4	1.1	.8	.6	.3	.15	.0
6	1.5	1.1	.8	.5	.2	.0
8	1.9	1.4	1.1	.65	.25	.0
10	2.2	1.7	1.3	.8	.36	.0
15	3.0	2.3	2.0	1.2	.4	.1
20	3.8	2.8	2.7	1.7	.5	.2
25	4.5	3.4	3.4	2.2	1.1	.3
30	5.1	3.8	3.9	2.6	1.2	.5
35	5.8	4 3	4.5	3.1	1.5	.7
40	6.3	4.8	5.1	3.5	1.8	1.0
45	6.9	5.2	5.7	4.0	2.2	1.2
50	7.5	5.6	6.3	4.4	2.6	1.5
60	8.6	6.5	7.6	5.4	3.2	2.2
70	9.7	7.3	8.6	6.2	3.7	2.5
80	10.7	8.0	9.6	6.9	4.2	2.9
90	11.7	8.8	10.6	7.7	4.8	3.3
100	12.6	9.5	11.6	8.4	5.3	3.7
125	15.0	11.2	14.1	10.4	6.7	4.8
150	17.2	12.9	16.7	12.4	8.2	6.0
175	19.2	14.4	19.2	14.4	9.6	7.2
200	21.3	16.0	21.3	16.0	10.6	8.0
300	28.8	21.6	28.8	21.6	14.4	10.8
400	35.8	26.8	35.8	26.8	17.9	13.4
500	42.3	31.7	42.3	31.7	21.1	15.8
600	48.5	36.4	48.5	36.4	24.2	18.2
700	54.4	40.8	54.4	40.8	27.2	20.4
800	60.2	45.2	60.2	45.0	30.1	22.5
900	65.7	49.3	65.7	49.2	32.8	24.6
1,000	71.1	53.3	71.1	53.3	35.6	26.6

For very hilly watersheds increase above cross-sectional areas 25 per cent.
For square or fan-shaped watersheds increase above cross-sectional area 15 per cent.
For sizes of pipes corresponding to the above cross-sectional areas see Table 2.
* From U.S.D.A. Farmers' Bull. 1234.

Table 2*

Cross-Sectional Areas of Pipes of Standard Diameters for Use in Selecting Sizes Corresponding to Areas in Table 1

Diameter of pipe	Cross-sectional area of pipe	Diameter of pipe	Cross-sectional area of pipe	Diameter of pipe	Cross-sectional area of pipe
Inches	Sq. ft.	Inches	Sq. ft.	Inches	Sq. ft.
6	0.20	18	1.77	33	5.94
8	.35	21	2.41	36	7.07
10	.55	24	3.14	39	8.30
12	.79	27	3.98	42	9.62
15	1.23	30	4.91	45	11.04
				48	12.57

* From U.S.D.A. Farmers' Bull. 1234.

engineer. The culvert may be of extra quality sewer pipe with tightly cemented joints, of high quality reinforced concrete, or of corrugated iron culvert pipe, set in a concrete bend. Care should be taken to have the culvert set on a firm, undisturbed bed of natural soil, and seepage collars should be provided every 12 to 15 feet of its length. The ends of the dam should be as high, at least, as the walls of the gully. If of concrete, the structure should be extended well into the floor and walls of the gully to prevent undermining by seepage. For the same reason, if the dam is of earth, the bed on which it is built should be thoroly cleared of all vegetable matter and every precaution should be taken to secure the tightest possible bond between the filled material and the natural bed upon which it rests.

CONTROL OF SHEET EROSION BY TERRACING

Terracing is the ultimate and most effective method of controlling erosion. It serves a double purpose as it checks washing of the soil by preventing the rapid movement of water over the surface and it helps to protect against drouth by holding the water on the slopes, thus giving the soil a chance to absorb more of it. (See cover page.)

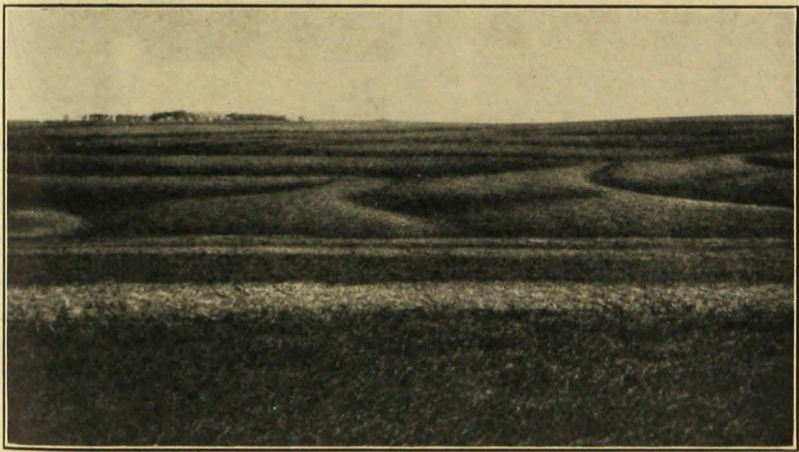


Fig. 18. A terraced field near Lewiston, Minn. Note how the terraces follow the general contour of the land.

Best types of terraces.—There are many types of terraces but the Mangum terrace, named after the man who originated it, is best suited to Minnesota conditions. It consists of a broad ridge of earth 15 to 24 inches high, thrown up across the slope approximately along the contour (see Fig. 18) but having, in the direction of its length, a varying rate of fall sufficient to carry the water **slowly** to an outlet channel at the end. (See Fig. 19.) The rate of fall should increase toward the outlet according to the schedule given in Table 3.

Limiting gradient for terraces.—The rate of fall should never exceed 6 inches per 100 feet, otherwise there will be washing behind the terrace. For lengths greater than 1,500 feet either the ridges of a terrace should be higher or the spacing between terraces should be decreased; but there should be no increase in the rate of fall.

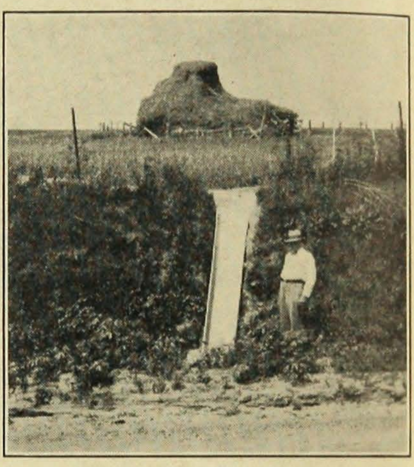


Fig. 19. Left. Water flowing off slowly to the outlet behind a broad-base terrace near Caledonia, Minn.

Fig. 20. Right. Terrace outlet flume of galvanized iron, in place near Caledonia, Minn. Drop about 10 feet.

Table 3*

Rate of Fall for Mangum Terraces Beginning at the Upper End

Length of Terrace	Drop of Terrace in 100 Feet of Length
0 to 300 feet	½ inch or 0.04 feet
300 to 600 feet	1 inch or 0.08 feet
600 to 900 feet	2 inches or 0.17 feet
900 to 1200 feet	4 inches or 0.33 feet
1200 to 1500 feet	6 inches or 0.50 feet

* From U.S.D.A. Farmers' Bull. 1669.

The uniform grade terrace is also in general use but it is not so desirable as the Mangum terrace because the surface water running off behind it is apt to pile up near the outlet with danger of causing overflow, breaks, and undue washing.

The level terrace should not be used in this state except on the advice of one experienced in terrace design and having a knowledge of local rainfall conditions.

Vertical distance between terraces.—The proper vertical drop between terraces depends upon the character of the soil and the slope of the land, the governing rule being to space them close enough that no appreciable washing may occur between them. Table 4 gives the suitable vertical drop between terraces for various rates of land slope for ordinary loam soils.

Table 4*
Vertical Interval Between Mangum Terraces

Slope of Land per 100 Feet	Vertical Distance of Drop Between Terraces
Less than 1 foot	1 foot
1 foot	2 feet
2 feet	2½ feet
4 feet	3 feet
6 feet	3½ feet
8 feet	4 feet
10 feet	4½ feet
12 feet	5 feet
14 feet	5½ feet

Where the soil is extremely susceptible to erosion so that washing is likely to occur between the terraces, the vertical distances given should be decreased by one-half foot. On the other hand, if the soil contains considerable humus and is capable of absorbing a large part of the rainfall so that it is not easily eroded, the vertical distance may safely be increased one-half foot.

* From U.S.D.A. Farmers' Bull. 1669.

Width of terraces.—"The terrace should be built ordinarily from 15 to 30 feet wide at the base, depending upon the slope of the land; the steeper the slope the narrower the base. Wide terraces are the more desirable from the standpoint of crossing them with farm machinery. The width may be increased each year by throwing the soil to the center of the terrace in plowing until, on moderate slopes, the lower edge of one terrace meets the upper edge of the next below, and the whole field, as often happens, becomes a series of terraces."[2] (See Fig. 21.)

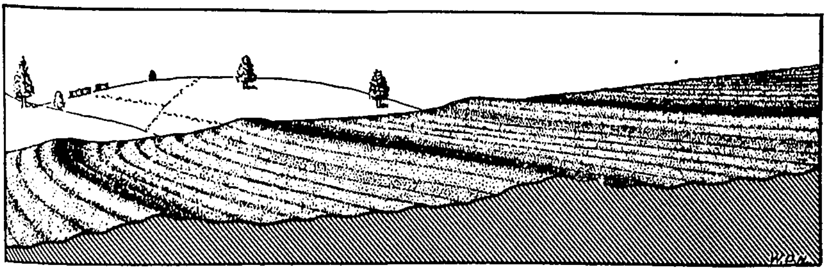


Fig. 21. Mangum terraces on a fairly steep slope showing how one blends into the other next below it, making the field a succession of terraces. (From U.S.D.A. Farmers Bull. 1669.)

A level necessary for terracing.—A farm level and the knowledge of how to use it are necessary for laying out terraces. The principle of leveling is simple and easily mastered. A simple method of leveling is

[2] From U.S.D.A. Farmers' Bull. 1669.

outlined in Circular No. 36, of the University of Minnesota Agricultural Extension Division, which also shows a practical home-made level. A commercially made farm level and rod giving good satisfaction and widely used in terracing work may be obtained for $20 or less.

How to lay out the terrace.—Twice the difference between two level readings 50 feet apart directly up and down the slope will give the slope of the land per 100 feet. This value known, the proper vertical drop between terraces, which is also the proper vertical distance from the top of the hill to the first terrace, can be taken from Table 4. The vertical drop from the top of the hill to the first terrace or from one terrace to the next, is then measured with the level, for a starting point for each terrace. From this point the line of the terrace may be run out each way, the rodman stepping off a continuous succession of 50-foot distances approximately along the contour. At each successive 50-foot point on the given terrace line the levelman will take a reading and move the rodman straight up or down the slope at right angles to the line of the terrace until the reading shows just half the proper rate of fall of the terrace per 100 feet, less or more than at the last preceding, according as the terrace line is being run up or down grade. For example, if the rate of fall for the section being laid out is 4 inches, or 0.33 of a foot per 100 feet, and at a given point the proper grade rod reading is 4.50, at the next point, 50 feet away, the grade rod reading will be 4.67 (4.7), if the line is being run down grade (toward the outlet); or 4.33 (4.3), if up grade (away from the outlet), the change in grade for 50 feet of length along a 0.33 per cent grade being 0.17 feet. At the next point the proper reading will be 4.84 or 4.17 according as the terrace line is being run down or up grade. Readings of the rod held on the ground should be made only to the 0.1 of a foot nearest to the proper grade rod reading. In the example, the numbers in parentheses are these readings to the nearest 0.1 of a foot. At each point found as above described, a stake should be set with the number or letter of the terrace marked upon it for the guidance of the man plowing out the line of the terrace. For example, if the top terrace is marked "A" all stakes on it should be so marked, all on the second one "B", all on the third "C", etc. On rough or rounding hillsides it may be necessary to set stakes every 25 feet along the terrace line for short distances. In staking out a terrace it is a good plan to divide the grade at the center point of the terrace and run the fall both ways from the starting point to the two edges of the field, as a terrace thus divided will not have to carry as much water as will one falling in one direction clear across the field. Sharp turns should be avoided, as they are apt to cause failures. When crossing a depression the crest of the terrace should be made higher, to prevent overflow.

TERRACE OUTLETS AND PROTECTION WORKS

The provision of suitable outlets for terraces is one of the most important items in terracing. Natural channels, drainage ditches, or road ditches may be so used if located convenient to the terraced field; but, if the drop from the mouth of the terrace to the bottom of the oulet channel is great enough to cause a considerable waterfall, a flume of sod, rock, concrete or galvanized iron is needed to conduct the water from the terrace level down to the outlet ditch, without serious damage to either. (See Fig. 20.) It is a good plan to keep terrace ends in tough, permanent sod for a distance of 25 feet or more back from the outlets. They may also be protected from cutting back by use of either the device shown in Figure 12 for stopping head erosion of gullies, or almost any of the check dams shown in Figure 15 if, on the down stream side, there is also built an apron of riprap or of concrete extending well across the floor of the outlet channel to check the force of the falling water and so prevent injury to the channel. Check dams of rock or of concrete should be placed at intervals along the outlet ditches, to prevent erosion, just as is recommended for gullies. Tile drains across the terrace lines, when they can be led to suitable outlets and provided with drop inlets behind the terraces make effective outlets. For methods and precautions for the construction of tile drains see Minnesota Special Bulletin 149, "Farm Drainage Practice."

How to construct terraces.—After the terrace is laid out, backfurrow a strip along the line of stakes about six furrows wide. Then drag the dirt to the center with a V-shaped drag, a road grader, or an adjustable terracing machine, several types of which are now on the market and giving satisfaction. (See Fig. 22.) These are made in different sizes, suited to either horse or tractor power. Experience at this station shows that if time is valuable a heavy road grader or terracer-grader with a high, curved adjustable blade and drawn by a crawler type tractor of sufficient power to draw the load with ease is the most effective and economical equipment. Continue plowing and dragging until the terrace is of the proper height, 15 to 24 inches. The top of the terrace should be checked with the level to see that it has been built to the proper height. If not high enough, it should be raised.

Order of construction of terraces.—The top terrace should **always be constructed first.** If it should rain before the job is completed the upper terrace could take care of the water falling above it; but if a lower terrace were constructed first it might not be able to carry all the water draining from above. In this case it would be washed out, causing greater damage than would unchecked erosion on an unterraced field.

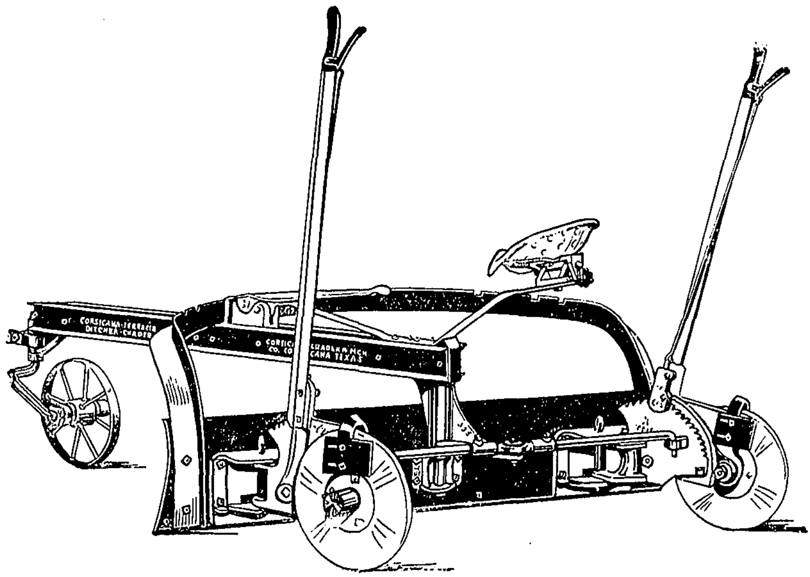


Fig. 22. A terracing machine much used with satisfactory results.

COST OF EROSION CONTROL

Cost of gully control.—Owing to the fact that gullies differ widely in size and general character, and, hence, require a great variety of methods of control, it is not possible to give even a range of costs of gully control that will be a reliable guide. The prices of construction materials can be had readily from local dealers and further counsel may frequently be obtained from the county engineer.

Cost of terracing.—The cost of building terraces is influenced by several variable factors. Terraces cost much more to construct in wet soils than in dry soils, and more in heavy soils than in light soils. Roots, rocks, sprouts, and stumps, as well as gullies in a field, add materially to the cost of terracing. Terrace-building by an inexperienced operator is likely to cost much more than terrace-building by an experienced one. The cost per acre will be greater on steep slopes and on short terraces than on flat slopes and on long terraces. Terracing by the regular farm forces during periods when farm work is slack is a recommended economy in terracing-labor cost.

So few reliable data have, as yet, been collected on terracing costs that it is impossible to give a definite cost range; however, the data in Table 5, collected from the various sources shown, will prove useful as a guide to such costs. The quoted portion of the footnote in the table, altho copied from U.S.D.A. Farmers' Bulletin No. 1669, applies very well also to the other items in the table. Engineering costs are not included in the table, but these are almost negligible in terracing. In districts where terracing is likely to become general it will be well for some of the farmers to learn to run a level so that they can lay out terraces for themselves and their neighbors.

Table 5

Approximate Cost of Constructing Terraces

Sources of data	Description of land	Size of terraces Height, in.	Width, ft.	Cost, dollars	Remarks
A bank in Dallas, Texas		18	20	1.99 per 100 ft.	Total, 19,700 lin. ft. 20 major fills about 5 ft. high, 100 ft. long
Oklahoma Station (G. E. Martin)		20	25	2.50 per ac.	
An Oklahoma farmer		10-12	20	6.38 per ac. 1.50-3.80 per 100 ft.	For real reclamation For ordinary sandy slopes
Kansas Station	Badly washed and gullied fields. Average conditions			10.00 per ac. Approximately same as plowing same area	
O. W. Howe on home farm, Kansas	Smooth cultivated slopes, residual limestone soil, heavily eroded	10-12	32	1.75 per ac.	40 ac. tract, many gullies; used 30 H.P. crawler tractor and 12 ft. road grader
Minnesota Station	Heavily rolling, cultivated knoll, wind-deposited soil with residual limestone outcrops; several small gullies	12	30	8.75 per ac.	16-ac. tract; corn stubble bothered; used 20 H.P. crawler tractor in poor condition and 8-ft. road grader
	Smooth cultivated slopes in wind-deposited soil; no gullies	8-10	30	3.57 per ac.	25-ac. tract; used 20 H.P. crawler tractor and 10 ft. road grader; good operator
U.S.D.A. Farmers' Bulletin No. 1669	Clean-cultivated land, no gullies	15	20	1.50-2.50 per ac.	
	Grass or virgin land, no gullies	15	20	2.00-3.00 per ac.	
	Clean cultivated land, small shallow gullies	15	20	3.00-6.00 per ac.	Depending upon number of gullies
	Clean-cultivated land, gullies 3 to 6 feet deep	15	20	7.00-15.00 per ac.	Depending upon number of gullies
	Newly cleared land, no gullies, most stumps grubbed out	15	20	7.00-12.00 per ac.	Depending upon kind and number of roots and stumps

* Terraces not less than 1,000 feet long, in light soils on moderate slopes "The costs given above are based upon the use of a steel ditcher or terracer of the V shape or grader type. In using a wooden V drag the number of trips required to build a terrace to a given width and height is greater than that necessary with a steel ditcher or terracer, the time required amounting to from one-fourth to one-half more. When the labor and power are paid for in cash the terraces thus constructed cost from 25 to 40 per cent more than when constructed with the steel terracer, depending upon soil conditions. Cost records also show that terraces built with a road grader in the hands of an experienced operator cost about 25 per cent less than when constructed with the steel terracer. For heavy soils about 50 cents per acre should be added to the costs given in the table."

TILLAGE OF TERRACED FIELDS

Terraces on natural slopes having a fall up to 10 feet in 100 feet can be crossed readily with any modern field machine, hence it is possible to plant and cultivate diagonally across them. (See Fig. 23.) It is better, however, not to cultivate along or across terraces the first year. If it is done, they should be watched with extra care to see that no breaks occur. All weak places and breaks should be repaired after each rain. All cultivated terraces should be graded up at least once each year. On slopes having a fall in excess of 10 feet per 100 feet the crop

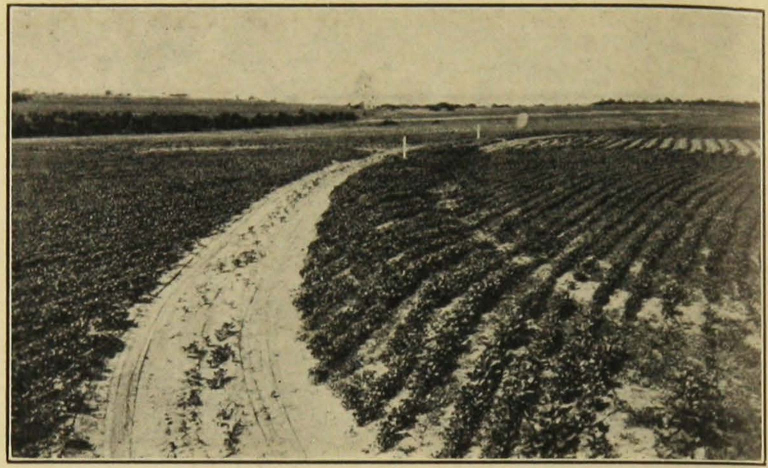


Fig. 23. Soybeans planted in rows diagonally across a Mangum terrace. Courtesy the U.S.D.A. Bur. of Agr. Eng.

rows should run parallel to the terraces and this practice is recommended for all cases.

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