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CONSERVATION TILLAGE FOR MINED-LAND REVEGETATION IN SOUTHWESTERN UNITED STATES

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INTRODUCTION

Science and technology for conservation tillage of croplands and rangelands has reached an advanced stage in the United States (Larson et al., 1978; Unger et al., 1977). Similar tillage technology has been successfully adapted and applied to reclamation of strip-mined land in the Appalachian and northern Great Plains regions (Armiger et al., 1976; Power et al., 1978). Conservation techniques used for revegetation of degraded rangelands, abandoned farmlands, highway embankments, and urban and industrial construction sites in southwestern United States can be applied, with minor modification, to vegetal reclamation of mined lands in this region (Dixon, 1977; Dixon and Simanton, 1978; Vallentine, 1974; Wright et al., 1978).

The need for efficient soil and water conservation measures in arid and semiarid mined lands is extremely critical. Annual precipitation averages from 4 to 14 inches with wide fluctuations in both annual and seasonal amounts. Because of absence of organic matter (and associated aggregation of primary particles) and presence of coarse gravel and rock fragments, these spoils have relatively low water-holding capacities. Furthermore, they disperse and seal at the surface under raindrop impact, thereby reducing infiltration rates to near zero. This fact, combined with high-intensity summer thunderstorms, means that runoff, erosion, flash flooding, and sedimentation hazards are high. In addition, nonuniform packing and sorting of the overburden materials contribute to a high incidence of piping.

Thus, rainwater that doesn't either runoff or run down pipes infiltrates the spoil surface superficially and is soon dissipated as surface evaporation. For these reasons, successful revegetation of southwestern mine spoils represents a challenging adaptation and application of conservation tillage practices.

Whereas a single conservation practice can be successful in establishing corn and wheat in the Corn Belt and Great Plains, a combination of complementary practices is usually required for successful revegetation of degraded rangelands and mined land in the Southwest. This is because cumulative conservations resulting from several complementary practices are usually required to offset the water-limiting conditions of (1) low and erratic rainfall, (2) high potential evapotranspiration, (3) low spoil water-holding capacity, and (4) low infiltration rates and shallow penetration depths.

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TILLAGE TOOLS AND FUNCTIONS

A wide range of tillage implements (usually modified versions of agricultural and industrial equipment) are available for rangeland and mined-land revegetation (Vallentine, 1974; Hodder, 1977). These implements perform such conservation functions as spoil loosening, mixing, and firming; rainwater shedding, concentrating and infiltrating; and spoil water conserving and using. Loosening and mixing are performed by rippers, subsoilers, and chisels; firming by packers, rollers, and drags; shedding, concentrating and infiltrating by basin formers, pitters, furrowers, and land imprinters; and conserving and using by mulchers, shreddders, cutters, planters, seeders, and drills. Establishing vegetation to use the spoil water is indirectly a conservation measure, because the water will be lost as evaporation if not used in transpiration.

Conservation tillage needs to be directed to holding spoil and water resources in place, not only to enhance vegetal cover establishment, but also to prevent these resources from becoming flash flooding, surface and groundwater pollution, and sedimentation problems in downslope land areas. The key to holding these resources in place is rainwater infiltration control within plant-sized areas. If the spoil surface can store and infiltrate rainwater as fast as it falls during intense summer thunderstorms, then, obviously, surface runoff, erosion, flash flooding, and sedimentation are nonexistent.

A newly-developed concept (referred to as the air-earth interface concept) for controlling rainwater infiltration (Dixon, 1972) can serve to interpret and unify the large array of conservation tillage practices to, in turn, facilitate their integration in a cost-effective system for mined-land revegetation.

AIR-EARTH INTERFACE CONCEPT

The air-earth interface (AEI) concept postulates that soil surface microroughness and surface macroporosity control rates and routes of water infiltration by governing flow of air and water in underlying macropore and micropore systems (Fig. 1 and 2). Exchange of soil air and ponded water occurs freely across a microrough and macroporous surface; consequently, water infiltrates rapidly via the relatively short, broad paths of the macropore system. In contrast, exchange of air and water is greatly impeded by a smooth sealed surface, and water infiltrates slowly via the relatively long, narrow paths of the micropore system. Field testing of this concept under diverse climatic, edaphic, and vegetal conditions indicated that rough open surfaces generally infiltrate rainwater about 10 times faster than smooth closed surfaces (Fig. 3). In addition, water entering via rough open surfaces is less susceptible to loss by evaporation since it is routed deeply into the soil along macroporous paths. Transformation of the smooth closed surface to a rough open one is greatly facilitated by the presence of some plant material that can be used as a mulch (Dixon, 1974). The mulch not only shields the soil against falling raindrops but also feeds the small soil invertebrate animals (ants, termites, etc.) which perforate the soil surface and underlying soil with their burrows, thereby creating macropore systems that can rapidly infiltrate rainwater and exhaust the displaced soil air (Fig. 1 and 2).

Since conservation tillage for mined-land revegetation entails conversion of a smooth closed AEI into a rough open one, the processes active in the development of these interfaces will now be discussed.

ROUGH-OPEN AEI

The rough-open AEI system is a natural consequence of soil genesis. This condition is created by numerous physical and biological processes acting over a long period of time. It is a living system which is maintained and improved by intense biotic activity at the AEI and directly below it (Dixon, 1974). This AEI is especially well developed in the tall grass prairies of the Corn Belt and eastern Great Plains regions where the ratio of annual precipitation to pan evaporation is one or greater. If the rough-open condition is destroyed by land disturbances such as clean tillage or overgrazing, it can be restored rather rapidly by reseeding to grasses, assuming the topsoil has not been eroded away in the meantime.

In southwestern grasslands, the rough-open AEI is not so well developed, especially at the lower elevations where the ratio of annual precipitation to pan evaporation is about 0.1 (based on 10 inches of rainfall and 100 inches of pan evaporation). Here, the rough-open AEI is fragile, can be easily disturbed, and is difficult to restore because of the thin soils, limited and unpredictable rainfall, and high evaporative demands (Dixon and Simanton, 1978).

SMOOTH-CLOSED AEI

In humid and subhumid regions, the closed AEI is usually a consequence of repetitive man-induced land disturbances. Although this AEI condition may occur naturally in arid and semiarid regions (especially as a consequence of extended periods of drought), its formation and maintenance is accelerated and favored by man's disturbances that strip the land of its protective vegetal cover, including such activities as dryland cropping of marginal lands, overgrazing of rangelands, road building, pipeline installation, urban and industrial construction, and mining. One such disturbance on sloping land is often all that is needed to set a vicious cycle of land degradation or desertification into motion that increasingly aridifies the plant's environment (Fig. 4). Once denuded, the land surface becomes tightly sealed under intense rain, infiltration rate falls off sharply, runoff accelerates abruptly, and networks of rills and gullies develop which efficiently drain rainwater from the upland slopes. The small amount of rainwater that does intiltrate penetrates the soil so superficially that it is quickly lost by surface evaporation. Thus, the rainwater that once infiltrated to nourish biotic activity is now largely dissipated as surface runoff and surface evaporation. Erosional loss of topsoil and the consequent loss in water-holding capacity, combined with increasingly improved surface drainage, accelerate these losses even more.

When desertification has reached this point, reversal is difficult and costly. Essential parts of the functional AEI infiltration system are either lost or severely damaged, including the topsoil and associated biota. The proposition set forth by Aldo Leopold that "the first prerequisite of intelligent tinkering is to save all the parts," has perhaps been violated (Nature Conservancy Staff, 1975). The land's life and life support system have been severely damaged, if not completely lost. If the old parts are beyond repair or lost, new parts will have to be trucked in to rebuild a functional AEI system capable of producing biomass while conserving and protecting the land resource base.

SMOOTH-CLOSED AEI VS. ROUGH-OPEN AEI

The smooth-closed infiltration system is characterized by an absence of vegetal cover, low levels of biotic activity, low infiltration rates, shallow water penetration depths, high runoff rates, high erosion rates, high surface evaporation, low biomass production and low water-use efficiency. It sheds most of the rainwater from high-intensity storms and evaporates most of the water from low-intensity storms. The smooth-closed system in upland areas causes severe problems in downslope areas including flash flooding, surface water pollution, groundwater pollution, and sediment filling of water courses and reservoirs. Deep infiltration, percolation, and groundwater recharge are largely restricted to the basal areas of downslope water courses (Dixon, 1977).

In contrast, the rough-open infiltration system is characterized by an abundance of low-growing vegetative cover, abundance of plant litter diffusely distributed vertically across the AEI; high levels of biotic activity including diverse plant communities, soil invertebrate animals, fungi, actinomycetes, and bacteria; high infiltration rates, deep penetration of water, low runoff rates, and low erosion rates; and low surface evaporation, high transpiration, high biomass production, and high water-use efficiency. This system absorbs most of the rainwater from high-intensity storms and conserves most of the water from low-intensity storms for nourishing biotic activity. The rough-open surface in upland areas effectively holds soil and water resources in place, thereby protecting downslope areas from flash flooding, surface water pollution, groundwater pollution, and sediment clogging of water courses and reservoirs. Infiltration, deep percolation, and groundwater recharge are diffusely distributed within the land area possessing the rough-open infiltration system (Dixon, 1977; Wadleigh et al., 1974).

AEI CONCEPT APPLICATION

Land imprinting is a new concept in conservation tillage involving the formation of networks of closed-geometry V-furrows without inversion of the soil surface (Fig. 5). Land imprinting evolved from the air-earth interface concept which states that rainwater infiltration is controlled by the two soil surface conditions--microroughness and macroporosity. Land imprinting is a practical method for controlling or manipulating these two conditions.

Design of land imprinters depends on the land management objective, soil conditions, and climatic conditions. The rangeland imprinter is designed to create surface conditions that concentrate, infiltrate, and conserve rainwater, thereby making more of this life-limiting resource available for seed germination, seedling establishment, and forage production in semiarid and arid regions. Rainwater is concentrated in seedbeds and seedling cradles by gravity flow from a series of water-shedding furrows. Water is absorbed by the seedbeds and seedling cradles which are a series of cross-slope furrows interconnecting with the shedding furrows (Fig. 5). Conservation of the absorbed rainwater is a consequence of both rainwater-concentrating and plant material-mulching functions of the rangeland imprinter. The concentrated (accumulated) rainwater penetrates the soil more deeply, and thus is less susceptible to loss by surface evaporation. The imprinter-formed mulch conserves the absorbed rainwater by suppressing evaporation and by increasing infiltration rates. Increased rates of infiltration, in turn, conserve rainwater by reducing runoff losses and by increasing the depth of water penetration per unit of rainfall.

Compared with a bare surface, water infiltrates more rapidly and more deeply under a mulched surface because soil macropores function better as major fluid flow routes.

Soil conservation is a consequence of (1) improved surface cover, (2) increased depression storage, (3) reduced runoff, and (4) conversion of concentrated runoff to diffuse runoff. Energy conservation results from the performance of a number of tillage functions in a once-over operation including weed controlling, mulching, soil firming, forming of seedbeds and seedling cradles, and seeding. An inexpensive broadcast seeder is mounted on the rangeland imprinter tow frame to disseminate a seed mix beneath the imprinting roller. The angular imprinting teeth press the seed in close contact with the soil to improve moisture flow during germination and seedling establishment. Attachments for spreading soil amendments, fertilizers, and herbicides may also be mounted on the tubular frame which surrounds the imprinting roller.

Land imprinting is a mechanical means to a biological end. Imprinting mechanically converts a smooth-closed AEI into a rough-open one to enhance establishment of permanent vegetative cover. The resultant cover (and associated biotic activity) then improves and maintains the rough-open condition, assuming that the introduced plant species are well adapted to spoil and climatic conditions.

REVEGETATION SYSTEM

As discussed previously, a single conservation practice usually will not be successful in establishing permanent vegetative cover and the associated conversion of the smooth-closed condition to the rough-open one. Instead, an appropriately ordered and timed sequence of complementary practices (constituting a revegetation system) will be required for a high probability of success. The following sequence represents a suggested revegetation system for southwestern mined lands:

1. Apply a 6-inch layer of topsoil to enhance water-holding capacity and to introduce useful soil organisms.

2. Rip at least 12 inches deep to loosen the soil and underlying spoil, and to interrupt the sharp soil-spoil boundary.

3. Apply mulch at 2 tons per acre to accelerate soil invertebrate activity, increase infiltration, suppress surface evaporation, and improve seedbeds and seedling cradles.

4. Imprint land on the contour to form a rain-fed microfurrow irrigation system for enhancing seed germination, seedling establishment, and plant growth.

5. Seed with imprinter-mounted broadcast unit using a mixture which contains annual grasses and forbs for quick protective ground cover, and perennial grasses and shrubs for long-term biomass production and land resource conservation (This step performed simultaneously with step no. 4.).

6. Sprinkle-irrigate, if necessary, to insure stand establishment.

7. Manage by maintaining low populations of browsers and grazers to maximize extent of low-growing ground cover and surface litter.

Some of the foregoing steps may not be needed or alternate methods may be substituted, depending on prevailing spoil and climatic conditions. Much more field experimentation is needed to determine the most cost-effective revegetation system for a given set of spoil and climatic conditions.

REVEGETATION COSTS

Mined-land reclamation per acre costs are difficult to estimate because of extreme variability in spoil conditions, climatic conditions, and reclamation objectives (Cwik, 1979; Kennedy et al., 1977). Earth-moving costs may range from $500 to $4,500; conservation tillage practices from $100 to $300; chemical amendments from $100 to $400; and seeding from $100 to $200 for a grand total ranging from about $800 to $5,400 (Cwik, 1979). These estimates do not include the cost of supplemental irrigation which will vary widely depending on the availability of water, quantity of irrigation water needed, and the type of sprinkling irrigation system used.

Operating costs of the land imprinting seeder are estimated at about $20 per acre, including the seed. This cost is considerably less than the minimal estimates given above for tillage and seeding.

CONCLUDING REMARKS

Homo sapiens might be set apart from other animals as "the maker of tools for disturbing the earth." Man's intelligence and curiosity have even taken him to the moon for some minor disturbance of earth's only natural satelite. In the short run, his disturbances have been remarkably beneficial, but in the long run, he is literally losing ground to the insidious processes of land degradation or desertification (Dregne, 1979; Schumm, 1979). Such degradation is estimated to annually cost the world $16 billion in lost agricultural production, and is expected to reduce arable land area by one third by the year 2000, at which time world food needs will have doubled (Biswas, 1978; Dregne, 1978).

In mining operations, lands are disturbed to uncover a nonrenewable resource capable of yielding only a single high value "crop." In the process, society loses a low value, but annually renewable crop of vegetation and the animals it supports. Our society is becoming increasingly aware of this loss and the need for revegetating these lands to recover at least some of the original production.

A wide selection of conservation tillage tools are at the disposal of the land manager for use in revegetation projects. Because of adverse spoil and climatic conditions in southwestern United States, such revegetation efforts will severely test the utility of conventional conservation techniques and tools.

Much field experimentation is needed to determine combinations of conservation practices rendering greatest cost effectiveness for a given set of spoil and climatic conditions. Much field testing is also needed to "fine tune"

servation techniques and tools to the unique conditions of these severely disturbed lands.

Results of these revegetation efforts will likely find wide application elsewhere in the world's ever-increasing acreage of degraded arid and semiarid lands.

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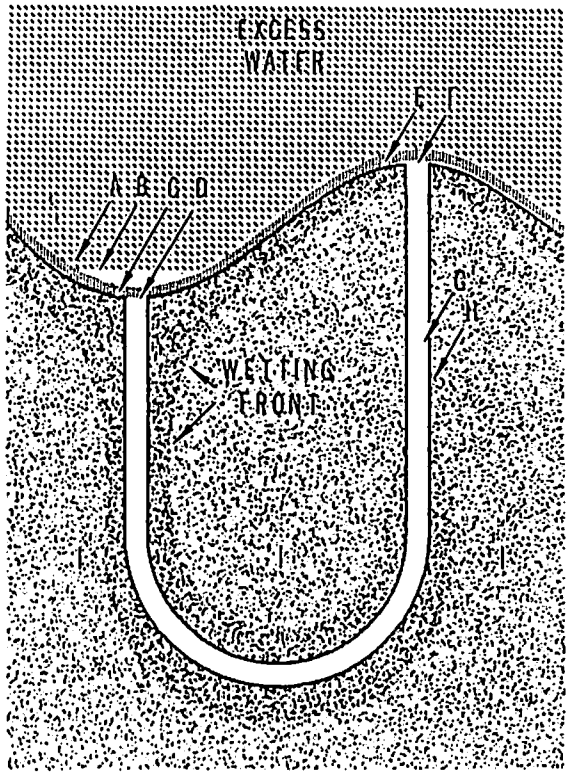

Fig. 1. Diagramatic soil containing a micropore system and a macropore system. The macropore system includes the space immediately above the air-earth interface and that within macropores, whereas the micropore system includes the space within and between individual soil aggregates. Symbol definitions are: A = plant residue cover on air-earth interface; B = free water surface; C = microdepression in air-earth interface; D = water intake port of macropore; E = microelevation in air-earth interface; F = soil air exhaust port of macropore space; G = macropore space; H = macropore wall; and I = micropore space (Dixon, 1978).

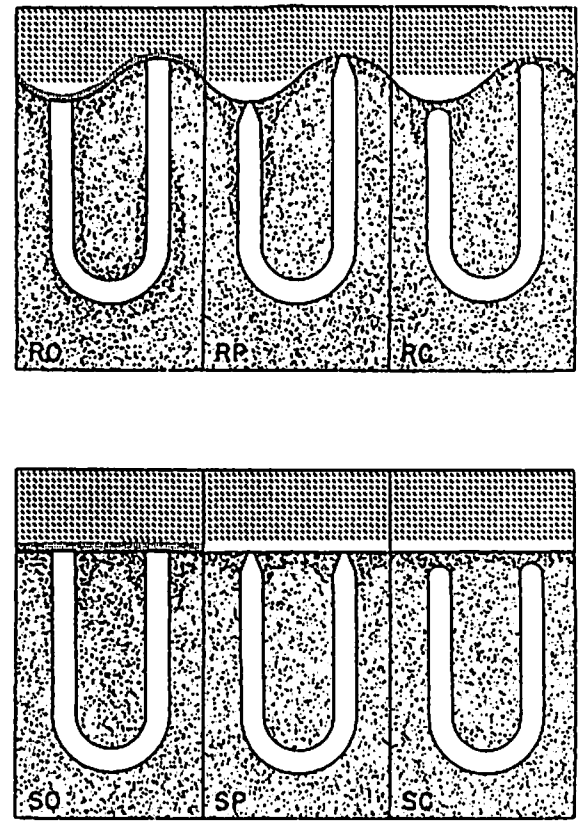

Fig. 2. Diagramatic air-earth interface conditions and associated U-shaped macropore for water infiltration into soils. Conditions RO, RP, and RC represent rough interfaces containing open, partly open (unstable), and closed macropores, respectively; whereas conditions SO, SP, and SC represent smooth interfaces containing open, partly open (unstable), and closed macropores (Dixon, 1978). The SC surface may be converted to the RO surface in a single operation using the new imprinting technique.

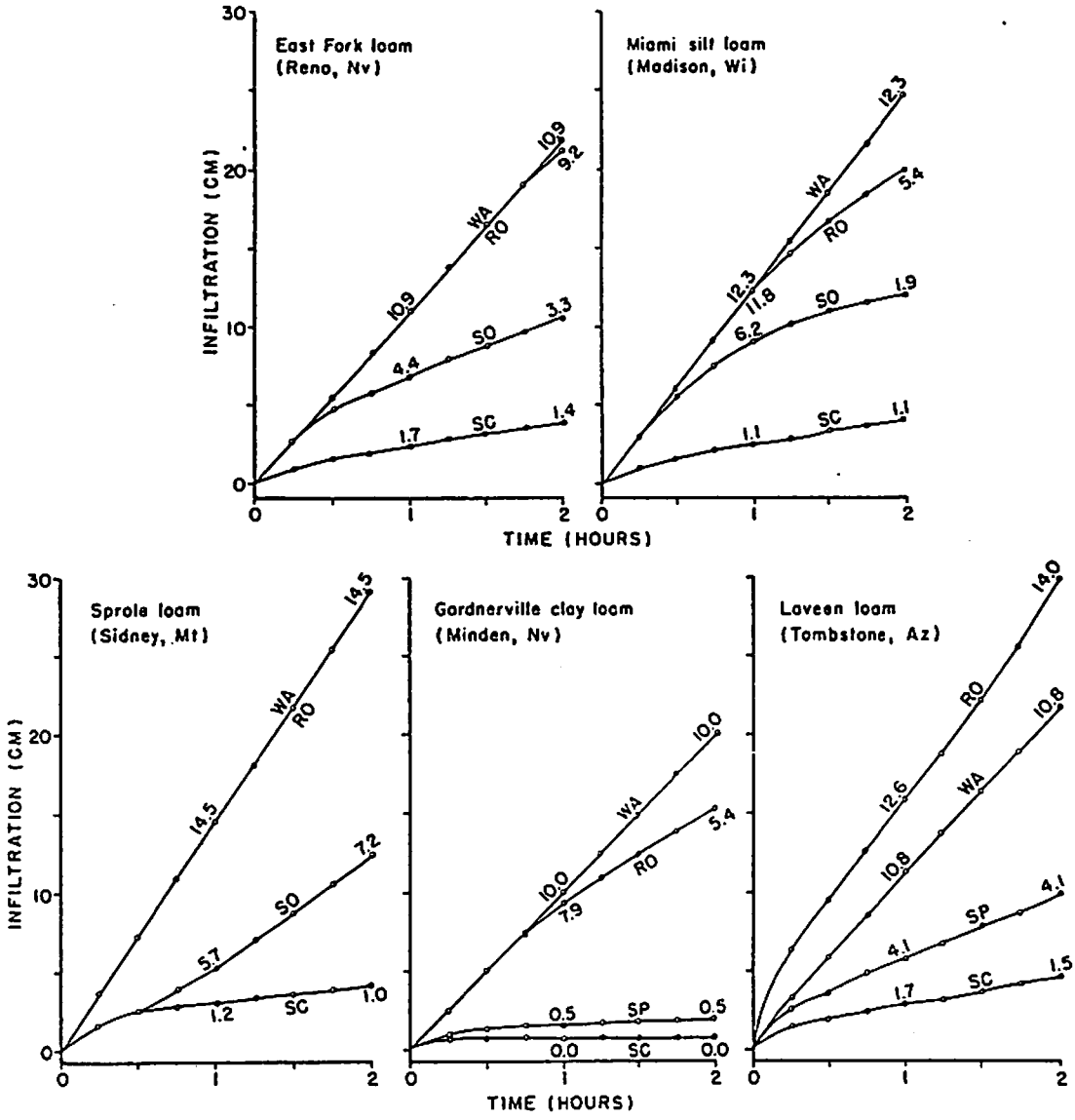

Fig. 3. Sprinkled-water infiltration under hand imposed air-earth interfaces RO and SC, and naturally occurring interface either SO or SP. The curve labeled WA gives the total water applied by the infiltrometer spray nozzle. Numbers near curves at 1- and 2-hour times denote infiltration rates in cm/hr for these times (Dixon, 1978).

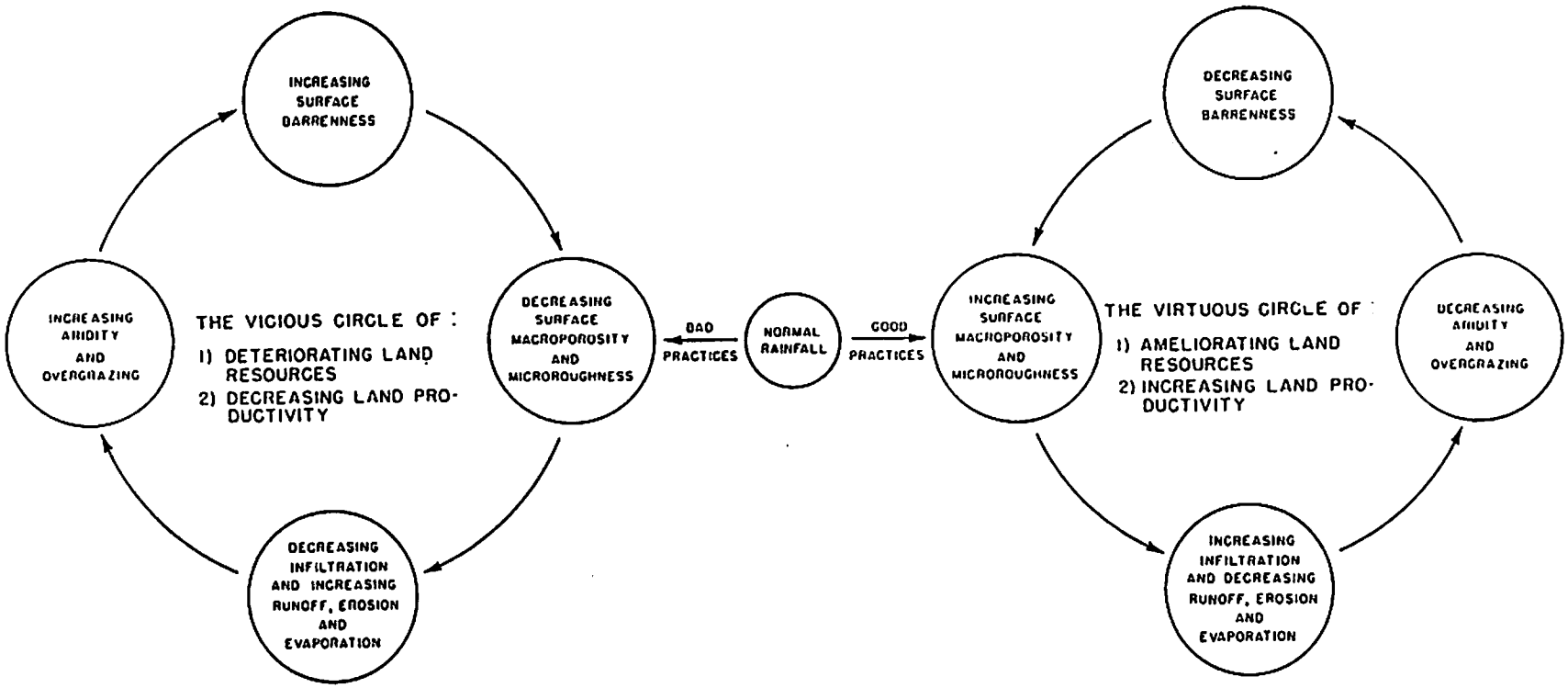

Fig. 4. Bad management practices such as overgrazing of southwestern rangelands reduce the microroughness and macroporosity of the soil surface, thereby triggering a vicious circle of land deterioration or desertification. Land imprinting is a new tillage method developed specifically to break this circle by increasing surface microroughness and macroporosity, mechanically and biologically (Dixon and Simanton, 1977).

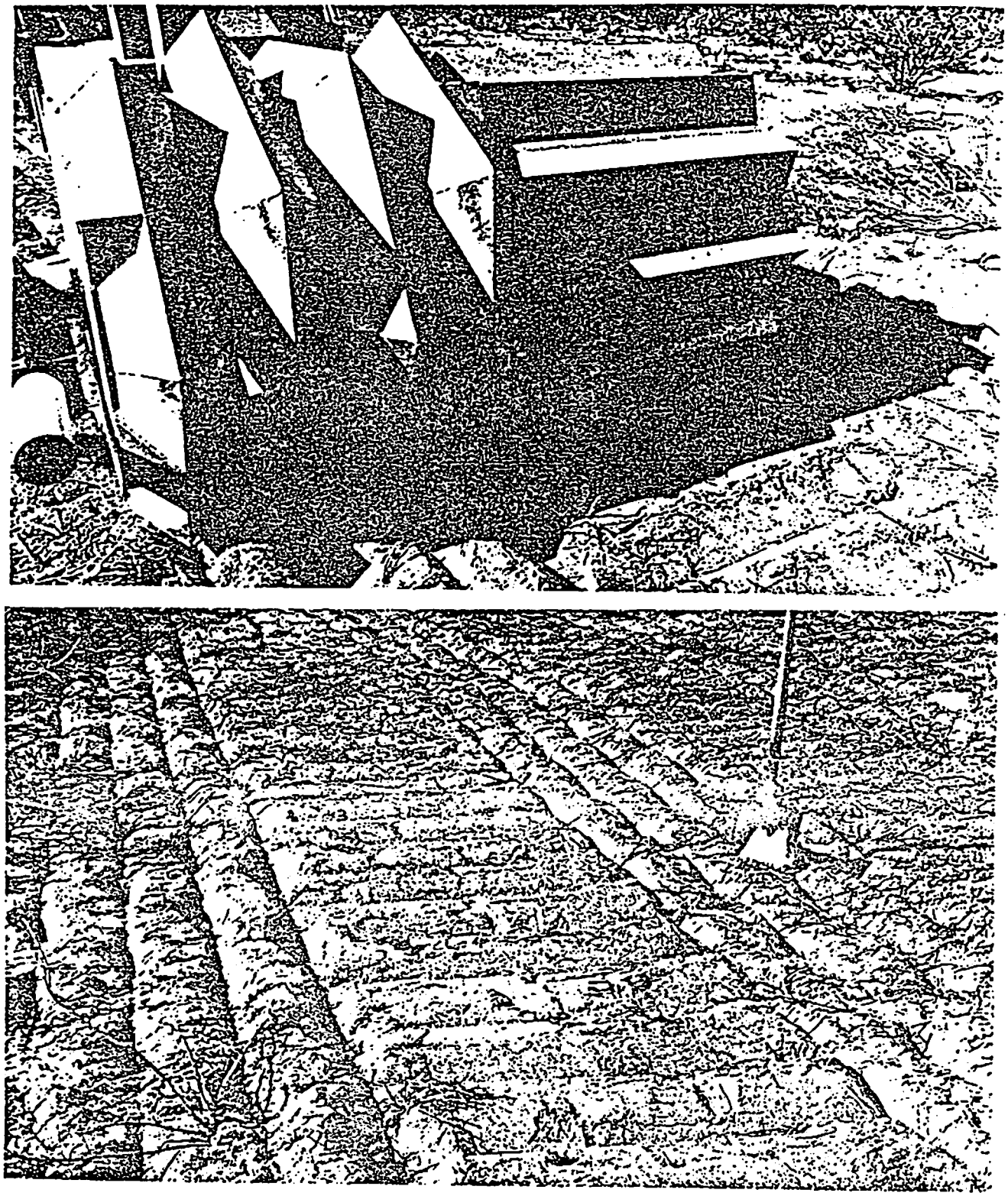

Fig. 5. Rangeland imprinting roller is faced with angular steel teeth that chew up above-ground plant material and bite deeply into the land surface leaving behind mulch-lined rain-fed seedbeds. Downslope vee-furrows formed by the axially-oriented teeth shed rainwater into the cross-slope furrows, in turn, formed by the radially-oriented teeth. Macroporosity in the cross-slope furrows is increased through both mechanical and biological means.