Reprinted from the Proceedings of the Symposium on
WATERSHED MANAGEMENT '80
ASCE/Boise, ID/July 21-23, 1980

LAND IMPRINTING FOR BETTER WATERSHED MANAGEMENT[a]

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ABSTRACT

We are developing a unique conservation plow for imprinting land surfaces with complex geometric patterns designed to increase and stabilize land productivity through improved control over rainwater infiltration. Worldwide overgrazing of pasture and rangelands and excessive tillage of croplands decrease rainwater infiltration and increase runoff and erosion, thereby triggering a vicious circle of land deterioration or desertification. To reverse this cycle of increasing land barrenness and aridity, the land imprinter forms rainwater-irrigated seedbeds and seedling cradles which help to ensure successful crop seed germination, seedling growth, and vegetative cover establishment. Thus, the temporary control of infiltration, runoff, and erosion provided by the land imprinter favors revegetation and relatively permanent biological control of these processes.

INTRODUCTION

Vast barren land areas, particularly in semiarid and arid regions of the world, need to be revegetated for protection against erosion and for 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 (14), brushland disc plows (12), root plows (1), moldboard plows (10), land rippers (8), land furrowers (11), and brush cutters and shredders.

The seedbed that is produced by any one of the preceding implements is usually not good enough to insure vegetative establishment in arid and semiarid regions. 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

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combinations, vegetation establishment is highly erratic. All of these implements operate unsatisfactorily in brushy, steeply sloping, deeply gullied, and rocky terrain. The surface geometries that are produced 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 essential for revegetation and the better protection and more efficient use of soil and water resources. Moreover, many of the traditional methods for revegetation destroy the existing protective vegetative cover and increase soil detachability, thereby rendering the land more susceptible to excessive rainwater runoff and wind and water erosion. These hazards are especially pronounced whenever the seeding effort is followed by the weather extremes of drought and intense rainstorms.

The need for a tillage implement that would reduce land erodibility from the outset and insure subsequent vegetative stand establishment prompted the design and fabrication of a device call the land imprinter. This new implement is under development primarily for establishing vegetation in near-barren land areas in arid and semiarid 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 suggested.

THEORETICAL CONSIDERATIONS

Worldwide overgrazing 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 (9). Mining and construction are also denuding large land areas. Marginal farm lands and abandoned irrigation lands are often nearly barren. Barren lands characteristically possess relatively low infiltration rates which are often only one-tenth of those for woodlands and grasslands (3, 7, 13). 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. 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).

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, more water evaporates, 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 required to replenish the soil-water reservoir for revegetating 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 principles for practical infiltration control through soil surface management (4).

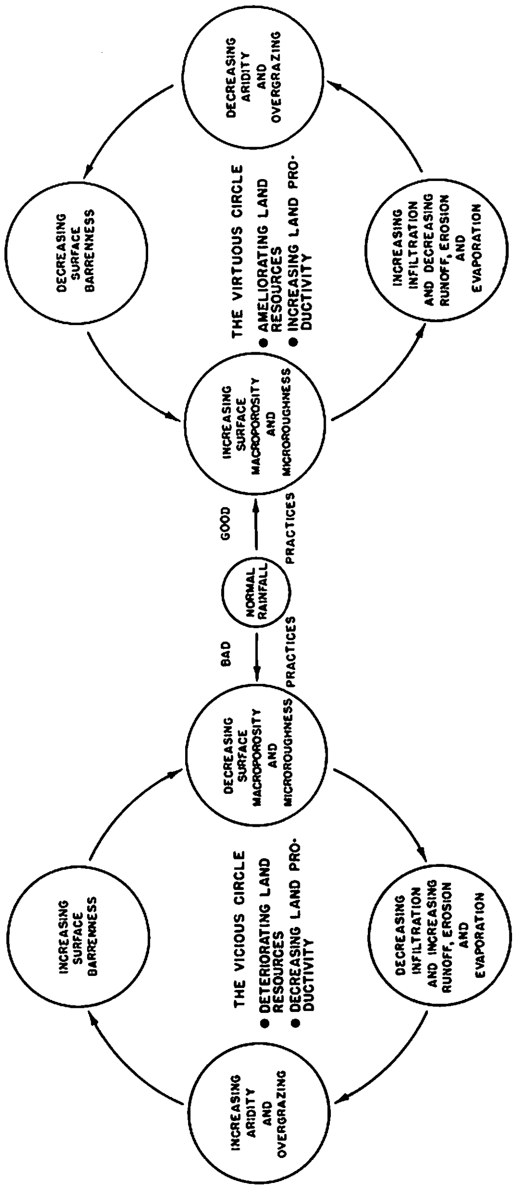

FIG. 1.—THE LAND IMPRINTER IS DESIGNED TO BREAK THE VICIOUS CIRCLE OF DETERIORATING LAND RESOURCES AND DECLINING LAND PRODUCTIVITY BY MOLDING MOIST SURFACE SOIL AND PLANT MATERIALS TOGETHER INTO RAINWATER-IRRIGATED SEEDBEDS AND ROOT ZONES

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 microrough and macroporus 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 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 macropore systems that can rapidly infiltrate rainwater and exhaust the displaced soil air.

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 to concentrate these resources onto part of the total land area by creating alternating strips of land with water shedding and water absorbing surface geometries. The land imprinter simultaneously forms interconnected downslope and cross-slope corrugations that shed rainwater and then infiltrate it deeply 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.

THE LAND IMPRINTER

Construction

The land imprinter is a simple and rugged machine designed to operate in rough, rocky, brushy terrain with little maintenance (Fig. 2). It 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 (one meter in diameter and one meter long) fabricated from steel plate 1.27 cm in thickness. A variety of imprint geometries are formed by welding short lengths of specially-cut steel angle irons (15.24-cm legs x 1.27-cm thick) to the outer surface of the cylindrical core. Twelve imprint capsules with distinctly different geometric patterns of steel angle irons have been developed and fabricated (Fig. 3).

Functions and Operation

Land imprinting is a unique new concept in land tillage. According to the land imprinting concept, the two major tillage functions are (i)

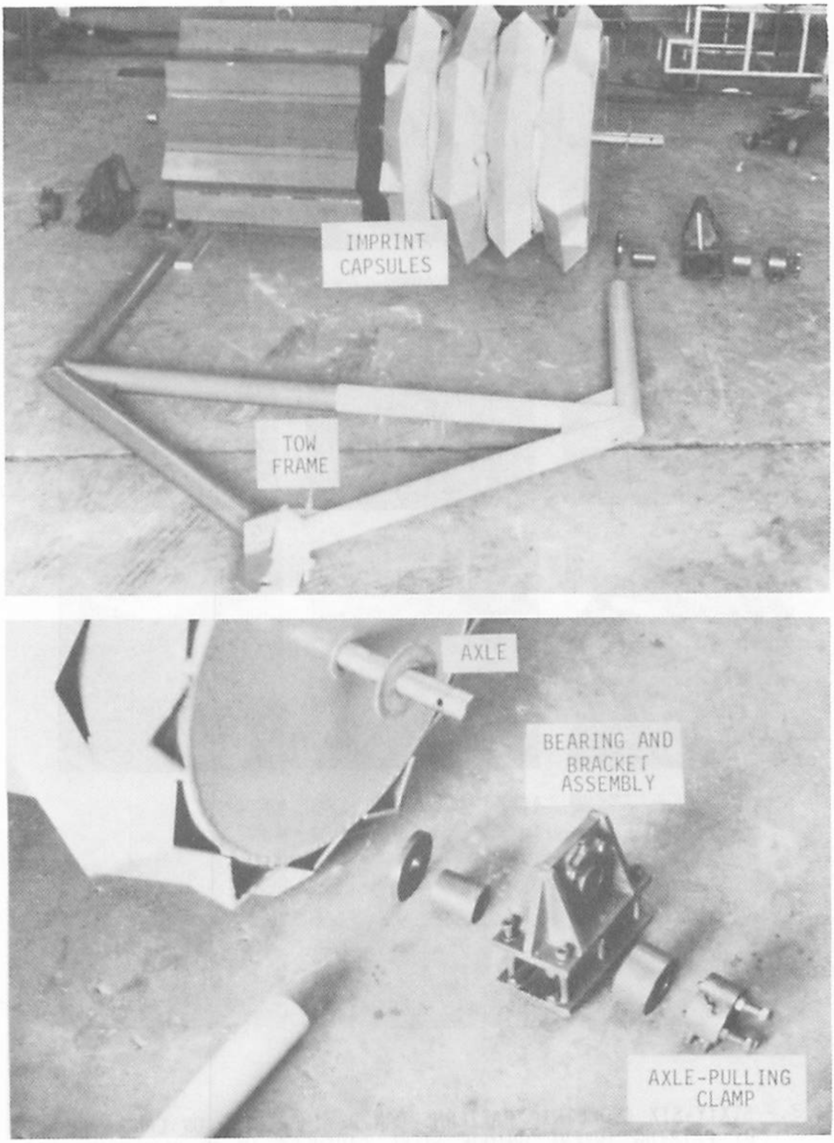

FIG. 2.—THE LAND IMPRINTER CONSISTS OF A COMPOUND ROLLER-AND-AXLE ASSEMBLY IN WHICH TWO IMPRINT CAPSULES ARE LINKED RIGIDLY TOGETHER BY MEANS OF THE AXLE AND A SPECIAL AXLE-PULLING CLAMP. THE PICTURED CAPSULES ARE DESIGNED TO IMPRINT INTERCONNECTED WATER SHEDDING AND WATER ABSORBING FURROWS SIMULTANEOUSLY

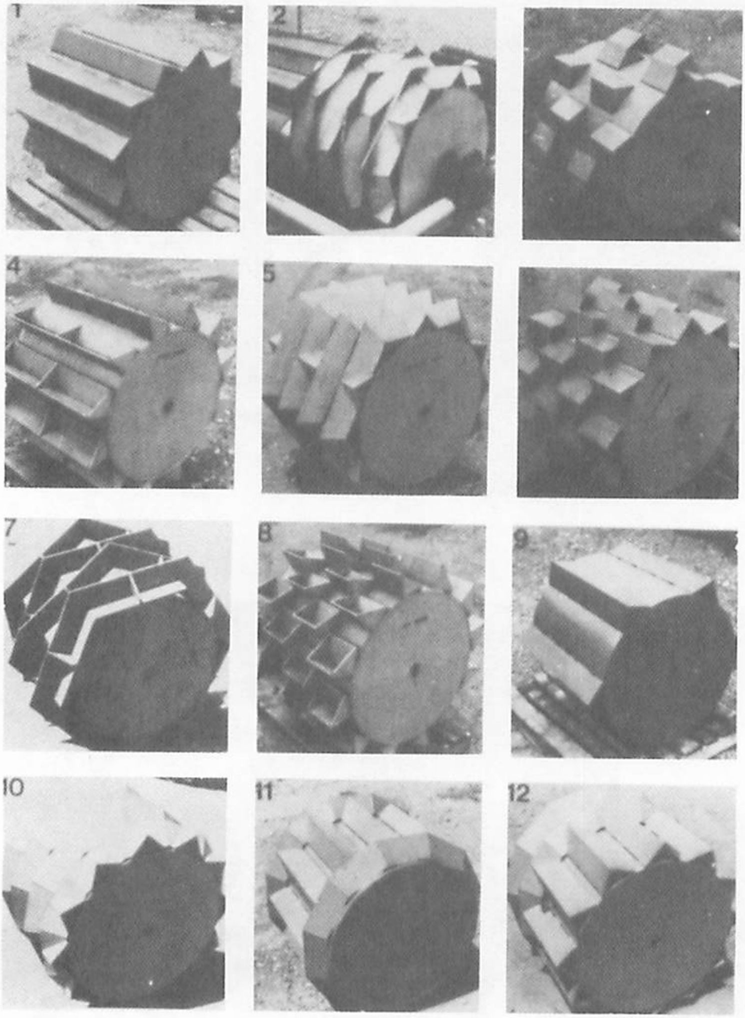

FIG. 3.—SIXTY-SIX GEOMETRIC PATTERNS CAN BE IMPRINTED ON LAND SURFACES BY PAIRING TWELVE UNIQUE STEEL CAPSULES IN AS MANY WAYS POSSIBLE. TILLAGE OBJECTIVES ARE ACHIEVED BY AN APPROPRIATE MATING OF TWO IMPRINT CAPSULES FOR COMPATABILITY WITH AMBIENT LAND AND CLIMATIC CONDITIONS

mechanical formation of seedbeds having surface geometries and physical properties appropriate for rainwater infiltration control, seed germination, and seedling establishment; and (ii) surface conditions appropriate for, and leading to, subsequent development of subsurface conditions that are optimal for growth of plant roots. The first function is performed mechanically by the land imprinter which creates unique rainwater-irrigated seedbeds through the formation of interconnected water shedding and water absorbing V-furrows (Fig. 4). By this means, rainwater is concentrated and infiltrated precisely where grass seeds are placed to insure adequate moisture for seed germination and stand establishment. The second function is accomplished mainly by biological processes (and resulting physical and hydraulic processes) that are favored by the imprinted surface geometry. The newly-established crop stand and the imprinter-created surface mulch interact to heighten the activity of soil invertabrates including ants, termites, etc. This activity increases surface microroughness and macroporosity, and thereby increases water infiltration in accordance with the air-earth interface concept. Thus, mechanical infiltration control with the land imprinter leads to enhanced infiltration through greatly increased biotic activity. Additionally, this biotic activity and associated physical and hydraulic processes produce the desirable effects of deep soil tillage (including soil loosening, mixing, and aeration) without the development of traffic and tillage pans beneath the loosened tillage layer which can restrict downward movement of crop roots and soil moisture.

By pairing the 12 imprint capsules (shown in Fig. 3) in as many ways as possible, 66 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 (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 (right angle to contour), or diagonal-slope (some angle between cross-slope and with-slope). 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 angle irons 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 firming, 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.

Penetration depth of the imprint angle irons depends on soil hardness, soil moisture content, and the weight or downward force of the imprinter. Downward force is increased by filling the capsules with sand, concrete, water (or other liquids), and by weighting the tow frame. 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.

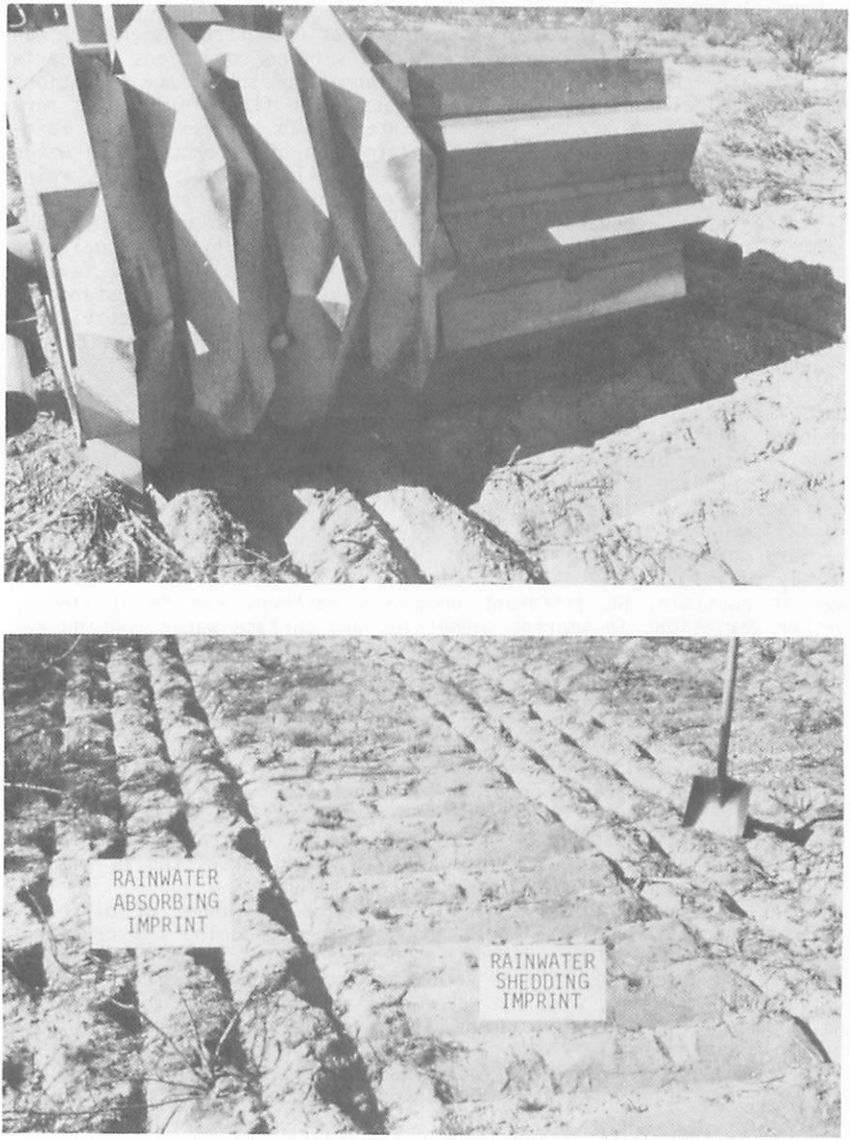

FIG. 4.—A RAINWATER-IRRIGATED SEEDBED CAN BE MOLDED IN TH SOIL SURFACE BY THE LAND IMPRINTER TO ASSURE ADEQUATE SOIL MOISTURE FOR SEED GERMINATION AND SEEDLING ESTABLISHMENT

Unequal weighting can also create microslopes in imprinted furrows for concentrating rainwater 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 operates satisfactorily in extremely dry soils, either with or without primary tillage.

As compared with other minimum tillage implements used in crop and rangelands, the imprinter may have slightly higher initial cost, but has somewhat lower operation and maintenance costs, 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 for root plowing. Satisfactory operation requires a tractor with a minimum of 30 horsepower (22 kw) at the drawbar. Maintenance entails only lubricating axle bearings, hard surfacing of cutting corners and edges, and oiling imprint angles to inhibit rust fromation while the machine is not in use.

Design Utility

In general, the land imprinter is designed to (i) better protect and more efficiently use soil, water, and vegetal resources for crop production; (ii) increase and stabilize range and cropland productivity; (iii) reduce land management costs and consumption of fossil fuels per unit of product; (iv) reverse the trend toward desertification of vast crop and rangeland areas; and (v) extend agriculture into rocky, hilly lands not otherwise arable. To achieve these broad design objectives, the land imprinter is uniquely capable of (i) safely increasing depression storage by forming relatively stable closed angular pockets (that can hold up to 5 cm of rainwater) without loosening and inverting the soil surface layer and without covering aboveground plant materials; (ii) forming a variety of complex and stable geometric surface configurations by compressing, shearing, and embossing of the immediate soil surface layer and the aboveground plant materials; (iii) increasing (rather than decreasing) effective surface mulch by crushing, chopping, mixing, and partially imbedding aboveground plant materials (thereby concentrating them at the immediate soil surface) while at the same time forming rainwater-irrigated seedbeds; (iv) impressing and embossing the soil surface with geometric patterns that give better control over rate, route, duration, and microsite of infiltration, runoff, and erosion for the purpose of enhancing seed germination, seedling establishment, crop growth, and crop yield; (v) making a smooth-sided V-shaped furrow for efficient line concentration of forage seeds, soil fines, plant residues, and rainwater through the processes of gravity, wind erosion, splash erosion, splash-off, and runoff; (vi) simultaneously imprinting a variety of good seedbeds and seedling cradles for collecting different amounts of rainwater and eroded soil to insure successful stand establishment under adverse and unpredictable soil and climatic conditions; (vii) operating satisfactorily without breakdown and rapid wear on rough, rocky, brush-covered terrain otherwise nonarable; and (viii) reducing land treatment costs because of the large number of tillage functions performed simultaneously and the low operation and maintenance costs. The foregoing eight capabilities, inherent in the land imprinter's basic design, suggest strongly that this new plow has many potential uses.

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 marginal croplands, expanding deserts (desertification), strip mining, road construction, and urban and industrial 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 crop production.

Although developed primarily for revegetation of rugged barren or near-barren rangeland, 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 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 could be used to compact and corrugate land surfaces for furrow irrigation while simultaneously forming an efficient seedbed and seedling cradle. This 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) assuming 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 (15). 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 to be a sounder approach to wind erosion control than the traditional approach of loosening the soil to form clods.

The land imrpinter could replace conventional wheatland drills for molding wind-stable seedbeds 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 V-furrows. The imprinter would then be operated up-and-downslope to mold discontinuous furrows on the contour. A dozer blade mounted in front of the tow tractor would be useful for smoothing out a path across steep-walled gullies and channels.

Presently, the land imprinter is being tested for 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 should increase the probability of grass seed germination and seedling establishment.

As in all minimum and no-tillage practices, excessive competition from weeds needs to be controlled with herbicides. However, the imprinter does kill most of the vegetative growth of broad-leafed species. The fibrous-rooted grasses are killed to a lesser extent, which can be an advantage in the renovation of pastures and rangelands. Additionally, disease and insects will present problems similar to those experienced in other mulch-tilled practices.

Refinements and Attachments

Adaptation of the basic land imprinter to a number of specific uses will necessitate many modifications, refinements, and attachments. This is to be expected since optimal geometry of a seedbed imprint depends on the species being seeded, ambient and inherent soil conditions, climatic zone, and climatic conditions following seeding. Because rangeland soils are typically highly variable spatially, and post seeding climatic conditions are not only highly variable but also unpredictable, imprinting a variety of seedbed geometries will greatly cut the risk of seeding failure. This can be accomplished either by developing an imprint capsule that will produce a variety of seedbed geometries (a general purpose capsule) or by developing imprint capsules for specific environmental conditions. Several of the special purpose capsules would then be used simultaneously to achieve the desired diversity in imprint geometry. This controlled variability in seedbed geometry should help the land manager cope successfully with the uncontrollable variability in soils and climate. To implement this approach of success through diversification, a multiple-unit land imprinter having an equilateral triangular-shaped tow frame is being fabricated which can imprint up to ten different imprint geometries simultaneously in rangelands.

Attachments for modifying the basic imprint geometries are being developed to achieve special results including the formation of (i) V-furrows with microslopes to concentrate rainwater on nearly level land, (ii) seed slots to facilitate adequate covering of the larger crop seeds, and (iii) step terraces on the sides of the V-furrows to increase seedbed variety. These attachments are either temporarily welded or bolted onto the basic geometries to permit pattern changes.

Additional imprint geometries can 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. Such geometries could be formed by sandwiching together many steel and plyboard discs, each of which would represent a different thin radial section of the imprint capsule.

Drags and trailing wheels are being fabricated for positive covering of various-sized crop seeds. Special seeders are being developed that are sufficiently durable to be mounted directly on the land imprinter, and that will uniformly disseminate fluffy (or trashy) seed ahead of, onto, or behind the land imprinter.

Alternative modifications and designs for the land imprinter include (i) self-propulsion through replacement of wheels of a farm tractor with imprint capsules; (ii) fabrication of imprint capsules from reinforced concrete to reduce cost of materials; (iii) utilization of imprint capsules singly or in combinations of three or more; (iv) reduction of imprint capsule diameter for smooth land use and enlargement of diameter for extremely rough land use; (v) utilization of smaller or larger steel angles in the fabrication of imprint patterns; (vi) use of more than one angle size on a single capsule to provide minor modification of imprint geometry; (vii) modification of number and spacing of steel angle pieces that are welded to the capsule's central core; and (viii) replacement of the polygonal angle frames with annular rings fabricated by welding together two right-angle cone sections. Self propulsion could also be accomplished by slipping imprinting rings onto the rubber tires of tractors, etc., and by welding or bolting imprinting grousers to the tracks of crawler tractors.

Additional cultural practices can easily be combined with the land imprinting practice when the expected economic benefit justifies the added cost. Commercially available accessories for vegetal shredding, cutting, or mulching; seeding grasses, legumes, and small grains; spraying herbicides and insecticides; and applying chemical soil amendments can be mounted on the A-frame of the land imprinter or on a U-frame which telescopes into the legs of the A-frame.

LAND IMPRINTER TESTING

Preliminary Tests

Since July, 1976 the land imprinter has been used in rangeland revegetation trials at several locations in western Texas and numerous locations in Arizona. Preliminary evaluation of the land imprinter and its imprints suggest the generalizations: (i) the land imprinter is a rugged, simple machine with no apparent design flaws emerging after 3,000 acres of testing under extreme conditions; (ii) the imprinter operates satisfactorily in soils ranging from rocky to clayey and from dry to moist; (iii) the imprinter functions as designed to concentrate rainwater where seeds are placed; (iv) imprinted land holds soil and water resources within the imprinted areas even under intense, long-duration storms; (v) the imprinter has successfully established vegetation during hotter and drier than normal growing seasons; (vi) imprint capsules effectively crush and chop aboveground vegetative material to improve the protective soil cover relative to the antecedent condition;

(vii) the land imprinter can roll over shrubs having basal diameters up to 4 inches, and even larger if shrubs are laid down in advance of the imprint roller; (viii) splash erosion provides adequate covering for seeds; (ix) small grains can be successfully planted with the land imprinter without special modifications of the imprint capsule geometry; (x) the land imprinter kills most of the aboveground growth of shrubs, mulching and anchoring this material at the same time, thereby helping to conserve water for grass establishment through reduction of both transpiration and evaporation; (xi) the imprinter uniformly thins existing grass stands, but the remaining grass responds rapidly to improved soil moisture conditions after the first good rain; (xii) the land imprinter operates satisfactorily on deeply dissected land surfaces strewn with boulders; (xiii) a bare imprint has sufficient longevity for successful grass stand establishment and the consequent stabilized-infiltration enhancement; (xiv) a mulched imprint will last for many years since rainfall impact energy is dissipated before it reaches the particulate mineral surface; (xv) excessive covering of seeds by splash erosion can be prevented by microterracing the sides of the V-furrow or by imprinter seeding during the season of low-intensity rainfall; and (xvi) to cut the risk of seeding failure due to uncontrolled variability in post-seeding climatic conditions and inherent (also ambient) soil conditions, a wide-diversity of good seedbed geometries should be imprinted simultaneously.

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 V-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 in relatively dry years the corner seedbed sites would be the best. Obviously, furrow depth variability is less with the dodecagonal imprint frame than with the hexagonal frame.

Splash erosion seems to be a suitable means for covering grass seeds in the imprinted V-furrows. 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.

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, shear, and emboss the soil to produce the imprint pattern. The resulting compaction or densification in moist soils increases the soil volumetric moisture content and correspondingly decreases the soil air volume and moisture tension. In dry soils, imprints are formed largely through a shearing and embossing process with little, if any, overall compaction.

In humid and subhumid regions, selecting the optimal soil moisture for imprinting involves a compromise between the need for soil surface stability (strength or detachability) 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 (2). If excessive soil compaction is a critical land management problem, then the imprinter should be operated only when final moisture contents are well below the lower plastic limit.

In arid and semiarid regions, the compromise between soil stability and looseness is usually not necessary 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 moist surface soil overlying dry soil facilitates the 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.

It is important to establish vegetative cover as soon as possible to protect the imprint geometry from raindrop impact. However, 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 (4). 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 gentler winter rains can subsequently protect the imprint from the beating raindrops of intense summer thunderstorms.

Although splash erosion shortens the life of the imprint, some possible advantages have been observed. Splash erosion (i) rapidly seals the bottoms of the downslope furrows, thus increasing runoff delivery to the cross-slope furrows; (ii) rapidly covers seeds in the cross-slope furrows; (iii) hills and braces seedlings in the bottom of the furrows with the transported soil; (iv) concentrates top soil and plant litter in the cross-slope furrows; and (v) smooths the soil surface for cropland harvesting equipment.

Rainwater is concentrated at the points or lines of seed placement by two different transport mechanisms functioning 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.

The imprinter has been operated at velocities up to 6 km/hr to determine the effect of surface printing rates on the resulting geometry. Preliminary tests indicated that the effect of velocity is minor. Some loose soil particles settle into the bottom of the V-furrow at the higher speeds, especially when soil moisture is 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, textural coarseness, 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.

Contrary to Darcy-based infiltration theory, the air-earth interface theory (4) indicates that high infiltration capacities 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 polygonal rings mechanically crack the soil due to the variable rolling diameters of the imprinting faces. In addition, 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 ponded-water 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 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 (4). 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.

Evaluation Plans

Further testing is needed to determine how well and under what conditions the land imprinter can achieve its broad design objectives. Basic to achieving these objectives is the land imprinter's ability to control rainwater infiltration rates and soil penetration routes. Sprinkling (6) and closed-top infiltrometers (5) 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 and summarized with the aid of Kostiakov's equation (7).

The land imprinter is designed to be a versatile no-till implement. Because of the success of preliminary tests and the widespread interest that has developed in the land imprinter's potential uses, plans are being developed for extensive cooperative testing for applications including: (i) conversion of semi-desert shrublands in southwestern United States and northern Mexico to grasslands; (ii) reclamation of surface-mined lands in western United States; (iii) revegetation of previously-irrigated, now-abandoned farmland to control wind erosion and tumbleweed problems in southern Arizona; (iv) revegetation and interseeding of sagebrush lands of the Great Basin for enhancing the habitat of cattle and wildlife; (v) revegetation of marginal wheatlands in the Great Plains for wind erosion control and forage production; (vi) interception of drainage from feedlots for point-source pollution control; (vii) pasture renovation in the Great Plains and Cornbelt regions; (viii) conservation seeding and planting of major food and feed crops in the Great Plains and Cornbelt regions; (ix) formation of rainwater-irrigated seedbeds and rootbeds for growing forage shrubs in the Middle East; (x) conservation tillage for controlling runoff and erosion from croplands and the control of nonpoint source pollution of surface waters and groundwaters; (xi) revegetation of military testing sites; (xii) sedimentation reduction in the Rio Grande River channel and the reestablishment of the international boundary through revegetation of eroding watersheds; and (xiii) revegetation and beautification of roadsides. These testing efforts will be evaluated by collecting data on plant stand establishment, plant yields, rainwater infiltration, rainwater runoff, soil moisture, and sheet and rill erosion.

Research plans are also being developed to relate successful seed germination and seedling establishment to the physical properties of the microniches formed by the land imprinter. The outcome of such research will be useful in modifying old imprint geometries and designing new ones.

The land imprinter produces geometries that are sufficiently stable to justify describing them mathematically. The V-furrow can be described by the general equation:

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

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 can 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.

CONCLUSIONS

Newly-developed science and technology for controlling rainwater infiltration can dramatically increase and stabilize the productivity of rainfed agricultural lands. The yield limiting factor in these lands is often available soil water. This new technology makes more of the rainwater resource available for crop stand establishment and production. More rainwater is routed to crop seeds and through plants, and less is lost by surface runoff and evaporation.

The new science and technology includes a set of infiltration control principles which are unified by the air-earth interface theory. This theory led to the development of a concept in land tillage called land imprinting, and a tillage implement for economically applying the concept to extensive land areas.

The land imprinting concept postulates that the two major tillage functions are the mechanical formation of (i) seedbeds having surface geometries and physical properties appropriate for rainwater infiltration control, seed germination, and stand establishment, and (ii) surface conditions appropriate for the subsequent development of subsurface conditions that are optimal for plant roots and plant growth. Application of the land imprinting concept to large areas can greatly reduce rainwater runoff, soil erosion, and pollution of surface waters through enhanced and stabilized infiltration relative to conventional practices.

The land imprinter has several intrinsic advantages relative to conventional tillage implements including its ability to (i) safely increase depression storage by forming relatively stable closed angular pockets without inverting the soil surface, (ii) increase (rather than decrease) effective surface mulch by concentrating all aboveground plant materials at the soil surface, and (iii) impress and emboss the soil surface with geometric patterns that give better control over infiltration, runoff, and erosion in plant-sized areas.

APPENDIX I.—REFERENCES

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