Contour Furrowing, Pitting, and Ripping on Rangelands of the Western United States[1]

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Highlight

The effects of mechanical treatments, such as contour furrowing, pitting, and ripping, on forage production and water storage were measured in Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. Of seven kinds of mechanical treatment evaluated, contour furrowing at 3- to 5-foot intervals and broadbase furrowing were most effective. The greatest beneficial responses occurred on medium- to fine-textured soils. Measurements at 20 locations including 8 types of vegetation receiving a single kind of treatment, contour furrowing, revealed that Nuttall saltbush responds most favorably to the treatment. Winterfat, black grama, and needleandthread provided unfavorable sites for mechanical treatments.

Mechanical land treatments such as contour furrowing, pitting, and ripping have been applied for more than 30 years in efforts to improve forage production, and to control erosion and floods. According to Caird and McCorkle (1946), over a million acres of pasture and rangeland were contour furrowed between 1934 and 1940. The practice has been continued and the number of acres that have been treated is now much greater. Although mechanical treatments have been applied extensively, relatively few published reports contain quantitative data on the results of such treatments. To obtain a better understanding of mechanical-treatment effects, the investigation reported here was conducted over a wide geographic range and on a variety of soil and vegetation types.

Field and laboratory assistance by L. M. Shown and William Buller is greatly appreciated.

Review of Literature

The many kinds of implements used to treat range- and pasturelands mechanically include mouldboard plows, listers, disc plows, rippers, motor patrols or road graders, the Holt trencher, the Kansas furrower (picks up a slice of sod and places it downslope), the Iowa furrower (lifts a slice of sod and pushes soil under it to make a furrow 6 to 8 inches deep), and the Model B contour furrower developed by the U.S. Forest Service. Large trenches designed primarily for flood control require larger implements, such as the "Pocatello plow" (Querna, 1938) or bulldozers (Bailey and Copeland, 1961).

Various spacings and depths of contour furrows have been used. The U.S. Soil Conservation Service (Bennett, 1939) considered furrows 5 inches in depth and spaced 42 to 84 inches apart the best for "heavy land with deep topsoil" but "ridges" were most effective on "sandy land sloping not more than 3%." Barnes (1948), in southeastern Wyoming, found that spacing furrows more than 5 ft did not significantly improve forage production and that spacings of 2 ft were the most effective and profitable. Spacings of 10, 20, and 30 ft affected such a small portion of the total area that little increase in production resulted.

There are few reports on the longevity of furrows. Caird and McCorkle (1946) estimated the longevity of listed furrows in Texas to be about 7 years. In the desert grassland of southern Arizona, Brown and Everson (1952) found that furrows and furrowing effects were present 10 years after treatment. The ripped furrows produced 2.5 times more grass than adjacent untreated range at the end of 10 years, and the authors estimated the longevity of ripped furrows to be about 15 years.

Climate, soil, grazing management, vegetation types, implements and their use affect the results of treatments applied. In Texas, Dickenson et al. (1940) reported that listed furrows 3 inches deep increased grass yields as much as 3.9 times. Soil moisture storage in the surface 6 ft of soil was 2.63 inches on the listed area but only 1.19 inches in the soil of the untreated grassland. In Canada, Hubbard and Smoliak (1953) found that furrows became filled with ice and snow, making them valueless for holding or spreading spring runoff. Spacing of the furrows (more than 10 ft) and their shallow depth (only 4 to 5 in) were thought to have contributed to the lack of favorable response from furrows in Canada. Five kinds of mechanical structures, including contour furrows, failed to cause improvement in vegetation cover in New Mexico (Valentine, 1947). The sandy nature of the soil was considered to be one of the causes of the failures.

The reports of favorable response to contour furrowing, such as some of the references cited above, are from arid and semiarid climates. The few reports available from the humid east (Smith, 1941; Stallings, 1945) do not show significant beneficial results of its use. The exact precipitation quantity where furrows become ineffective apparently is unknown.

In the past, contour furrows have been applied in an effort to improve native range, but in re-

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cent years seeding of native and exotic species has been included as a part of the practice. Two recent reports have shown that furrowing and seeding of crested or desert wheatgrass *(Agropyron desertorum)* increased forage yields. In Montana forage yields were increased 118% (Branson, Miller, and McQueen, 1962) and in Wyoming 136% (Nichols, 1964). In both States the treatment was applied to stands of Nuttall saltbush *(Atriplex nuttallii)*. Crested wheatgrass production was increased from nothing on untreated sites to 270 lb/acre in Montana and 481 lb in Wyoming. In addition to increased grass production, contour furrowing also increased the yields of the native nuttall saltbush in Montana and Wyoming. The furrow spacing was 3 ft in Montana and 5 ft in Wyoming.

Large structures, such as terraces, have seldom been considered practical on rangelands, mainly because of the high construction expense. In Oklahoma (Cox et al., 1951), terracing increased runoff and reduced grass production. Unterraced land had only 13% runoff and produced 3,911 lb/acre of hay, but terraced land had 25.6% runoff and only 1,203 lb of hay production.

Pitting is a mechanical treatment that has been extensively applied on rangelands during the past decade (Barnes, 1952; Lang, 1961; and Rauzi, Lang, and Becker, 1962). Implements used in pitting are of two general types, the eccentric disc and the spike tooth or rotary pitter. Pits made with the eccentric disc vary in size according to the machine used, but are usually 2 to 6 ft long, 6 to 8 in wide, 3 to 6 in deep, and spaced 16 to 42 in apart. Spike tooth or rotary pitters usually make pits 10 to 18 inches in depth and spaced 3 to 6 ft apart. Forage production was increased 30 to 100% by eccentric disc pitting on short grass range in southeastern Wyoming (Barnes et al., 1958). Life of the pits was estimated to be at least 10 years. Pitting in Wyoming was considered to be of little value on sandy soils, wheatgrass bottomlands, dense sagebrush, or rangelands in poor condition. Pitting failed to cause seedling establishment in Wyoming but appeared to cause seedling growth in Arizona (Anderson and Swanson, 1949). In Texas, pitting was found to be less effective on fine-textured soils on tobosa flats and old lakebeds than on upland soils (Barnes et al., 1958). These authors stated that rotary pitting increased moisture penetration and increased plant yield 100% in eastern Colorado the first year after treatment.

Ripping, chiseling, subsoiling, and deep plowing are all terms applied to a similar treatment. The objective of the treatment is to fracture the soil, especially the subsoil which may have a "hardpan," and thus increase water infiltration and storage. Implements used for ripping are usually equipped with wheels and with vertical blades that penetrate the soil 14 to 30 in, requiring tractors the equivalent of Caterpillar D-6 to D-9. As a general practice subsoiling or ripping has not resulted in large yield increases or greatly improved soil conditions (Frevert et al., 1955). Ripping with a chisel to depths of 12 to 15 in with spacings of 5 to 30 ft gave no significant improvement in plant production in Wyoming (Barnes et al., 1958). An intensive study of the effects of ripping in New Mexico (Dortignac and Hickey, 1963; U.S. Forest Service, 1964) revealed that runoff and erosion were decreased by the treatment, but attempts to seed forage species during 3 successive years were mostly unsuccessful. The soil ripper used in New Mexico had a rotating soil auger behind the lower point of each chisel. A channel or soil pipe about a foot in diameter was created at the bottom of each ripped furrow, resulting in some instances in enlargement of the ripped furrow and gully formation. On this saline silty clay, runoff and sediment yields were reduced 96 and 85% the first year and 85 and 31% the third year.

Methods

During the growing season of 1964, the effects of mechanical treatment on rangelands administered by the Bureau of Land Management were measured in Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. A variety of site conditions were considered essential for the determination of optimal and minimal requirements for mechanical treatment success. Variables evaluated in the study included kinds of mechanical treatments, soils, vegetation types, and variation in precipitation, altitude, latitude, and longitude. To sample this large geographic area in one season, relatively rapid field methods were required. Vegetation was measured by the use of the all-contacts point quadrat method of Levy and Madden (1933). Sampling at each site consisted of 200 pin projections in treated and adjacent untreated areas. A regression line of yields and point quadrat data obtained from previous work by the authors (unpublished) permitted conversion of point quadrat data for grasses to estimates of yields. The regression line ($Y = 12.8 + 1.09_x$) was derived from a total of 2,670 pin projections into 89 yield plots in a variety of vegetation types. The correlation coefficient ($r = .541$) was significant at the one % level. Pin projections were spaced 2 in apart along a tape stretched across treated and adjacent untreated land. Where possible, sampling was done on areas that had been treated 3 years or more prior to the season of sampling, because a minimum of 2 years is usually required for seeded grasses to reach full development. An additional objective was to evaluate the effects of different time intervals on the various kinds of treatments.

Field characterization of soils and obtaining samples for laboratory analyses were accomplished by means of a pit dug at each site. Samples from the A, B, and B_3C_1 were placed in separate cloth bags and retained for laboratory analysis.

In the present study the average maximum depth of root penetration was considered the lower extent of the B_3C_1 horizon. Laboratory analyses included determinations of saturated soil percentage (Method 27b, Richards, 1954), electrical conductivity of saturated soil samples (Method 5, Richards), and pH of saturated soil samples by the use of a glass electrode pH meter. Saturated soil percentages were measured because the results are quantitative and can be related to field moisture storage capacity.

Results and Discussion

Annual precipitation on the study areas ranged from 8 to 15 in and altitudes were 2,000 to 8,000 ft. No well-defined relationship was found between these variables and responses to treatments. Although not consistent, the latitudinal range of 16° 20′ (31°40′ N. to 48°00′ N.) appeared to have some effect on treatment response. In general, more areas were successfully treated in Montana and Wyoming than in Colorado, Utah, Arizona, or New Mexico.

For ease of understanding, the data are grouped to show the effects of soil characteristics, kinds of mechanical treatment, and vegetation types. Included in the 58 areas sampled are 20 vegetation types, 7 kinds of mechanical treatment, and a variety of soil conditions.

Soil Effects

Factors related to soil-moisture storage capacity are probably the most important determinants of success or failure of mechanical land treatments. If soils are coarse enough there will be little or no runoff and no beneficial response can be expected from mechanical treatments. The primary purposes of mechanical land treatments are to reduce runoff, thereby increasing moisture storage for plant use, and to decrease sediment and water movement from the treated sites. These generalizations leave unanswered the questions, "What soils are too coarse to respond beneficially to treatment?" and "Do soils become too fine to respond favorably to mechanical treatment?" To supply answers to these questions, data are shown in Fig. 1

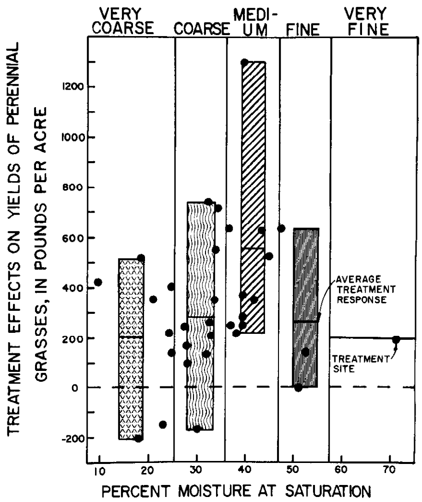

FIG. 1. Relationships between moisture storage capacities (saturation percentages) and increase or decrease in perennial grass production due to mechanical land treatments. Subsurface treatments such as auger ripping are not included.

from one kind of mechanical treatment, contour furrows made by the Model B furrower, on a variety of soil textures. The soil-saturation percentages in Fig. 1 are weighted averages for soil columns sampled at each site. Soil of medium texture is the most favorable for this treatment, as shown by differences in perennial grass yields. Nearly all of the treated sites were seeded to crested wheatgrass at the time furrows were made. The few instances in which contour furrowing actually decreased perennial grass production were found on sandy or gravelly soils. However, it is also apparent that on fine and very fine soils plant production increases were not as great as on medium-textured soils. The data indicate that medium- to medium-fine textures are most suitable for mechanical treatment. Most of the sites that responded favorably to mechanical treatments were also characterized by sparse plant cover and moderate to high runoff rates.

Plotted data for soil osmotic stress and treatment responses showed a slight negative relationship between yields and stresses, but there were exceptions. There is no apparent relationship between pH and responses to mechanical treatments.

Effects of Kinds of Mechanical Treatments

Although many factors are associated with treatment success or failure, different kinds of treatment have different effects on soil surficial geometry and can be compared and related to plant responses (Fig. 2). Kinds of treatments will be described separately.

The *Model B contour furrowing* machine developed at Arcadia, Calif., by the U.S. Forest Service (Fig. 3) has been used extensively on the Public Domain in Montana and Wyoming and on scattered tracts in Colorado and New Mexico. The machine makes two furrows 5 ft apart, 8 to 12 in deep, 20 to 30 in wide, and dammed at intervals of 4 to 20 ft. The damming device makes furrowing on an exact contour less critical than for furrows without dams. The machine is equipped with a broadcast seeder with seed tubes spaced about 10 in apart. Power required to pull the machine is a Caterpillar D-6, D-7, or D-8 or its equivalent. The power required is dependent upon kind of soil and depth of furrowing. Cost of the treatment including grass seeding has ranged from $3.50 to $15.30/acre.

As can be seen in Fig. 2, contour furrowing was the second most productive treatment sampled. The average increase in perennial grass yields for the 26 sites sampled was about 500 lb/acre. Because of similar effects on soil surface and vegetation, the results of 3 machines other

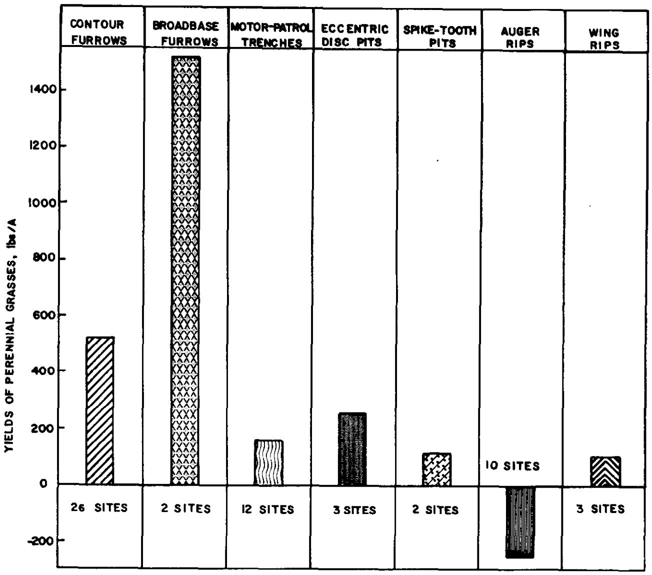

FIG. 2. Effects of different mechanical treatments on yields of perennial grasses. Average yields shown are differences between treated and adjacent untreated land.

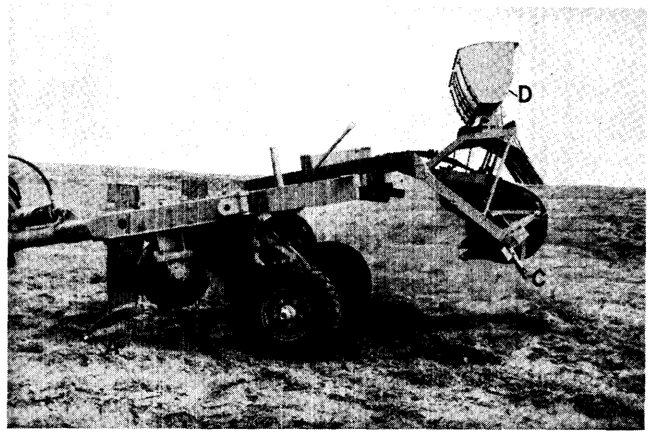

FIG. 3. View of the Arcadia Model B contour furrowing machine showing (A) ripper tooth which rips soil about 2 inches below depth of furrow, (B) discs that open furrow, (C) damming device, and (D) broadcast seeder box and tubes. (Photo by Bureau of Land Management, Worland District.)

than the Model B contour furrower, sampled at a total of 5 sites, are included in the average for contour furrows.

When newly constructed, the water-storage capacity of furrows made by the Model B furrower exceeds 2 in of precipitation. For most of the area studied, a 2-hour rainfall of this intensity would not be expected more frequently than once in 50 years (Hershfield, 1961). Assuming infiltration rates of at least 0.5 in/hr the storage capacity should not be exceeded.

With time, the storage capacity of furrows decreases (Fig. 4). In general, it decreases rapidly during the first 5 years to less than one inch of precipitation, and thereafter tends to stabilize at about 0.5 inch after 9 or more years. In Montana, furrows spaced 4 ft apart retained a storage capacity of 0.6 inch at the end of 15 years. With spacings greater than 5 ft, the furrows often became breached by runoff that exceeded furrow storage capacity. This was true even in areas with annual precipitation of less than 10 in. These data and

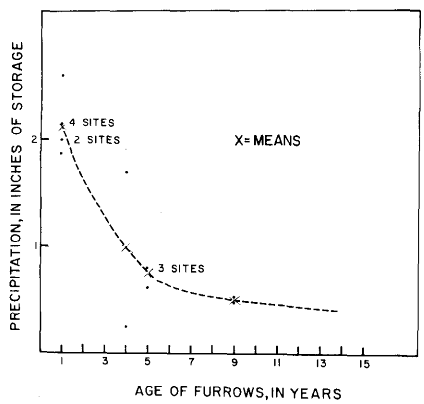

FIG. 4. Decrease in water storage of Model B contour furrows as affected by time. Note the rapid decline in storage during first 5 years. Storage capacities were computed from field measurements of depth, width, and spacing of furrows.

observations apply to areas with medium- to fine-textured soils—on sandy soils furrows were seldom damaged by runoff and also had little effect on runoff or vegetation.

Broadbase furrows (Fig. 5) differ from the usual contour furrows or trenches. In broadbase furrow construction a motor patrol or similar machine is used to push earth downdrainage to form low dikes 1.5 to 2 feet in height. The series of low dikes thus formed resemble waterspreaders but differ in that water is not diverted onto the systems from intermittent streams. Only incident moisture and moisture from adjacent hillslopes is applied to the treated area. The very high yields, over 1,500 lb/acre from the 2 sites sampled, may represent exceptionally good conditions for the treatment, but they are impressive enough to suggest that the treatment might be tried elsewhere. Annual precipitation for the area is about 9 in and soils are of medium to coarse texture. The Nuttall saltbush vegetation type was present prior to the construction of broadbase furrows and seeding of crested wheatgrass and Russian wildrye (*Elymus junceus*).

To produce favorable results, perhaps this treatment should be applied only to areas having characteristics similar to the sites sampled. It should be noted that only the upper portions of narrow valleys having low drainage divides were treated.

FIG. 5. Broadbase furrows showing vigorous growth of seeded grasses in catchment area above furrow. Height of the black and white scale is 30 cm.

FIG. 6. Detrimental effects produced by auger ripping to depth of 18 inches. Treatment does not result in a furrow to catch and retain moisture. Area treated 7 years prior to photographing. Grasses are galleta *(Hilaria jamesii)* and alkali sacaton *(Sporobolus airoides)*.

Motor patrol trenches are relatively ineffective in improving grass production (Fig. 2). However, on most of the 12 sites sampled motor patrol trenches appeared to be effective in reducing runoff and sediment yields. Contour trenches are larger structures than contour furrows, and in the areas sampled their depths ranged from 18 in to 2.5 ft when constructed. Owing to wide spacings, 15 to 200 ft, the water-storage capacities of trenched areas were lower than for contour furrows spaced at 5-ft intervals. These statements about runoff and storage capacities of motor patrol trenches and contour furrows are contrary to expected results. They are partly explained by the fact that most of the motor patrol trenches were created in medium- to coarse-textured soils which had high infiltration rates and low runoff rates before treatment.

Because of their larger size, contour trenches retained effectiveness for longer periods than most of the other treatments studied. Nevertheless, one of the oldest treatments sampled showed a reduction of nearly 90% in water-storage capacity at the end of 24 years.

The cost per acre of motor patrol contour trenching is affected by size of area treated and spacing between furrows. For small areas with closely spaced trenches the cost has been as high as $18.00/acre; widely spaced trenches have cost as little as $1.00/acre.

A number of areas treated with *spike-tooth or rotary pitters* were examined but were not sampled because no physical or biological effects could be observed. Some areas treated only 3 years before examination showed no treatment effects. The data in Fig. 2 are from an earlier study and represent the average values for samples obtained 1, 2, and 3 years after treatment. Yields were obtained by clipping under 10 portable exclosures in each of two pitted and two untreated basins. Yields of perennial grasses increased slightly as a result of pitting but total yields, including annual forbs such as Russianthistle *(Salsola kali)*, were nearly the same for the treated and untreated basins. Spike-tooth pitting is relatively inexpensive (contract prices of $1.65 to $3.58/acre), but our studies indicate that it is of questionable value as a land-treatment practice.

The *eccentric disc pitting* treatment effects reported in Fig. 2 were the result of a somewhat larger machine than is often used. The pits were 6 ft long, 6 to 8 in deep, and spaced 42 in apart. When constructed, the pits had a storage capacity of about 0.4 in precipitation. Water storage in pitted pastures at Archer, Wyoming (Barnes et al., 1958), was only 0.03 in/acre. At the end of 8 years the pits had been obliterated but the biological effect, growth of seeded crested wheatgrass, was evident. Areas that had been treated as many as 22 years previous to examination also showed no physical evidence of mechanical treatment, but several had stands of the introduced crested wheatgrass that had been seeded as a part of the treatment practice. It was not possible to determine whether seeding alone might have resulted in the stands of crested wheatgrass, but it is probable that pitting resulted in removal of competition and in favorable moisture and soil conditions for seedling establishment on the treated areas.

Cost of eccentric disc pitting has ranged from $1.00 to $5.00/acre, depending upon kinds of machines used, size of areas treated, and other cost factors.

Auger ripping is the only practice that was found to decrease perennial grass production (Fig. 2 and 6). The six ripping sites sampled had been treated by a machine known commercially as the Jayhawk Soilsaver. These unexpected results should be explained fully, but in the absence of detailed studies only hypotheses can be offered.

Although ripping thoroughly fractures the soil surface when the treatment is applied, there is little surficial or subsurface evidence of the treatment after 2 or 3 years. On soils containing gravel or platy shale, auger ripping forms ridges that remain 1 in high several years after treatment. In fine-textured soils a furrow about 1 in deep is formed. Neither of these minor soil surface modifications has a marked effect on runoff or water retention. If the statement by the U.S. Forest Service (1964) that "Near the bottom of the furrow, a channel about a foot in diameter is created by the auger" were of universal application, one might postulate that water becomes unavailable to plants because of movement in channels. However, careful examination of seven soil pits in areas ripped 2 to 10 years before sampling did not reveal subterranean channels or pipes.

Reduction of plant cover in the disturbed soil is caused by burial. Blue grama and galleta were killed even by shallow burial where this was induced by ripping. However, in one area, a sparse stand of western wheatgrass became established and in another, big sagebrush invaded the soil disturbed by ripping. The general failure of plants to reoccupy soil disturbed by the auger ripping remains mysterious, but it may be concluded that the mechanical disturbance creates an environment drier than that in undisturbed ground.

The above statements implying a decrease in moisture available for plant growth appear to be in conflict with the decrease in runoff reported by Dortignac and Hickey (1963). The possibility of lack of agreement of results is reduced by later statements by the U.S. Forest Service (1964):

"On some of the ripped plots, the amount of surface runoff decreased year after year. A survey of the plots showed subterranean channels or pipes were being formed, and runoff was occurring below the surface of the ground. These pipes often finally enlarge to form open gullies."

A recent modification of the auger ripper included a furrow opener or wings near the top of the blade. *Wing ripping* results are shown in Fig. 2. With 20-in wings or openers, a furrow or trench about 2 ft wide and 5 in deep is formed. Although in use for only a few years, the new machine appears to be far more effective than the unmodified version. At the end of 3 years, the furrow-forming auger ripper caused an increase in plant production on two lowland sites with run in moisture and a decrease in grass on a sandy upland site. These results support the view that soil surface, not subsoil, must be modified if conservation practices such as these are to be effective in retaining water and sediment and increasing forage production.

Most reseeding attempts with the auger ripper have been unsuccessful. One reason for these failures with both native and exotic species has been improper mounting of the broadcast seeder. All machines designed at present have seeding devices mounted in front of the ripper blade. The result has been that seed has been covered too deeply or the seed has been pushed to the sides of the furrow. Mounting the broadcast seeder on the rear of the Model B contour furrower has resulted in excellent stands of seeded grass such as shown in Fig. 9.

Commercially available construction rippers have produced more satisfactory results than the relatively thin blades used on auger rippers. Construction-type ripper teeth are 3 to 4 in wide as compared with auger support blades that are about 1 in wide. The wider ripper teeth create a furrow that improves infiltration and water retention. Ripper furrows in Arizona (Brown and Everson, 1952) increased forage production 2.5 times in the 10th year after treatment. In the present (1964) study, 24 years after treatment, resampling of the area revealed that the downslope furrow of each pair spaced at 5-ft intervals was still evident and that forage production was 1.6 times greater on the treated than on the untreated range (Fig. 7). Brown and Everson (1952) predicted that the longevity of the furrows might be 15 years, but both the furrows and their effects have persisted for 24 years and will obviously be present for many more years.

Field observations clearly indicated that, to have a lasting effect, mechanical treatment must modify the soil surface, not the subsoil, in such a manner that precipitation is detained and stored in the soil. Results of treatments such as spike-tooth and rotary pitting are apparently so temporary that they are of questionable value. On sites that were considered to be suitable for mechanical treatment, either insufficient intensity of treatment or failure to affect enough of the soil surface geometry caused poor treatment responses.

Effects of Vegetation Types on Responses to Mechanical Treatments

The 7 kinds of mechanical treatments discussed in the previous section were applied to 20 different types of vegetation. To remove the confounding effects of different treatments and to isolate the effects of vegetation types, data are shown in Fig. 8 for one kind of treatment sampled at 20 locations and including 8 types of vegetation.

FIG. 7. Response of desert grassland in Arizona to treatment by tractor-mounted construction rippers 21 years previous to photographing.

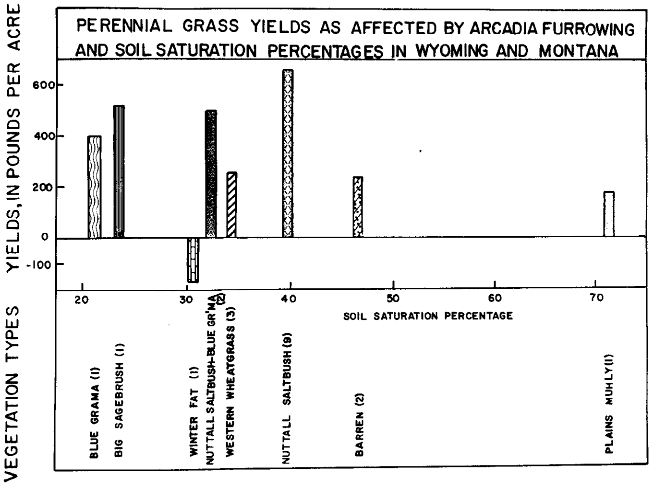

FIG. 8. Responses of different vegetation types to Model B contour furrowing. Bars in the graph represent increase or decrease in perennial grass production.

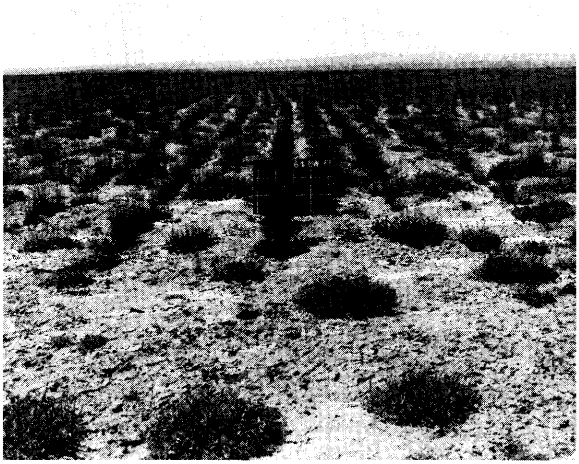

FIG. 9. Sparse cover of Nuttall saltbush in foreground and dense cover of crested wheatgrass and Nuttall saltbush in background resulting from contour furrowing and seeding with Arcadia Model B furrower.

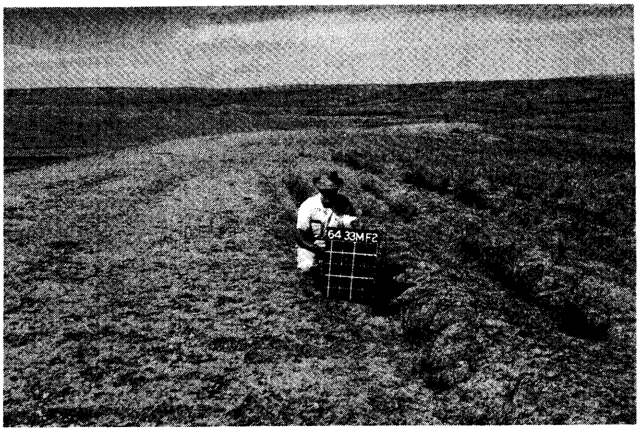

FIG. 10. A formerly barren site in Wyoming converted to a moderately successful stand of crested wheatgrass by Model B contour furrowing.

To one familiar with the sites on which the halophytic Nuttall saltbush is found, it may be surprising to learn that this vegetation responded more favorably to contour furrowing than did any other type sampled. The soils of only one vegetation type (barren) had a higher salt content, and only two types (the plains muhly and barren) had finer textures or higher saturation percentages (Fig. 8). Apparently when furrowed to reduce runoff, the increase in moisture storage for plant use was sufficiently beneficial to counteract possible detrimental effects of high osmotic stress due to salts.

In Fig. 9 the pre- and post-treatment conditions in a Nuttall saltbush type can be seen. In addition to increasing production of perennial grass, the treatment also increased yields of the palatable Nuttall saltbush. Obviously, spacing of the furrows at 5-foot intervals does not eliminate the species present before treatment. Also, contrary to the usual recommendation that grass seed should be drilled, broadcast seeding of crested wheatgrass here resulted in an excellent stand. It should be noted further that the seeder on the Model B contour furrower is mounted so that seed falls behind the machine. Although the result must be a variety of seeding depths, it is apparent that enough seed is planted at optimal depths to give satisfactory stands. Combined seeding and mechanical treatment requires application of the treatment at the optimum time for seeding success. It is generally recognized that fall seeding is favored in regions of high winter precipitation and spring seeding is advisable in regions with heavy summer precipitation.

A winterfat *(Eurotia lanata)* community was the only vegetation type to show a decrease in grass yields when contour furrowed. On this vegetation the effect of mechanical treatment was to destroy some of the valuable winterfat and inhibit the establishment of perennial grass. Salinity of this soil (4.3 mmhos/cm) may have contributed to the failure of grass establishment; however, on other sites where salinity was even higher, satisfactory stands of grass were established. Possibly some factor not measured in the present study inhibited the establishment of grass.

One objective of the study was to find both optimal and minimal sites in terms of potential for success of mechanical treatments. It was expected that sites devoid of native vegetation would have minimal potential, but field evidence revealed that even on barren sites some degree of success was achieved (Fig. 10). In terms of percentage increase of perennial grass, the increase shown in Fig. 10 is infinite. However, the average production for the two barren sites is low. These two sites were the most saline of the sites sampled —7.3 and 8.9 mmhos/cm in the A horizon and more at depth. At the more saline of the two sites, treatment resulted in widely spaced crested wheatgrass plants and in the establishment of the poisonous plant halogeton *(Halogeton glomeratus)* in the furrows. Therefore, it appears that some sites may be too saline for successful treatment but that for most sites salinity is not an important problem. Barren sites also had high soil-saturation percentages, or, stated differently, were clayey or fine textured.

In addition to the winterfat type, vegetation types that did not respond favorably to mechanical treatment were black grama *(Bouteloua eripoda)* and needleandthread *(Stipa comata)*. Both types are usually found on coarse soils that are not suitable for mechanical treatment. Variable results were obtained on alkali sacaton sites, but the variation appeared to be due to differences in kinds of implements used rather than to soil characteristics. Yields of blue grama *(Bouteloua gracilis)* were decreased by mechanical treatment of coarse soils.

Effects of Mechanical Treatments on Soil Moisture and Chemistry

Intensive study 10 years after furrowing and seeding in Montana (Branson, Miller, and McQueen, 1962) showed that soil moisture and plant production were increased by the treatment. Some unpublished data obtained in the Montana study are presented below. The average moisture storage in two soil types during 2 years of measurement was nearly 8% greater in furrowed soils than in unfurrowed soils (Fig. 11). Although this increase in moisture does not appear to be great, forage production on the treated area was increased by 118%. Moisture storage must have been greater during the years immediately after treatment than during the sampling period, because aboveground water storage in furrows decreases with time.

The furrowing treatment caused a decrease in salts in the upper portion of the treated soils (Fig. 12). Calcium and magnesium were decreased from 51 to 8 (milliequivalents per liter) and sodium from 41 to 6 meq/l in the upper 10 cm of soil. Concentrations of these elements at lower depths indicated that furrowing caused movement of ions to and below 60 cm. The removal of salts from the upper portions of soils should result in greater availability of water to plants.

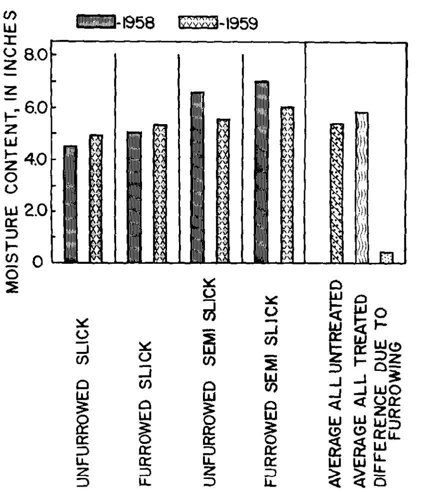

FIG. 11. Effects of contour furrowing on soil-moisture storage 10 years after treatment. Quantities of water shown are for the upper 30 inches of soil.

Summary

The effects of mechanical treatments, such as contour furrowing, pitting, and ripping, were measured in Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. Included in the study of 58 sample areas were 20 types of vegetation, 7 categories of mechanical treat-

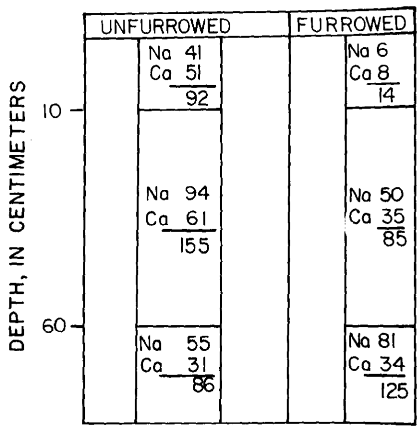

FIG. 12. Translocation of cations in furrowed soil 10 years after treatment. Furrowing caused a decrease in salts above 60 centimeters and an increase in salts below 60 centimeters. The cation quantities shown are milliequivalents per liter of saturated soil past extract.

ments, and a variety of soil conditions.

The most consistent beneficial responses to mechanical treatments occurred on medium- to fine-textured soils. Except under a few extreme conditions, salinity and pH did not appear related to treatment success.

Of the seven kinds of mechanical treatments, the two that were the most effective were contour furrowing at intervals of 3 to 5 ft and depths of 8 to 10 in, and broadbase furrowing which consisted of low dikes about 1.5 ft in height.

Biological effects of mechanical treatments persisted many years but storage capacities of most mechanical treatments decreased rapidly during the first 5 years after treatment.

The Nuttall saltbush sites, although saline and fine-textured, showed the most improvement in forage production of 8 vegetation types treated by Model B contour furrowing. Treatment of winterfat resulted in a decrease in perennial grass production. Other vegetation types that did not respond favorably to mechanical treatment were black grama and needleandthread.

Contour furrowing increased moisture storage and caused the transport of salts from surface layers to depths of 60 cm or more.

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