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A LAND IMPRINTER FOR REVEGETATION OF BARREN LAND AREAS THROUGH INFILTRATION CONTROL

by

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ABSTRACT

A new minimum tillage implement, "the land imprinter," has been designed and fabricated, and is currently being tested. Its design is based on water infiltration control theory developed during the past decade. The land imprinter was developed primarily for establishing vegetation in barren land areas in semiarid and arid regions of the world. It simultaneously forms interconnected downslope and cross-slope corrugations that shed water and then infiltrate it precisely where vegetative growth is to be encouraged. This controlled short distance routing of water along short waterways into small reservoirs makes more rainwater available for seed germination and seedling establishment, and less water available for loss by surface runoff and evaporation.

The imprinter has only one moving part, in the form of a massive compound roller and central axle which turn together as a rigid assembly during operation. The compound roller consists of two imprint capsules which are linked together on the axle shaft by an axle pulling clamp. The core of the imprint capsule is a hollow steel cylinder (1-m diameter and 1-m long) fabricated from 1.27-cm steel plate. A variety of imprint geometries are formed by welding short lengths of specially-cut steel angles (1.27 cm x 15.24 cm x 15.24 cm) to the outer surface of the cylindrical core. Ten imprint capsules with distinctly different geometric patterns of steel angles have been developed and fabricated. By pairing these capsules in as many ways as possible, 45 different geometric patterns can be imprinted.

The patterns of steel angles perform a number of different tillage functions including (1) brush and soft rock crushing, (2) brush and rock imbedding, (3) runoff inducing and directing, (4) infiltration inducing and directing, (5) biomass concentrating, (6) seedbed forming, (7) surface and vertical mulching, (8) wind and water erosion controlling, (9) surface compacting, and (10) surface trenching and pitting.

Advantages of the land imprinter as compared with alternative tillage methods include (1) greater stability, diversity, complexity, and precision of surface geometric patterns; (2) better control of point infiltration, runoff, erosion, and evaporation; and (3) greater utility in brush-covered, steeply-sloping, deeply gullied, and rocky land. The land imprinter should have widespread utility in both range and croplands because of its unique ability to mold runoff-watered seedbeds that increase the probability of seed germination and seedling establishment.

INTRODUCTION

Vast barren land areas, particularly in semiarid and arid regions of the world, need to be vegetated for environmental protection and efficient use of soil and water resources in the production of food, feed, and fiber. Historically, cropland tillage implements have been modified and redesigned in an attempt to revegetate such land areas. The resulting implements are referred to in the literature as the eccentric disc pitters (Wight, 1973); brushland disc plows (U.S. Forest Service, 1974); root plows (Abernathy and Herbel, 1973); moldboard plows (Rauzi, 1975); land rippers (Dortignac and Hickey, 1963); land furrowers (U.S. Forest Service, 1970); and brush cutters and shredders.

Disc pitters gouge out basins that collect and infiltrate water. Although soil moisture is increased, these basins do not provide adequate sites for vegetation establishment. Soil surface barrenness and looseness is increased, thereby increasing splash erosion. Such erosion contributes to the short life of the basins and the frequent excessive covering of seeds and seedlings with sediment. Ponded water depths are sufficient to cause drowning of seedlings in wet years. Brushland disc plows loosen the soil and give partial control of forbs and shrubs; however, much of the existing plant material is buried, thereby exposing the surface to wind and water erosion. The soil is often too loose and too dry for successful seed germination and seedling establishment. Root plows performs about the same tillage functions as disc plows and have similar disadvantages. They give better control of shrubs than disc plows. Moldboard plows also loosen the soil, bury plant materials, and provide excellent control of forbs; however, operation is unsatisfactory in shrublands. Disadvantages of these plows are

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similar to those noted above for disc plows. Land rippers fracture the soil deeply with a narrow chisel or wedge-shaped tool. This fracture usually increases infiltration until surface sealing occurs, at which time infiltration may fall below the pretreatment level. Bulk density is too variable in the fractured zone to provide an adequate seedbed. Sealing of the ruptured soil surface occurs rapidly because of the high instability of the loosened and exposed soil material. Furrowers or listers produce contour corrugations, but in the process loosen the soil surface and bury plant materials. Advantages and disadvantages of furrowers are similar to those given for disc pitters except that operation is severely hampered by shrubs. Brush cutters and shredders do not directly alter the shape of the soil surface. The additional litter on the soil surface and the tractor tracks will reduce sealing and increase surface ponding, thereby increasing infiltration. The increased litter also reduces surface evaporation following rainfall. Obviously, seedbed soil moisture is improved only where vegetation is available for cutting or shredding.

The seedbed that is produced by any one of the preceding implements is usually not good enough to insure vegetation establishment except under the most favorable climatic conditions. These implements generally require a large amount of energy to perform each tillage function. Tillage functions are often too few in number, inappropriate in kind or intensity, and conflicting in purpose. Consequently, both the longevity and the initial suitability of the seedbed is diminished. Even when these implements are used in combinations, vegetation establishment is highly erratic. All of these implements operate unsatisfactorily in brushy, steeply sloping, deeply gullied, and rocky terrain. Surface geometries that they produce generally may be characterized as irregular, imprecise, and highly unstable. Very little control over point infiltration, runoff, erosion, and surface evaporation is provided by any of these implements, even though such control is basic to revegetation for the better protection and efficient use of soil and water resources.

The need for a better implement prompted the design and fabrication of a device called the land imprinter. This new tillage implement was developed primarily for establishing vegetation in barren land areas in semiarid and arid regions of the world. In this paper, the theoretical basis for the land imprinter is presented; fabrication and operation details are summarized; preliminary testing results and further testing needs are discussed; and some advantages and disadvantages of the imprinter relative to conventional implements are listed.

DESIGN THEORY

Worldwide over-grazing of pasture and rangelands and excessive tillage of croplands, combined with short-term droughts, are causing rapid expansion of the already vast barren land areas. Strip mining and highway construction are also denuding large land areas. Abandoned irrigation lands are often nearly barren. Barren land characteristically possesses relatively low infiltration rates which are often only one-tenth of those for woodlands and grasslands (Dixon, 1966). Consequently, barren soils shed most of the rainwater from intense thunderstorms, whereas litter-covered soils infiltrate most of the water where it falls. Bare soils shed water readily since they possess well-developed surface drainage patterns and are sealed tightly by raindrops impacting on their surfaces. Litter-covered soils absorb water rapidly because their surfaces are hydraulically rough and macroporous. The small amount of water that does infiltrate barren land areas, penetrates the soil so superficially that most of it is lost by surface evaporation soon after the rain ceases. Thus a vicious circle begins that is responsible for desertification and increasing aridity on both a micro- and macroscale (Fig. 1).

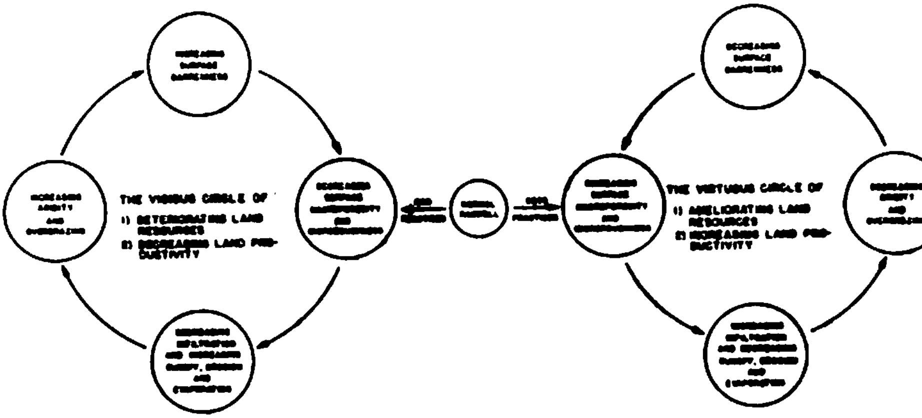

Fig. 1. The land imprinter is designed to break the vicious circle of deteriorating land resources and declining land productivity by molding moist surface soil and vegetal material to precisely shape a stabile runoff-irrigated seedbed and rootbed.

This circle is driven by physical processes such as surface sealing and is accelerated by overgrazing, over-cultivation, and short-term droughts. As the surface becomes increasingly barren, smooth, and sealed, less water infiltrates and less water is available for plant growth, which in turn further increases barrenness. The land imprinter is designed to break this circle by reestablishing the high infiltration rates necessary to replenish the soil-water reservoir required, in turn, to revegetate the soil. This involves converting the smooth closed surface to a rough open one in accordance with the air-earth interface concept - - a recently developed theory setting forth the principles for practical infiltration control through soil surface management (Dixon, 1975a).

The air-earth interface concept postulates that soil surface microroughness and macroporosity control the rates and routes of water infiltration by governing the flow of air and water in underlying macropore and micropore systems. Exchange of soil air and ponded water occurs freely across a rough open 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 closed 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 water about 10 times faster than smooth closed surfaces. In addition, water entering the soil via a rough open surface 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. The mulch not only shields the soil against falling raindrops, but also feeds the small soil animals (ants, termites, etc.) which perforate the soil surface and underlying soil with their burrows, thereby creating infiltration-increasing macropore systems.

The soil, water and vegetal resources of arid and semiarid regions, although vast in magnitude, are somewhat sparsely and diffusely distributed. Thus, to insure vegetation establishment the land imprinter is designed specifically to concentrate these resources onto part of the total land area by creating alternating strips of land with runoff enhancing and infiltration enhancing surface geometries. The land imprinter simultaneously forms interconnected downslope and cross-slope corrugations that shed water and then infiltrate it precisely where vegetative growth is to be encouraged. This controlled short-distance routing of water via minute waterways into minute reservoirs makes more rainwater available for seed germination and seedling establishment, and less water available for loss by surface runoff and evaporation.

CONSTRUCTION AND DESCRIPTION

MATERIALS AND SPECIFICATIONS

Excluding the axle bearings, the imprinter has only one moving part in the form of a compound roller and central axle which turn together as a rigid assembly during operation (Fig. 2).

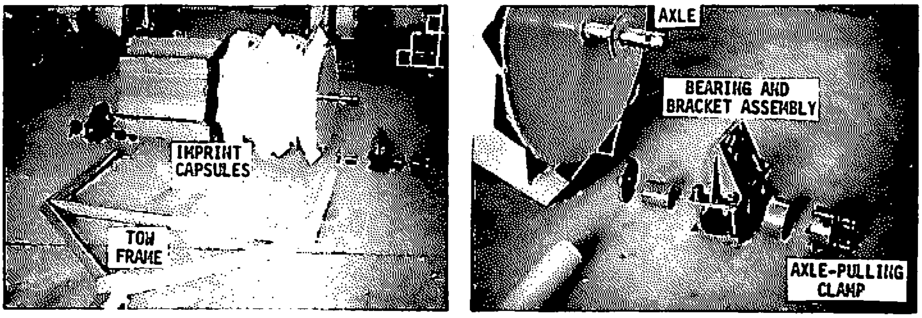

Fig. 2. The land imprinter consists of a compound roller-and-axle assembly in which two imprint capsules are linked rigidly together by means of the axle and a special axle-pulling clamp. The pictured capsules are designed to shape runoff-fed seedbeds by molding moist surface soil and plant materials into complex geometric patterns.

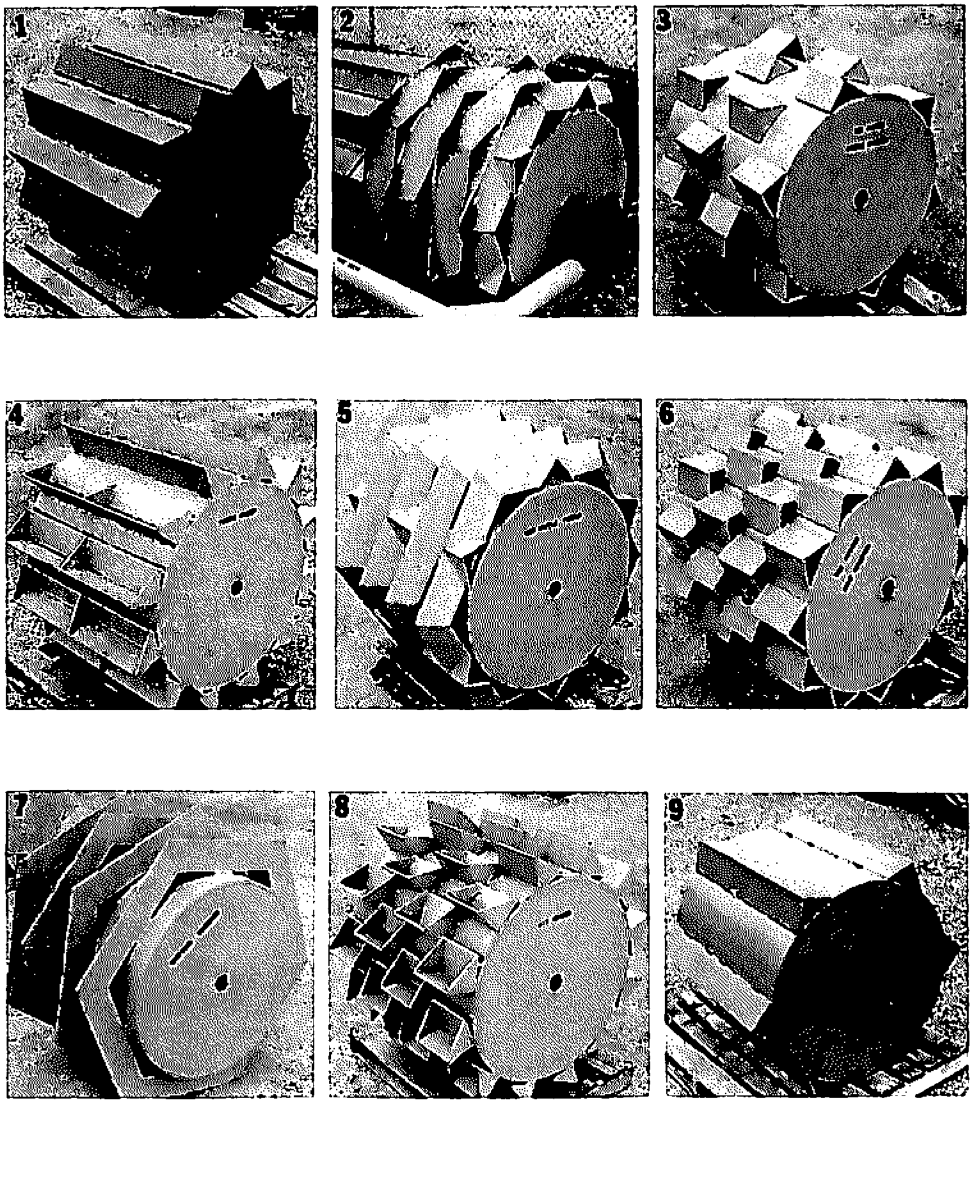

Fig. 3. Forty-five different geometric patterns can be imprinted on land surfaces by pairing ten unique capsules in as many ways as possible. Tillage objectives are achieved by an appropriate mating of two imprint capsules for compatibility with ambient land and climatic conditions.

The compound roller consists of two imprint capsules which are securely linked together on the axle shaft by an axle-pulling clamp. A 0.64-cm thick disc of spring rubber is sandwiched between the two imprint capsules to absorb the shocks of rocky land operation and to maintain the desired alignment between the two capsules. The core of the imprint capsule is a hollow steel cylinder (1-m diameter and 1-m long) fabricated from 1.27-cm steel plate. A variety of imprint geometries are formed by welding short pieces of specially-cut steel angle (1.27-cm thick with 15.24-cm legs) to the surface of the cylindrical core. The outermost edges or corners of the angles are hard-surfaced to resist abrasive wear and to self-sharpen with use. Ten imprint capsules (nine of which are shown in Fig. 3) with distinctly different geometric patterns of steel angles have been designed and fabricated. Imprint capsule No. 1 is fabricated by equally spacing (26.2 cm apart) and welding 12 angle pieces to the cylindrical core with the angle vertex pointed out radially as shown in Fig. 3. Capsule No. 2 is fabricated by welding four hexagonal-shaped angle frames (spaced 25 cm apart) to the core. Angle vertices are oriented radially outward and the corners of the hexagons are staggered as shown in Fig. 3. Capsule No. 3 is fabricated by equally spacing and welding 24 steel angle pieces (25-cm long) to the core with the angle vertex oriented as in Capsule 2. Capsule No. 4 is similar to No. 1 except that an angle leg is oriented outward rather than the vertex. The angle legs are tied together with welded gussets. Capsule No. 5 is similar to No. 2 except that the hexagonal frames are aligned radially. Short angle pieces are welded between the sides of adjacent hexagonal frames to interconnect the vee furrows imprinted by the hexagonal frames, thereby directing rainwater on a zig-zag path through the seeded or vegetal strip. Capsule No. 6 is similar to No. 3 except that twice as many angle pieces are welded to the core at half the spacing. Capsule No. 7 is similar to No. 2 except that the hexagonal frames are fabricated with one angle leg oriented radially outward. As in No. 4, angle legs are reinforced with gussets. Capsule No. 8 is like No. 6 except that an angle leg is pointed outward rather than the vertex. Again, legs are reinforced. Capsule No. 9 is like No. 1 except that half as many angles are welded to the core at twice the spacing. Imprint capsule No. 10, (not shown in Fig. 3) is similar to No. 2 except that dodecagonal (12-sided) frames are substituted for the hexagonal frames.

FUNCTIONS AND OPERATION

By pairing the 10 imprint capsules in as many ways as possible, 45 different geometric patterns can be imprinted. Further variations in imprint geometries and surface water routing can be achieved by radial alignment of the two capsules with respect to each other and orientation of the compound roller with respect to the land slope or grade. The appropriate land slope orientation of the imprinter or the direction of travel with respect to land grade depends on the combination of imprint capsules selected and the tillage objectives or functions. Travel directions include cross-slope (contour), with-slope (contour normal), or diagonal-slope (angle formed by the lines of travel and contour). For instance, if the tillage objective is to increase depression storage, then the direction of travel for imprint capsule No. 1 should be with-slope; but if water harvesting is the desired objective, then travel should be cross-slope.

The patterns of steel angles perform a number of different tillage functions including brush and soft rock chopping and crushing, brush and rock imbedding, runoff inducing and directing, infiltration inducing and directing, biomass concentrating, seedbed forming, surface and vertical mulching, wind and water erosion controlling, soil compacting, and surface trenching and pitting. Each angular pattern performs some or all of these functions with varying degrees of efficiency. Selection of the best pattern and pattern pairs is based on the tillage objective, soil and vegetative conditions, landslope, season, and climatic conditions.

Soil penetration by the imprint angles depends on soil moisture content and the weight or downward force of the imprinter. Downward force is increased by filling the capsules with water or other liquids and by weighting the tow frame with solid steel bars.

Unequal side-to-side weighting can sometimes produce the most desirable penetration depths. Such weighting may be required for uniform penetration, depending on the geometry of the paired capsules. Unequal weighting can also create microslopes in imprinted furrows which would be desirable in nearly level terrain. The maximum weight of the land imprinter is about 5 metric tons, with the water-filled roller-and-axle assembly weighing about 3 metric tons and the weighted tow frame about 2 tons. The land imprinter operates best when the soil is moist, yet dry enough at the surface to prevent sticking of soil to imprint angles. In this respect the imprinter is similar to other tillage implements; however, unlike other implements, the imprinter does not lift and turn the soil over.

Imprint formation involves the shearing and compressing of surface soil material. Since very little soil lifting occurs, less energy is consumed with this type of implement. Also, unlike conventional implements which produce a somewhat haphazard and highly unstable surface geometry, the land imprinter can create a great diversity of precise surface geometries which are relatively stabile. It is possible to form closed surface drainage geometries which can pond considerable water on the surface to enhance infiltration. Much of the plant material remains on, or imbedded in, the soil surface where it can retard surface runoff, surface sealing, erosion and surface evaporation; and enhance surface microrougness, surface macroporosity and water infiltration. The plant material mulch also helps to stabilize the imprint geometry by absorbing raindrop impact energy. Through a chopping and crushing action, the imprinter kills the above-ground growth of brittle shrubby species such as creosotebush, thereby conserving the transpiration water long enough to aid in grass seedling establishment. Since this action increases the concentration of biomass near the soil surface, the imprinter should facilitate brush control by burning.

As compared with other minimum tillage implements used in crop and rangelands, the imprinter has a slightly higher initial cost, but has a somewhat lower operation and maintenance cost and is much more versatile. The land imprinter is extremely durable since it is constructed to withstand even the shocks and stresses encountered in rocky hilly land. Cost of imprinting should be less than half that of root plowing. Satisfactory operation requires a 30-hp tractor or larger. Maintenance entails only lubricating axle bearings and oiling imprint angles to inhibit rust formation while the machine is not in use.

MODIFICATIONS, ACCESSORIES AND ALTERNATIVES

The basic imprint capsule design is being modified to permit deeper covering of seed and thus facilitate planting of the small grains, sorghum, corn, cotton, and soybeans. Either a steel rod or a steel bar is welded to the vertex of the steel angle. Rods are 1 cm in diameter, whereas the bars are either 1-cm square or 1 x 2 cm in cross section. This modification forms a 1-cm-wide seed slot in the bottom of the vee furrow. Seed can be covered by rainfall splash erosion, a drag ball or chain, or concave press wheels.

The basic imprint capsule design is also being modified to improve performance of the imprinter on nearly level terrain. Steel angles are altered by removing part of both legs by cutting them diagonally. These altered angles, when welded to the surface of the capsule core, can imprint vee furrows with microslopes to concentrate rainwater.

Other cultural practices can easily be combined with the land-imprinting practice when the expected economic benefit justifies the added cost. Accessories for vegetal shredding, cutting or mulching; seeding grasses, legumes and small grains; spraying herbicides and insecticides; and applying chemical soil amendments are presently being mounted on the A-frame of the land imprinter.

Alternative modifications and designs for the land imprinter include (1) self-propulsion through replacement of wheels of a farm tractor with imprint capsules; (2) fabrication of imprint capsules from reinforced concrete to reduce cost of materials; (3) utilization of imprint capsules single or in combinations of more than two; (4) reduction of imprint capsule diameter for smooth land use and enlargement of diameter for extremely rough land use; (5) utilization of smaller or larger steel angles in the fabrication of imprint patterns; (6) use of more than one angle size on a single capsule to provide minor modification of imprint geometry; (7) modification of number and spacing of steel angle pieces that are welded to the capsule's central core; and (8) replacement of the polygonal angle frames with rings fabricated by welding together two right-angle cone sections.

Other imprint geometries could be created by welding 3- and 4-sided polyhedrons (fabricated from triangular steel plates) to the imprint capsule core in a variety of patterns. For circular geometries, specially-cut pipe sections could be substituted for the steel angles. An infinite number of complex geometries, including sinusoidal waves having a variety of amplitudes and magnitudes, could be created through laminar construction of the imprint capsule. The design geometry would be formed by sandwiching many steel and plyboard discs, each representing a different thin radial section of the imprint capsule.

UTILITY AND TESTING

DESIGN UTILITY

In general, the land imprinter is designed to (1) better protect and more efficiently use soil, water, and vegetal resources in the production of food, feed, and fiber; (2) increase and stabilize range and cropland productivity; (3) reduce land management costs and consumption of fossil fuels per unit of product; (4) reverse the trend toward desertification of vast crop and rangeland areas; and (5) extend agriculture into rocky hilly lands not otherwise arable. To achieve these design objectives, the land imprinter is uniquely capable of providing wide-range control of point infiltration, runoff, erosion, and evaporation; creating precise and stabile surface geometries that can be easily described mathematically; forming a minimum of 45 complex imprint patterns or soil surface configurations for a good fit to ambient land conditions and management objectives; simultaneously creating an efficient surface water routing system (at a microscale level) and seedbed so that rainwater is concentrated and infiltrated at the point where vegetal growth is to be encouraged; performing several complementary tillage functions simultaneously with a relatively small consumption of fossil fuel per function; crushing, chopping and imbedding plant material and rocks in the compacted soil surface to stabilize the geometric imprint pattern against the erosive forces of wind and water; and operating satisfactorily in shrub-covered, steeply sloping, deeply dissected, and rocky terrain.

The land imprinter is expected to be particularly useful in the revegetation of barren land areas produced by short term droughts, overgrazing of rangelands, overcultivation of croplands, overcutting of woodlands, abandoning of croplands, expanding deserts (desertification), strip mining, road construction and urban development. The land imprinter should prove useful in solving land management problems which are aggravated by uncontrolled infiltration including excessive upland runoff and flash flooding; excessive soil erosion and sedimentation of upland waterways and reservoirs; shallow penetration of rainwater into the soil and excessive evaporation losses; pollution of surface and groundwaters; inefficient water harvesting for off-site precipitation uses; and inefficient on-site use of precipitation for food, feed, and fiber production.

Although developed primarily for revegetation of rugged barren land, the imprinter may well find widespread use in croplands either as a secondary or primary tillage implement for preparing efficient seedbeds. The precise control of rainwater movement (at the microscale level) on the soil surface and into the soil could lead to increased and stabler dryland yields of major crops like corn, soybeans, grain sorghum and wheat. The imprinter could eliminate the need for bare fallow as practiced in wheatland areas of the Northern Great Plains. It could also be useful in second cropping, where lack of moisture is the major factor limiting success of this practice.

The imprinter can be used to compact and corrugate land surfaces for furrow irrigation while simultaneously forming an efficient seedbed. Such a practice could increase irrigation efficiency of soils normally having excessive infiltration rates. The imprint made by capsule No. 1 serves as a linear gear, in which this capsule becomes enmeshed on successive passes (return trips) if there is a small amount of overlap. This feature could be useful for forming continuous downslope furrows for irrigation or water harvesting. Capsules Nos. 2 and 10 would also be well suited for creating furrows.

The land imprinter may be used to stabilize abandoned irrigation lands that are highly susceptible to wind erosion. Eroding soil pollutes the air and causes visibility problems along major highways in semiarid regions. The microroughness produced by the imprinter has suitable dimensions for effective wind erosion control (Woodruff and Siddoway, 1973). The imprint would be expected to perform somewhat better than soil clods in wind erosion control because of the lower wind turbulence associated with the imprint and the absence of loose soil. Compressing the soil to form a stable microroughness would seem, therefore, to be a sounder approach to wind erosion control than the traditional approach of loosening the soil to form clods.

The land imprinter could replace conventional wheatland drills for molding a wind-stable seedbed in the stubble of the previous year's wheat crop. This substitution would be particularly advantageous during dry years when wind-eroding wheat fields often pose severe land management problems in the Great Plains.

Soils of the Great Basin in Nevada commonly exhibit a vesicular surface horizon, which severely impedes penetration of rainwater. This horizon could easily be disrupted with the land imprinter to facilitate revegetation. The imprinter should also be effective in mulching the sagebrush of this region.

The imprint produced by capsule No. 1 is expected to be appropriate for vegetating rocky, deeply dissected, hill lands. Two of these capsules could be coupled together with the imprint angles staggered to produce discontinuities in the resulting vee furrows. The imprinter would then be operated up-and-downlope to mold discontinuous furrows on the contour. A dozer blade mounted in front of the tow tractor would be useful for roughing out a path across steep-walled gullies and channels.

Presently, the land imprinter is being applied to increasing rangeland forage production in Arizona through the concentration of sparsely and diffusely distributed soil, water, and vegetal resources onto part of the total land area. Use of the imprinter to create alternate contour strips of land with high and low infiltration geometries, can greatly increase the probability of grass seed germination and establishment. The land imprinter with an appropriate capsule combination forms and firms the soil to produce a precise microdrainage pattern that directs rainwater downslope to the desired point for ponding and subsequent infiltration.

PRELIMINARY TESTING

Seedbed imprint. The imprint capsules with the hexagonal and dodecagonal frames create a variety of favorable seedbed environments, thereby increasing the probability of an adequate stand establishment for a given plant species and set of climatic conditions. The polygonal frames produce vee furrows of variable depth, ranging from a minimum to a maximum depth as the frame rolls from the mid-side to the corner position. Thus, water concentration and depth of seed covering are greatest where the corners deeply indent the soil, and are least midway between these indentations. It is expected that on relatively dry years the corner seedbed sites would be the best. Obviously, the furrow depth variability is less with the dodecagonal imprint frame than with the hexagonal frame.

The initial test of the land imprinter conducted during the summer of 1976 succeeded in revegetating two small experimental areas on the Santa Rita Experimental Range near Tucson, Arizona. Hand broadcast sideoats grama (*Bouteloua curtipendula*) seed quickly germinated in a seedbed prepared with the imprinter. Most of the seedlings subsequently became well established. By pairing capsules Nos. 1 and 2, an imprint was formed that directed runoff from upslope microwatersheds to the lines and points of seed placement (Fig. 4). A many-fold concentration of rainwater thereby infiltrated the seedbed soil and penetrated deeply beneath the seeds. Additionally, the seedbed firming produced by the imprinter probably enhanced moisture flow to the seeds - - particularly the duration of such flow.

Seed broadcasted over the imprint blew, settled, and washed into the vee furrow bottoms and thus germinated and became established in rows (Fig. 5). Consequently, aerial seeding of imprinted land could probably achieve the results of rangeland drilling.

The most successful imprint sites for grass seedling establishment were where the points of the hexagonal steel frames indented the bottom of the V-shaped furrow. Grass establishment was the highest where such indentations contained mulch to suppress sealing and subsequent evaporation (Fig. 5).

Splash erosion seems to be a suitable means for covering grass seeds in the vee furrows produced by capsules Nos. 2 and 10. Depth of seed covering by splash erosion depends on several factors, including imprint capsule loading (depth of imprint), plant residue cover, rainfall intensity and duration, antecedent soil moisture, capsule design, and soil texture and structure.

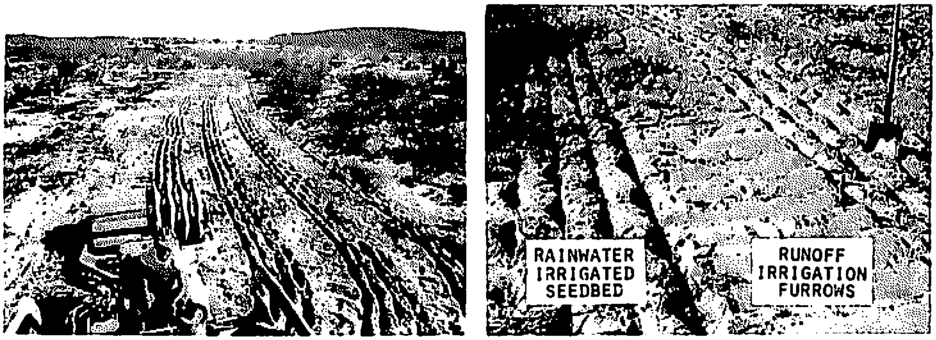

Fig. 4. A rainwater-irrigated seedbed can be molded at the soil surface by the land imprinter to assure adequate water for seed germination and seedling establishment.

Fig. 5. A. Grass seed broadcasted over the V-shaped imprints germinated and became established in distinct rows giving the appearance of having been drilled.

Fig. 5. B. Mulch-filled indentations produced by the land imprinter were favorable sites for grass seed establishment.

Imprint stability. The imprinter can be operated at soil moisture contents below the sticky point, or when the soil dries enough after rainfall to prevent soil from adhering to and building up on imprint angles. The imprinter produces soil-deforming stresses which compress and sheer the soil to produce the imprint pattern. The resulting compaction or densification increases the soil volumetric moisture content and correspondingly decreases the soil air volume and moisture tension.

In humid and subhumid regions, selecting the optimal soil moisture for imprinting would involve a compromise between the need for soil surface stability (strength) and soil looseness (aeration), since stability increases with compaction. Maximum imprint stability and strength would be expected with an initial moisture content near the lower end of the plasticity range and a final moisture content in the upper end of this range, but just below the sticky point (Baver et al., 1972). If excessive soil compaction is a critical land management problem, then the imprinter should be operated at final moisture contents below the lower plastic limit.

In arid and semiarid regions, the compromise between soil stability and looseness is often unnecessary since land can often be imprinted when the surface 10 to 15 cm of soil has a plastic consistency, and the underlying soil has a hard or harsh consistency. This combination of a wet surface layer overlying a dry layer facilitates molding of a stable imprint without compacting the root zone. In southern Arizona, these soil moisture conditions are prevalent after the first large rain of the July-August monsoon season. This depth distribution of soil moisture could be easily created in irrigated lands by allowing the soil to dry and then irrigating lightly before imprinting. However, moderate compaction of the seedbed is usually desirable, especially in coarse-textured soils. The optimal initial soil moisture for operating the land imprinter will usually be somewhat greater than it is for conventional tillage implements, since the principle purpose of the imprinter is to produce a stabile (strong) imprint geometry rather than a layer of loose friable soil.

Uniformly high imprint stability results in efficient routing of rainwater to the vegetal site, uniform covering of seeds by splash-eroded soil, rapid development of a stabile surface macroporosity in the bottoms of cross-slope furrows, and a long effective life of the imprint geometry. The soil moisture contents for maximum traction, tractor tire life, and imprint stability would probably be nearly identical. Preliminary results suggested that imprint stability (under the erosional forces of wind, water and gravity) could be maximized by operating the imprinter at a final moisture content just below the sticky point. Maximum soil compaction and bulk density also occur at this moisture content. Consequently, sandy and gravelly soils should be imprinted as soon as possible after ponded surface water infiltrates following a large rain, whereas clayey soils should be allowed to dry for several days or until soil no longer sticks to imprint angles. Additional imprint stability and longevity can be achieved by shredding all existing plant materials and depositing them on the seedbed strip, imprinting during a low-intensity rainfall season, and seeding a variety of plant species, including some that will provide a quick vegetative cover.

It is important to establish vegetative cover as soon as possible to protect the imprint geometry from raindrop impact. Even where the imprint has no protective mulch, its life is sufficient to insure seed germination and establishment, after which time the vegetative growth can create and maintain the surface hydraulic roughness and macroporosity which are essential for high infiltration rates (Dixon, 1975a). By placing a variety of adapted seeds in a variety of suitable seedbeds, the likelihood of achieving an adequate stand of plants under prevailing climatic conditions is greatly enhanced. In southwestern United States, vegetation established during the gentle winter rains would protect the imprint from the beating raindrops of the intense summer thunderstorms. Ideally, the seeding mixture should contain both legumes and grasses, because of their contrasting rooting depths and the ability of legumes to fix nitrogen for possible use by the grass. Annual, perennial, warm-season, and cool-season grasses should be included.

Runoff and erosion. Rainwater is concentrated at the points or lines of seed placement and seedlings are established by two different transport modes acting during three time periods. During the initial period, water is transported by raindrop splash alone; during the intermediate period, by a combination of splash and rill flow; and during the final period, after rainfall ceases, by rill flow alone. If rainfall is of very short duration or of very low intensity, only splash concentration will occur.

Although splash erosion shortens the life of the imprint, some possible advantages were observed. Splash erosion (1) rapidly seals the bottoms of the downslope furrows, thus increasing runoff delivery to the cross-slope furrows; (2) rapidly covers seeds in the cross-slope furrows; (3) hills and braces plants in the bottom of the furrows with the transported soil; (4) concentrates top soil and plant litter in the cross-slope furrows; and (5) smooths the soil surface for cropland harvesting equipment.

Imprinting speed and depth. The imprinter has been operated at velocities up to 6 km/hr to determine the effect of surface molding rates on the resulting geometry. Preliminary tests indicated that the effect of velocity is minor. Some loose soil particles settled into the bottom of the vee furrow at the higher speeds, especially when soil moisture was below the plastic range. As expected, penetration depth of the imprint angles is a function of imprinter loading, soil texture, initial bulk density, and initial soil moisture, with the depth increasing with increasing imprinter weight, initial soil moisture, and texture coarseness up to certain limits; and with decreasing bulk density. With the imprint capsules filled with water and the tow frame fully loaded, the land imprinter can penetrate even a dry, compact clayey soil.

Imprint macroporosity. Contrary to Darcy-based infiltration theory, the air-earth interface theory (Dixon, 1975a) indicates that high infiltration rates and high bulk densities are not mutually exclusive conditions. Soils with relatively high bulk densities will have relatively high infiltration rates, if their surfaces are microrough (hydraulically) and macroporous. In contrast, soils with relatively low bulk densities will have relatively low infiltration rates if their surfaces are smooth and microporous.

The imprinter initially increases surface bulk density, microroughness, depression storage, and litter; and decreases surface macroporosity. However, the increases in microroughness and surface litter cause rapid development of surface macroporosity in the cross-slope furrows. This microroughness, combined with intense rainfall, produces a hydraulic head that favors macropore formation through a micropiping process whereas the mulch stabilizes the microroughness and the developing macroporosity. The mulch directly promotes macropore formation by feeding the small animals that burrow in the surface soil. Additionally, the imprinted geometry favors the germination and establishment of newly seeded vegetation with consequent formation of root-void macropores. Wetting and drying of the cross-slope furrows also creates macropores in the form of shrinkage cracks, which commonly can be observed in the furrow bottom. Thus, the range in infiltration control is expected to widen rapidly after the downslope and cross-slope corrugations are imprinted (Dixon, 1975a). The widest infiltration range is expected to develop in fine-textured soils, imprinted at a moisture content favoring maximal densification, with available plant materials forming a complete mulch cover for the cross-slope furrows.

Imprint modeling. The land imprinter produces geometries that are sufficiently stabile to justify describing them mathematically. The vee furrow can be described by the general equation:

$$y = a|x - b\lambda| + c$$

where the variables x and y represent horizontal and vertical distances, respectively; and the constants a, b, c and λ represent, respectively, the furrow side slope y/x, the number of furrows from the origin, the y-intercept of the furrow bottom, and the furrow wave length or spacing.

Sinusoidal imprint patterns could be modeled by the equation

$$y = A \sin Bx$$

where the constant A is the furrow amplitude (half the furrow depth) and the constant B is $2\pi/\lambda$. Splash erosion of the vee configuration may cause it to approach a sine wave shape. Fourier series analyses may provide a quasi-quantitative method for describing progressive changes in the vee and sinusoidal geometries resulting from splash erosion. Such an approach could provide a convenient way for estimating depression storage and the depth and distribution of ponded surface water as it is affected by splash erosion.

Further testing. Testing is still needed to determine how well and under what conditions the land imprinter can achieve its broad design objectives as listed previously. Basic to achieving these objectives is the land imprinter's ability to control point water infiltration rates and soil penetration routes. Sprinkling (Dixon and Peterson, 1964) and closed-top infiltrometers (Dixon, 1975b) will be used before and after imprinting to evaluate the immediate and long-term infiltration effects of land imprinting under diverse edaphic, climatic and vegetal conditions. Specifically, the initial infiltration control range, rate of range change, and the final (equilibrium) range will be determined.

Numerous seeding trials must be conducted with success of vegetation establishment treated as a function of several variables including imprint geometry, seeding mixture, and soil and climatic conditions.

Initially, the land imprinter will be tested relative to its use in revegetation of barren land areas; however, some exploratory studies will be directed to related potential uses of the imprinter, including brush control and wind and water erosion control.

REFERENCES CITED

Abernathy, G. H., and C. H. Herbel. 1973. Brush eradicating, basin pitting, and seeding machine for arid to semiarid rangeland. Journal Range Management 26(3): 189-192.

Baver, L. D., W. H. Gardner, and W. R. Gardner. 1972. The dynamic properties of soils. In: Soil Physics. Fourth Edition. John Wiley and Sons, Inc., New York, N.Y. p. 74-129.

Dixon, R. M., and A. E. Peterson. 1964. Construction and operation of a modified spray infiltrometer and a flood infiltrometer. Wisc. Agr. Exp. Sta. Res. Rept. 15.

Dixon, R. M. 1966. Water infiltration responses to soil management practices. Ph.D. Thesis, Univ. Wisconsin, Univ. Microfilms, Ann Arbor, Mich. (Order No. 66-5903, Diss. Abstr. XXVII:4). 175 p.

Dixon, R. M. 1975a. Infiltration control through soil surface management. Proc. Symposium on Watershed Management. Irrigation and Drainage Division, ASCE and Utah State University. p. 543-567.

Dixon, R. M. 1975b. Design and use of closed-top infiltrometers. Soil Sci. Soc. Amer. Proc. 39:755-763.

Dortignac, E. J., and W. C. Hickey, Jr. 1963. Surface runoff and erosion as affected by soil ripping. In: Proc. Federal Interagency Sedimentation Conference. USDA Misc. Pub. 970. p. 156-165.

Rauzi, Frank. 1975. Severe mechanical and chemical range renovation in northeastern Wyoming. J. Range Management 28(4):319-326.

U.S. Forest Service. 1970. Service and parts manual for the contour furrower (Model RM 25). United States Forest Service Equipment Development Center, San Dimas, California.

U.S. Forest Service. 1974. History of the range seeding equipment committee (1946-1973). U.S. Government Printing Office: 1974-799-636/78. 66 p.

Wight, J. R. 1973. Range improvement practices: mechanical and fertilization. Proc. The Range Beef Cow, a Symposium on Production III. Rapid City, South Dakota. 11 p.

Woodruff, N. P., and F. H. Siddoway. 1973. Wind erosion control. Proc. National Conference Conservation Tillage. Soil Conservation Society of America, Des Moines, Iowa. p. 156-162.