V. MECHANICAL TREATMENT MEASURES

5.1 General

A viable means of reestablishing and maintaining a stable post mining landscape is to mechanically manipulate the land surface. The ultimate purpose is to decrease the time required to reconstruct a relatively stable land surface. This is done by (1) reducing runoff, (2) increasing rainfall depression storage and (3) converting concentrated flow to diverse flow, with the ultimate goal being to establish or improve vegetative cover.

Science and technology of land surface treatments (including conservation tillage) of cropland and rangeland have reached an advanced stage in the United States and similar practices have been adapted to mine lands. Surface roughening treatments which have been modified from rangeland practices include furrowing, terracing, trenching, ripping, chiseling, tracking, pitting and water spreading and harvesting. Equipment commonly used are modified versions of rangeland, agricultural and industrial implements including backhoes, bulldozers, disks, harrows, rakes, tillers, drills, chiselers and scrapers.

These practices have been developed largely for semi-arid and arid lands where water and soil conservation is critical. On mined lands in these regions, several complementary treatments may be necessary to offset scanty moisture supplies resulting from (1) erratic and low rainfalls (4 to 14 inches of average annual precipitation), (2) high evapo-transpiration, (3) low spoil water-holding capacity and (4) low infiltration rates. Land manipulation in humid areas is generally considered inefficient because standard seedbed preparation, seeding and vegetative management are more successful and well-accepted reclamation practices.

Four land surface treatments are presented in this manual: furrowing, imprinting, pitting and ripping. The following design methodology quantifies and assesses the effects of these land surface treatments.

5.2 Design Procedures

The procedural guidelines for predicting the effects of erosion control structures and land treatments are given in Chapter IV. Two additional sets of design information are required before applying this design procedure to land surface treatments.

First, the relationship between the treatments and the roughness coefficient, K_g, is graphically illustrated in Figure 5.1. Values of K_g can also be determined for different ages of the treatment, depending on when the treatments were implemented. If vegetation is established during this time, the largest K_g value corresponding to the appropriate cover in Figure 4.2 (Chapter IV) or selected treatment in Figure 5.1 should be chosen for use in the design procedure.

Values of K_g and the detachment coefficient, D_f, for each of the treatments corresponding to general soil textural classes are tabulated in Table 5.1. As previously stated, if vegetation is established, the largest K_g value corresponding to the appropriate cover (Table 4.2) or treatment (Table 5.1) should be selected. If sufficient data are available to determine particle size distribution (Appendix A) and site specific values of erodibility, K_e, (Appendix B), then more specific values of K_g and D_f can be determined from Figures 5.1 and 4.3, respectively.

Values of the curve number, CN, are also required for each of the treatments. Table 5.2 gives the CN values for the 4 mechanical treatments corresponding to zero vegetative cover and 100 percent cover. The actual value of CN to be used will be based on the percent ground cover as given by the equation (4.1), $CN = CN_H - (CN_H - CN_L)C_g$, where CN_H and CN_L are the 100 and zero percent CN values, respectively, and C_g is the decimal percent cover.

5.3 Contour Furrowing - Design Information, Planning Considerations Specifications, and Maintenance

Design Information

Furrowing is a mechanical treatment done on the contour which creates small trenches or grooves by throwing the soil on each side of the trench. Contour furrows are generally spaced five feet apart, are 20 to 30 inches wide and 8 inches deep, and should be dammed at intervals of 4 to 9 feet (see Figure 5.2). This treatment is considered to be a highly successful mechanical treatment for establishing vegetation. Although the land surface pattern illustrated in Figure 5.2 is the result of a disk furrower, a similar roughening pattern can be effectively produced by modifying equipment listed in Table 5.3, e.g., a moldboard plow bottom creates dikes by throwing the soil on the downslope side of the ditch, forming a ridge or dike (one to two feet high).

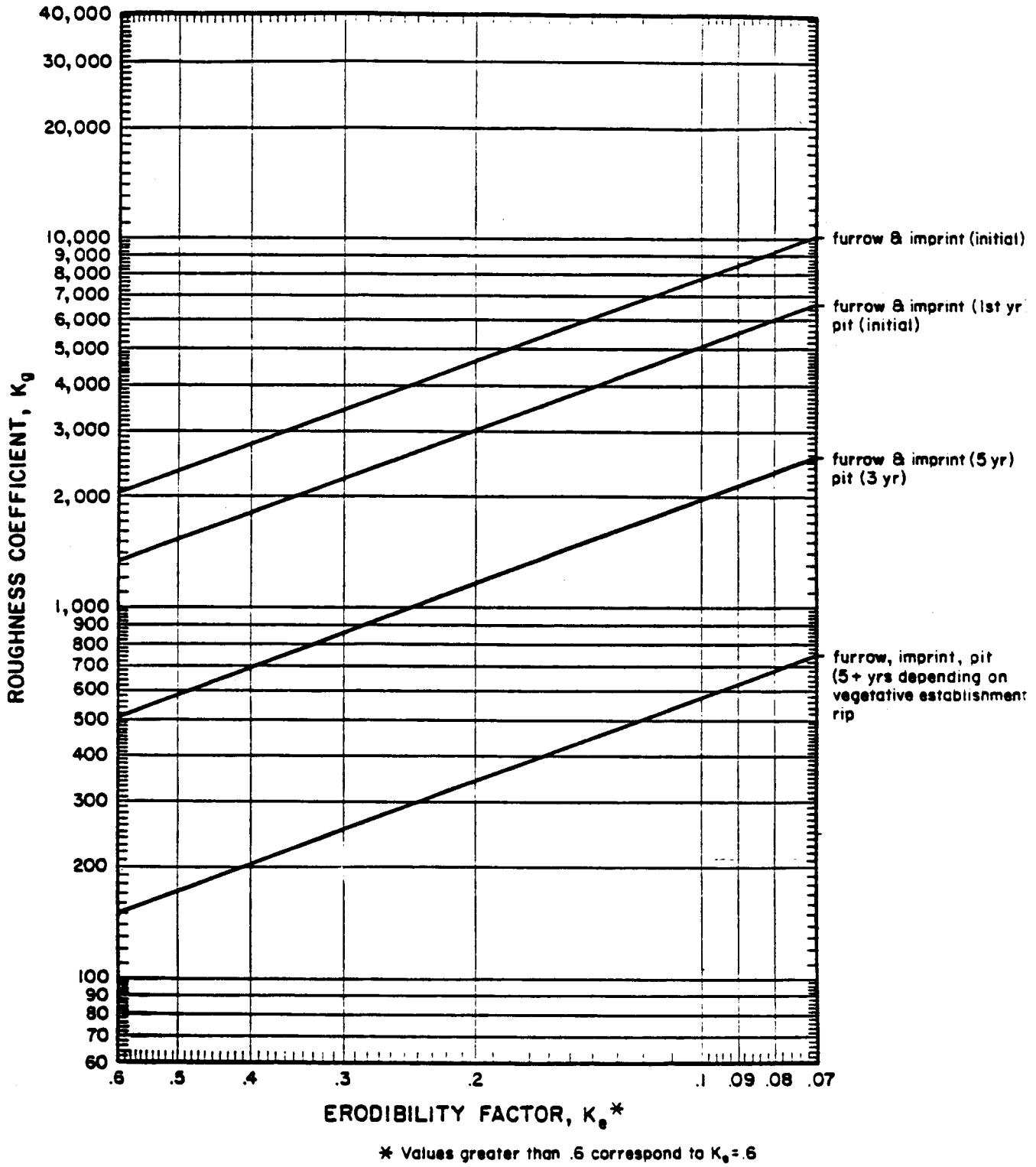


Figure 5.1. Relationship between mechanical treatments, roughness coefficient and erodibility factor (from Simons, Li & Associates, Inc., 1982).

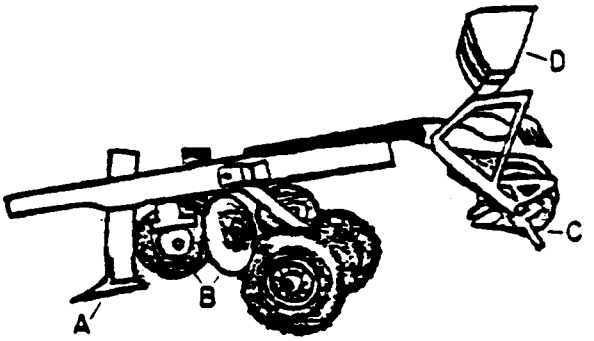
Table 5.1. Simplified Listing of Roughness Coefficient, K_g, and Overland Flow Detachment Coefficient, D_F, for General Soil Textural Groups and Associated Erodibility Values, K_e (Table 4.1)

Textural Class	Suggested K_e	K_g				D_f
		Furrow, Imprint (Initial)	Furrow, Imprint (1st Year) Pit (Initial)	Furrow, Imprint (5 Years) Pit (3 Years)	Furrow, Imprint Pit (5+ Years) Rip	
Sand	.20	4,900	3,000	1,150	340	1.000
Loamy Sand	.30	3,600	2,200	860	255	1.000
Sandy Loam	.43	2,700	1,720	680	190	1.000
Loam	.36	3,150	1,950	750	220	.550
Silty Loam	.48	2,550	1,600	610	180	.160
Silt	.83	2,100	1,350	500	150	1.000
Sandy Clay Loam	.26	4,000	2,500	960	280	.088
Clay Loam	.28	3,800	2,400	920	270	.046
Silty Clay Loam	.31	3,500	2,150	840	250	.025
Sandy Clay	.13	6,800	4,200	1,600	470	.0023
Silty Clay	.25	4,200	2,600	1,000	290	.0074
Clay	.20	4,900	3,000	1,150	340	(~0.0)

Table 5.2. CN Values of Surface Treatments Under No Vegetative Cover Conditions and 100 Percent Cover Conditions.

		Hydrologic[1] Soil Group			
		A	B	C	D
Contour Furrowing	(low)[2]	26	57	70	78
	(high)	47	67	81	88
Imprinting	(low)	30	58	71	78
	(high)	47	67	81	88
Pitting	(low)	34	59	72	79
	(high)	57	73	83	88
Ripping	(low)	39	61	74	80
	(high)	68	79	86	89

[1] See section 3.3
[2] Low and high end of range for reclaimed mine spoil with vegetative ground cover (see Equation 4.1)



Keith O. Eggleston

E

Figure 5.2. Contour furrowing implement and land pattern. A. ripper tooth to rip soil about 2 inches below furrow depth; B. standard disks that open furrow; C. damming device; D. broadcast seeder; E. surface pattern of dammed furrow system.

Table 5.3. Specifications for Contour Furrowing.

Item	Common Specifications
Equipment	Disk-type, modified moldboard plow, modified listers, blade-tips of graders (broad base furrower)
General Components	Furrow opener creating ditch and throwing soil on opposite sides or on the downslope side; an adjustable ripper tooth may precede the furrow opener (optional); damming device
Number of Furrows	1 - 3 depending on equipment
Maximum Penetration of Ripper	12" (or approximately 2" below depth of furrow)
Damming Interval	4' to 20'
Furrow Spacing	3' to 5'
Width of Furrow	18" to 30"
Maximum Furrow Depth	8"
Power Requirements	Minimum of 15 to 20 HP per furrow former (equivalent of caterpillar D6)
Pay Item	Per acre

Planning Considerations

Contour furrowing is a versatile treatment on slopes less than 10 percent which are not rocky. Furrowing is best accomplished on moderately deep and deep soils (approximately 10 to 12+ inches) in arid and semi-arid regions which receive greater than 8 inches of annual precipitation. Limited data do not show significant beneficial results from humid regions or regions receiving less than 8 inches of precipitation.

Specifications - Contour Furrowing

This work shall consist of mechanically contour furrowing in accordance with the specifications given in Table 5.3. The accepted basis of payment for standard furrowing will be paid at the contract unit price according to the pay unit given in the Table.

In-Service Performance

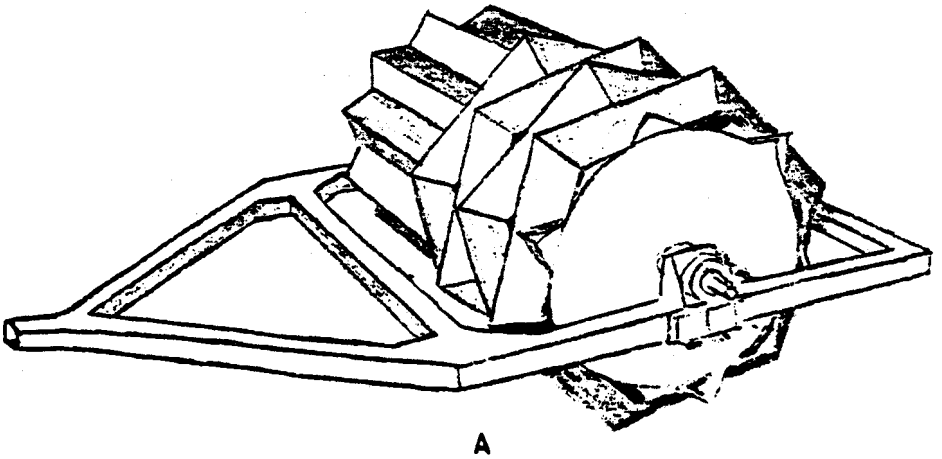
Of the mechanical treatments used on rangeland and mined land, the conservation effects of furrowing are relatively well documented. Under the recommended field conditions and standard specifications, the water holding capacity is approximately two inches of rain the first year and one inch by the 5th year. Infiltration rates can increase by 10 fold and runoff can decrease by 84 percent. The effects of furrowing generally persist (in a degrading mode) from five to twelve years. The in-service performance is dependent upon a complex interaction between pit size and soil type, microclimate, and vegetative establishment. A general rule of thumb for furrowing and most mechanical treatments is that the hydrologic conditions of a site can be expected to improve as vegetative cover is established and approaches that of the surrounding landscape or approaches 70 percent cover if annual precipitation is adequate.

Although little data are available on broad-base furrows, their performance appears to be comparable with standard contour furrows.

5.4 Land Imprinting

Design Information

Land imprinting is a relatively new minimum tillage practice which forms microfurrows to reduce and diffuse runoff and microbasins to pond water (see Figure 5.3). It concentrates above-ground plant material at the surface



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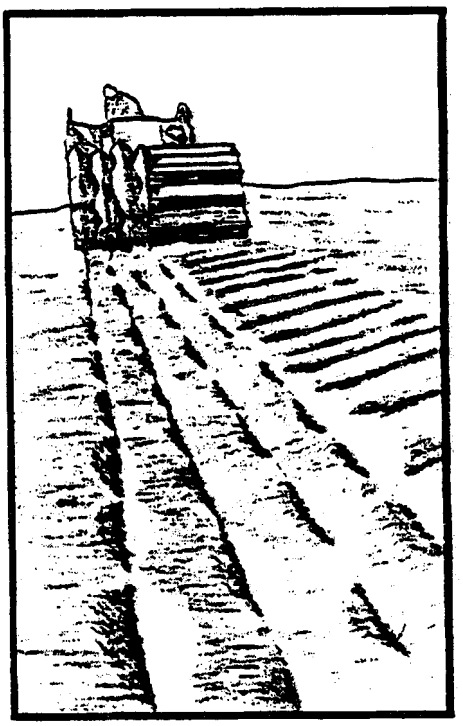

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Figure 5.3. Land imprinting implement and land surface pattern. A. Standard imprinter consists of a single moving part, which is a compound roller having angle irons on external surface. B. Mechanically formed geometric pattern. V furrows (RH) collect and shed runoff to microbasins (LH) where runoff is collected and absorbed.

thereby increasing the effective mulch. Imprinting roughens the surface with wedges creating geometric patterns approximately four inches deep, depending on soil compaction, soil moisture, and weight on the implement. The V-furrows combined with the closed geometric ponding pattern create a relatively stable seed bed and runoff is diffuse. The microbasins have been found to perform successfully in concentrating meager amounts of rainfall runoff in arid lands.

Design and specification instructions for home fabrication can be obtained from Robert Dixon, USDA-SEA, 2000 E. Allen Road, Tucson, Arizona 85719.

Planning Considerations

Land imprinting can be used to treat all soil textures including rocky, soil and shallow or deep soils. Imprints can be constructed under wet or dry conditions although the optimum condition of soil in humid-subhumid regions is the lower end of the plasticity range for a particular soil; optimum conditions in arid and semi-arid regions are the plasticity range on less. In regions receiving less than 8 inches of annual rainfall, imprinting should be done in conjunction with ripping, topsoiling and mulching.

Imprinting can be done parallel to the slope to enhance harvesting of runoff from the V-furrows to the microbasins. However, imprinting perpendicular to the slope is recommended for steep slopes (greater than 8 percent) to create firm microterraces or horizontal stairsteps on the hillside (see Figure 5.4). The maximum slope for imprinting depends on operator safety. Cabling can be utilized for steeper slopes.

Soils with less than 150 lb/in^2 load bearing capacity require a 3 ton imprint implement. For soils with higher bearing capacities, 3 to 5 ton implements perform well, or, alternatively, the soil can be ripped prior to imprinting. To increase the weight of standard imprints, the imprinter can be filled with water or sand (Figure 5.3).

Specifications - Land Imprinting

This work shall consist of mechanically imprinting in accordance with the specifications given in Table 5.4. These specifications are defined for the standard imprinter illustrated in Figure 5.3. Specifications for other imprinting patterns, such as a simple V-furrow pattern or the crimped V-furrow (see Figure 5.5) are not included, although many of the specifications are

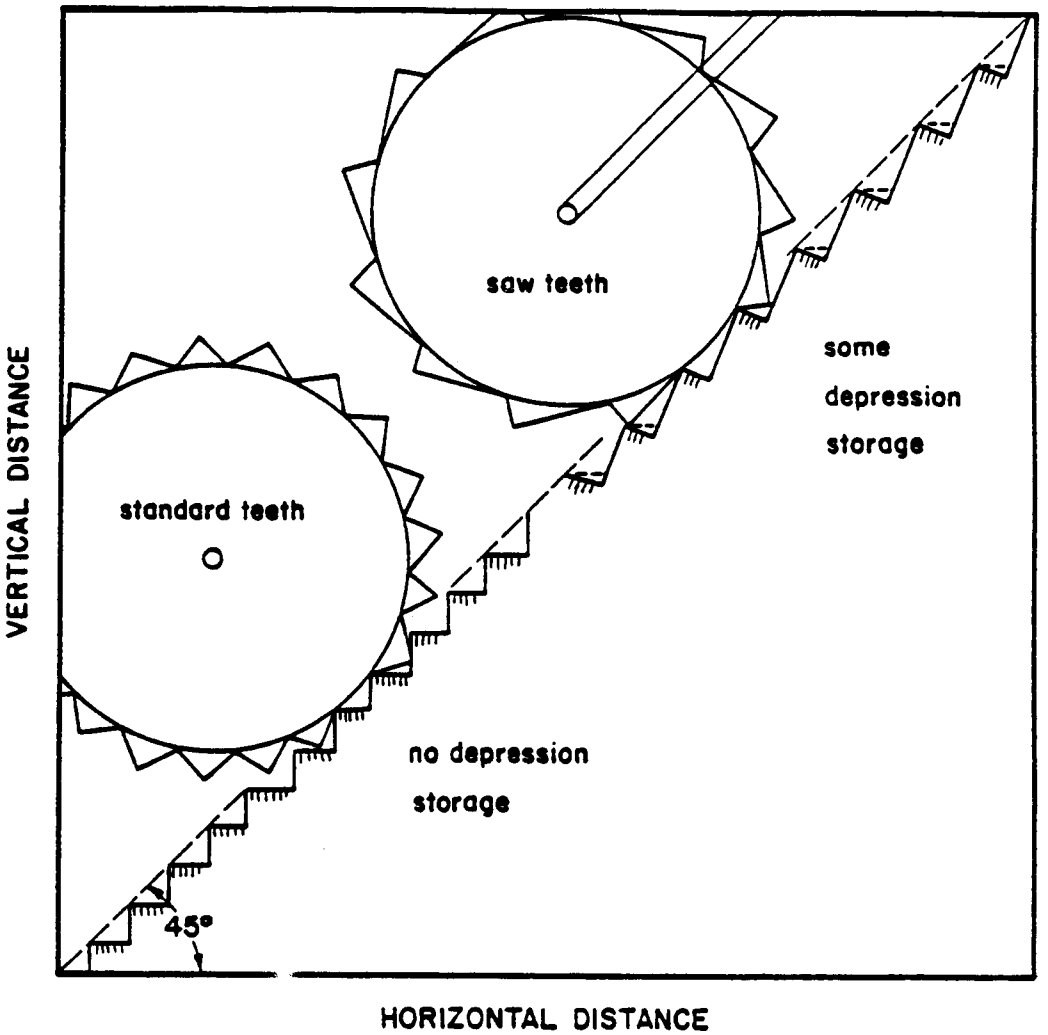


Figure 5.4. Comparison of imprints made on a 45° (100%) slope by imprinting angles having equal legs (standard teeth) and unequal legs (saw teeth). Saw teeth on $\geq$ 45° slopes provide some depression storage. For slopes > 45°, capsules can be cabled onto the slope (after Dixon, R.M., unpub.).

Table 5.4. Specifications for Land Imprinting.

Item	Common Specifications
Equipment	Commercial or home-fabricated imprinter modified crawler or tillage implements
General Components	V-furrow former; microbasin former
Imprint Implement Weight	3 to 5 t
Furrow Width	10" to 12"
Furrow Depth	4" to 6"
Furrow Length	40" to 45"
Furrow Spacing	10" to 12"
Microbasin Width	2" to 10" (variable)
Microbasin Depth	2" to 5" (variable)
Microbasin Length	Continuous with direction of travel
Microbasin Spacing	10" to 12"
Number of Microbasin/Trip	4
Power Requirement	30 HP
Pay Item	Per acre

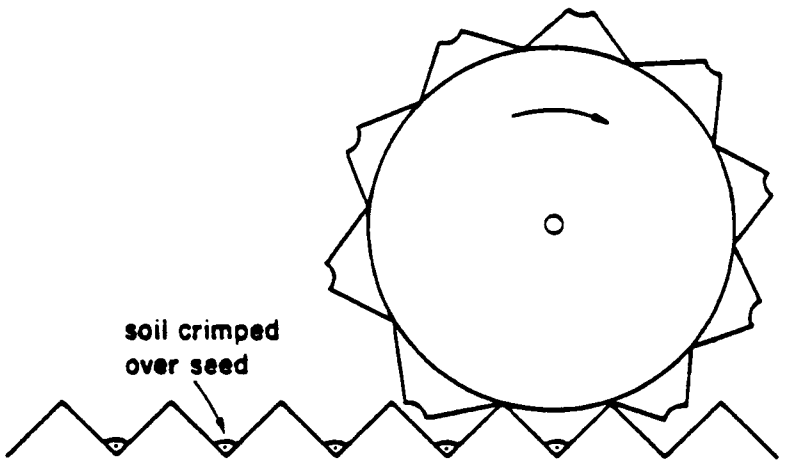


Figure 5.5. Soil crimping imprinter. Larger seeds are covered with soil simultaneously with imprinting. Seedbed preparation and seeding can be accomplished during the same operation by attaching a seeder to the imprinter (after Dixon, R.M., unpub.).

general enough to be applicable. The accepted basis of payment for imprinting will be paid at the contract unit price according to the pay unit given in Table 5.4.

In-Service Performance

Performance records of the land imprinting indicated that the water holding capacity is approximately 2 inches and does not significantly deteriorate for at least 2 to 3 years. Infiltration rates may increase substantially depending on the site conditions. Imprint patterns can potentially persist for 10 to 12 years if the recommended conditions exist at the time of emplacement and vegetation is established. However, if imprinting is done in an arid region in dry clayey soil and no vegetation is established, the pattern will naturally be obliterated in 2 years.

5.5 Pitting

Design Information

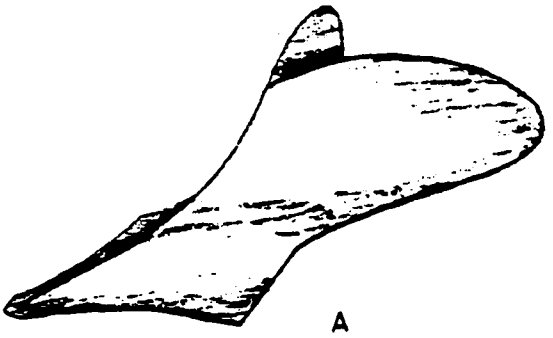
Pitting is a treatment which creates small basins to increase storage and infiltration, thereby increasing vegetative establishment (see Figure 5.6). Pits are generally 3 to 8 feet long, 8 to 12 inches wide and 4 to 8 inches deep.

Planning Considerations

As a water conservation and erosion control measure, pitting has been almost exclusively used on arid and semi-arid regions with varying degrees of success. Best results are received where annual precipitation exceeds 8 inches and where the pits are placed on the contour of less than 10 percent slopes in moderately dry, medium textured soil. It is not recommended for use on clayey, sandy, shallow or rocky soil.

Specifications - Pitting

This work shall consist of mechanically pitting in accordance with the specifications given in Table 5.5. These standard specifications are defined for disk, plow, and gouging type pitters; spike or rotary pitters do not meet these specifications. The accepted basis of payment for pitting will be paid for at the contract unit price according to the pay unit given in Table 5.5.



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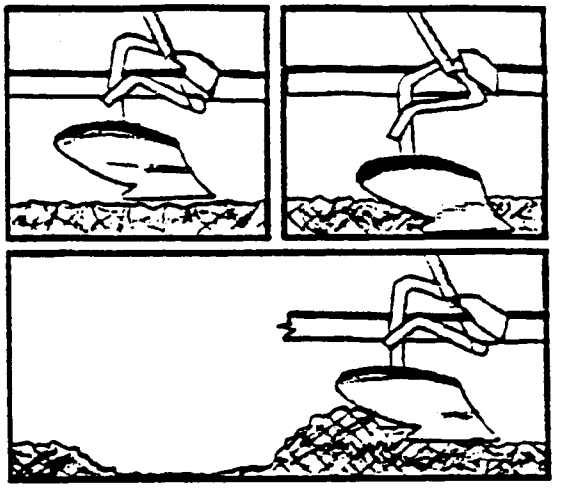

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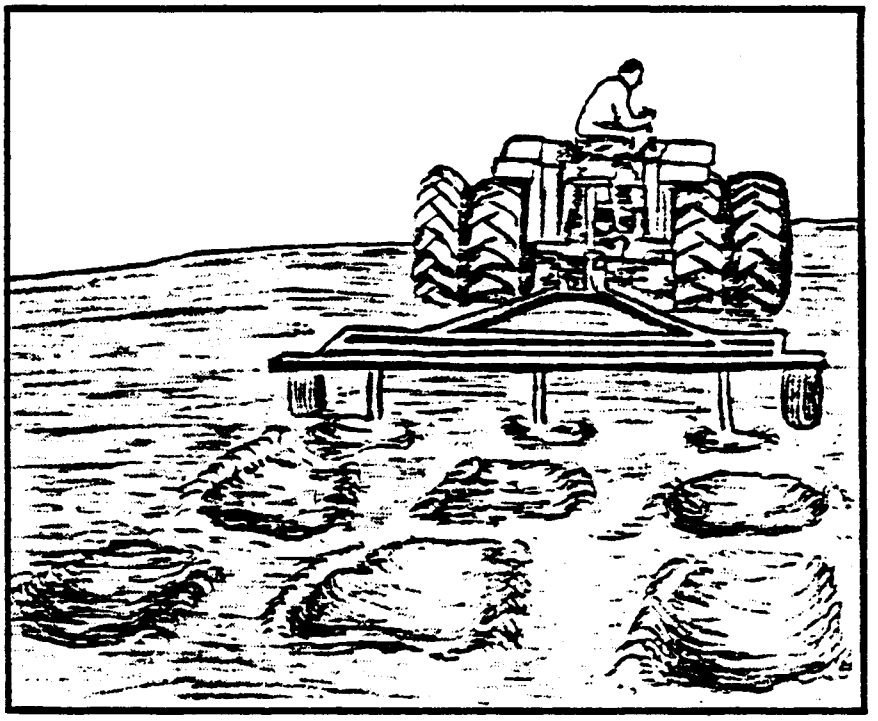

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Figure 5.6. Pitting implements and land surface pattern. A. A lister plow can be modified and rearranged for use in creating pits. B. Pits can be created by hydraulically raising and lowering a lister or other type of shank forming a pitted surface configuration. C. Land surface pattern. Hydraulically operated gouging machine creates elongated water traps 8-10 inches deep, 2 feet long and 1-1/2 feet wide. A seedbox with tubes can be fitted onto the implement to distribute seeds in depressions.

Table 5.5. Specifications for Pitting.

Item	Common Specifications
Equipment	Lister-type gouging pitters; eccentric cutaway, or cam shaped disk pitter; modified brushland, wheatland, standard disk, tandem disk, or moldboard plow
General Components	Pit former creating pit with ridges or check dams separating the pits; mechanical structure (eg. modified tripping action) or hydraulic device to control spacing (depending on equipment)
Number of Pits	3 to 5 depending on equipment
Pit Spacing	15" to 40"
Pits/Acre	Approximately 5,000
Width	8" to 18"
Depth	4" to 10"
Length	2' to 5' (8' maximum)
Power Requirement	30 to 45 HP
Pay Item	Per acre

In-Service Performance

Data collected in the northern Great Plains and southwest suggests that the water holding capacity of pits is relatively low, ranging from 0.03 to 0.6 inches the first year and decreasing to approximately 0.08 during the next 3 to 5 years. Infiltration was found to double and runoff decreased by 13 to 24 percent the first year, and by 4 to 16 percent the third year. The average longevity of pits is 4 years in the southwest although they have persisted for as long as 6 to 15 years in the northern Great Plains.

These performance values apply to disk-type (see Figure 5.7), modified plow and gouger pitters (see Figure 5.6). Spike tooth pitters have significantly lower performance records and are not recommended as a satisfactory treatment.

5.6 Ripping

Design Information

Ripping or deep chiseling is a subsoil mechanical treatment used to break or scatter compacted layers, heavy clays, or soil/minesoil interfaces (see Figure 5.8). Ripping will loosen and mix the subsoil and allow root penetration and moisture storage below the surface. The ripper shanks should be spaced 7 feet apart and create parallel slots 4 to 10 inches wide. Ripping depth varies from about 10 inches to 36 inches depending on the depth to the resistant layer.

Planning Considerations

Ripping as a land surface treatment is recommended for use in conjunction with other treatments. Ripping is best implemented on moderately dry, shallow mine soil which is medium or fine textured and underlain by a compacted spoil, hard pan or hardened caliche layers. Rippers should be operated on the contour of slopes less than 10 percent. Maximum benefit of subsoil moisture storage is received when precipitation is greater than 8 inches annually.

Three ripper or chisel points are recommended for use on mined land as illustrated in Figure 5.8. The standard point has the most general application and is suitable for nearly all ripping operations. Twisted points may be a viable tool for increasing the surface roughness and bringing clods to the surface. Spikes are thicker and more durable and have a special application

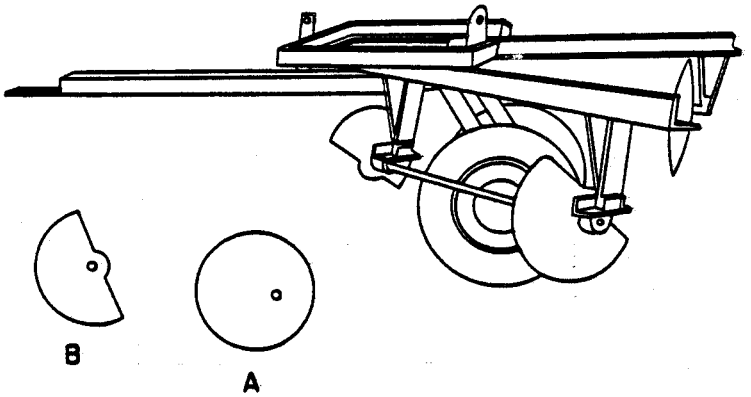
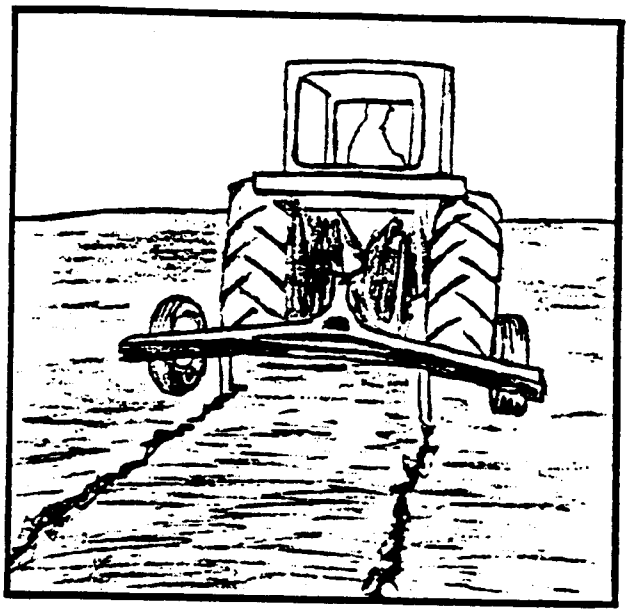


Figure 5.7. Disk-type pitting machine.
A. Eccentric (offset) disk;
B. Cutaway disk, (from Vallentine, 1971).



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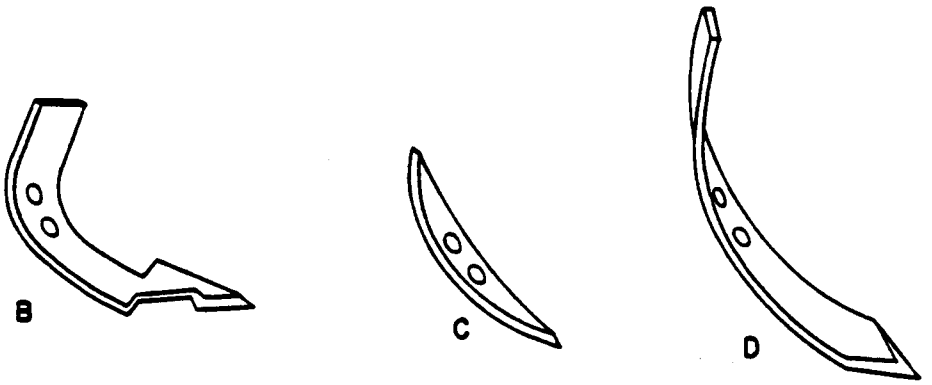

Figure 5.8. Soil ripping implement and land surface pattern. A. soil ripper is pulled through the soil and a temporary slot is formed; B. standard ripper (chisel) point; C. spike ripper point; D. twisted ripper point.

in extremely hard soil conditions. Commercially available construction ripper points are 3 to 4 inches wide and produce very satisfactory results.

Specifications - Ripping

This work shall consist of mechanically ripping in accordance with the specifications given in Table 5.6. The accepted basis of payment for ripping will be paid for at the contract unit price according to the pay unit given in the Table.

In-Service Performance

No data are available on the water holding capacity or changes in infiltration rates of ripped soil. Ripping produces a significant decrease in runoff and soil loss from small areas if applied under recommended conditions given above. These effects decrease, sometimes quite drastically, within the first three years because erosion from low intensity storms can fill the ripped surface slots. Ripping under optimum conditions will last 7 to 12 years.

Table 5.6. Specifications for Ripper.

Item	Common Specifications
Equipment	Ripper; deep chisel; subsoiler; subsoil chisel
Shanks	Rugged with general slope forward for maximum penetration and lift; curved to tapered end with replaceable chisel points
Number of Shanks	2 to 3 mounted shanks
Shank Spacing	Approximately 7 feet
Disturbed Band or Slot Width	4" to 10"
Ripper or Chisel Points	Standard; twisted; spike
Maximum Penetration	Approximately 36" depending on shank and soil conditions
Power Requirement	20 to 45 HP per shank depending on type of shank, depth of penetration, soil conditions (commonly the equivalent of a D6-D9)
Pay Item	Per acre

5.7 Example Problem

Problem: Compute the sediment yield from a disturbed mine site under baseline conditions outlined in Chapter IV, section 4.7, after an initial mechanical treatment of furrowing.

Input Data: As in baseline conditions (section 4.5) except CN = 81 (Table 5.2).

hydrologic soil group:	C
curve number, CN:	81 (from Table 5.2)
textural class:	Sandy loam
storm rainfall amount:	4 inches
percent ground cover:	zero percent
catchment area:	10 acres
slope:	9 percent
length:	660 feet

Step One: Particle size distribution as in baseline conditions (section 4.5).

Clay	P_1	P_2	P_3	P_4
5	25	20	20	30

Step Two: Roughness coefficient (K_g) and detachment coefficient (D_F).

K_e = 0.43 (Table 5.1)

K_g = 2700 (Table 5.1)

D_F = 1.000 (Table 5.1)

Step Three through Step Seven: see attached worksheets.

Step Eight: Mean concentration of settleable solids (C_S).

C_S = (35.57 + 1.51)+/(2.12 x 10) (8830)

C_S = 15,400 ppm

Discussion of Results

The mean concentration of settleable solids has been decreased by over a factor of 10, from 160,300 (baseline conditions) to 15,400 ppm (initial treatment of contour furrowing). Even though a large reduction in sediment yield occurred by furrowing the area, erosion of the soil is still high (15,400 ppm). To further decrease the sediment concentration, ripping the soil/subsoil interface before furrowing would effectively increase infiltration and vegetative establishment. Ripping would change the "C" hydrologic soil group to a "B" group and give a CN of 67. Without going into the details

of the calculations, the settleable solids would be reduced to 11,200 ppm. After one year, vegetation may become quickly established due to the ripped subsoil layer. Under the conditions of 55 percent vegetative cover over a one year reclamation period, the settleable solids are again reduced to 9,300 ppm. This is nearly half the sediment yield from the conditions of initial furrowing without ripping and zero percent cover. Sediment yield can be further reduced by one-third (from 9,300 ppm to 6,000 ppm) if the slope is reduced from 9 percent to 5 percent. The overall effect of these erosion control measures is a substantial reduction in sediment yield of 97 percent of the initial baseline conditions.

(1) Time (hr)	(2) Δt (hr)	(3) P/P_t	(4) P (inches)	(5) Pe (inches)	(6) ΔP (inches)	(7) ΔPe (inches)	(8) I (in/hr)	(9) Q (cfs)	(10) q (cfs/ft)
7.04		0.12	0.47	0.00					
	1.96				0.13	0.007	0.0667	0.035	5.34×10^{-5}
9.00		0.15	0.60	0.007					
	2.25				0.40	0.091	0.178	0.405	.000613
11.25		0.25	1.00	0.098					
	0.92				1.78	1.05	1.93	11.4	.0173
12.17		0.70	2.78	1.15					
	1.83				0.50	0.385	0.273	2.11	.00319
14.00		0.82	3.28	1.53					
	10.00				0.72	0.589	0.0720	0.589	.000893
24.00		1.00	4.00	2.12					

Small area characteristics:

Area = 10 acres

Length = 660 feet

Width = 660 feet

Example Problem 5.1. Step Three worksheet.

(1) Δt (hr)	(2) I (in/hr)	(3) G_r (tons)
1.96	0.0667	0.57
2.25	0.178	4.61
0.92	1.93	223.
1.83	0.213	8.85
10.00	0.0720	3.36

Area = 10 acres

$G_r = 6.48\ \Delta t\ I^2\ A_b$ (Eq. 4.7)

Ground Cover Ratio = 0.00

Width = 660 feet

$A_b = (1 - C_g)A$ (Eq. 4.8)

Example Problem 5.1. Step Four worksheet.

(1) Δt (hours)	(2) q (cfs/ft)	(3) g_{t1} (tons/ft/hr)	(4) g_{t2} (tons/ft/hr)	(5) g_{t3} (tons/ft/hr)	(6) g_{t4} (tons/ft/hr)	(7) G_{t1} (tons)	(8) G_{t2} (tons)	(9) G_{t3} (tons)	(10) G_{t4} (tons)	(11) G_t (tons)
1.96	5.34×10^{-5}	.00005	.000090	0.00	0.00	0.03	0.00	0.00	0.00	0.03
2.25	.000613	.00131	.00236	.000072	0.00	0.88	0.02	0.00	0.00	0.90
0.92	.0173	.113	.203	.00934	.000018	30.8	1.14	0.00	0.00	31.94
1.83	.00319	.0119	.0213	.000792	0.0	6.44	0.19	0.00	0.00	6.63
10.00	.000893	.00216	.00389	.000126	0.0	6.43	0.16	0.00	0.00	6.59

Roughness Coefficient, K_g = 2,700

Slope, S = 0.09

Width = 660 feet

Example Problem 5.1. Step Five worksheet.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Δt	G_t (tons)	G_r (tons)	G_f (tons)	G_s (tons)	G_{s1} (tons)	G_{s2} (tons)	G_{s3} (tons)	G_{s4} (tons)
1.96	0.03	0.57	0.00	0.57	0.14	0.11	0.11	0.17
2.25	0.90	4.61	0.00	4.61	1.15	0.92	0.92	1.38
0.92	32.03	223.	0.00	223.	55.8	44.68	44.68	67.0
1.83	6.63	8.85	0.00	8.85	2.21	1.77	1.77	2.66
10.00	6.59	3.36	3.23	6.59	1.65	1.32	1.32	1.98

Flow Detachment Coefficient = 1.00

$G_f = D_f(G_t - G_r)$ (Eq. 4.10)

where $G_t < G_r$

Example Problem 5.1. Step Six worksheet.

	(1)	(2)	(3)	(4)	(5)
	G_{y1}	G_{y2}	G_{y3}	G_{y4}	G_y
	0.03	0.00	0.00	0.00	0.03
	0.88	0.02	0.00	0.00	0.90
	30.8	1.14	0.00	0.00	31.94
	2.21	0.19	0.00	0.00	2.40
	1.65	0.16	0.00	0.00	1.81
TOTAL	**35.57**	**1.51**	**0.00**	**0.00**	**37.08**

Example Problem 5.1. Step Seven worksheet.

5.8. References

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