

EFFECTS OF DIFFERENT TILLAGE OPERATIONS ON PROBLEM SOILS

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Soil problems that may be improved by tillage fall generally into four groups: (1) soils with natural layers that restrict water percolation, aeration, root growth or a combination of these, (2) saline or sodic soils for which tillage can be part of the reclamation process, and (3) clay soils, and (4) soils compacted, layered, or sealed by agricultural practices. In the sections that follow these problems will be described, their effects on the alfalfa root environment will be discussed, and tillage methods to alleviate the problems will be presented.

SOILS WITH NATURAL RESTRICTING LAYERS

Natural restricting layers usually occur deeper in the soil than do those artificial layers created by agricultural practices. The natural layers therefore require deeper tillage to effect an improvement. However, if the deep tillage is done properly it may only need to be done once, since these layers do not normally re-form. In contrast, shallow layers compacted by agricultural traffic may need periodic tillage to loosen them.

Stratified Soils

Stratified soils consist of layers of different soil textures, often with abrupt boundaries between the layers (Fig. 1). The soils are found on recent floodplains, alluvial fans, and in basins. Table 1 lists some common soil series that may be stratified. The layers represent deposition at different times in the recent past, and the differences in texture result from differences in the velocity of water that deposited the materials. Rapidly moving water deposits gravel and coarse sand, slowly moving water deposits fine sand and silt, while still water deposits the finest clay materials. The layers of contrasting texture may be in any sequence and vary in thickness from a fraction of an inch to many inches.

Water does not move uniformly downward in stratified soils. Fine layers underneath coarse layers will slow down the rate of water percolation through the smaller pore spaces. This builds up a temporary saturated zone above the fine layer, and results in poor aeration for plant roots in that zone. If the fine layer is above the coarse layer, almost the same thing happens, but for a different reason. In this case the smaller pores in the fine layer hold onto water more tightly and will not release it across into the coarse layer until the fine layer becomes completely saturated. Again a poorly aerated zone is created, and this one may last longer than the first one. Because of these discontinuities in water-air relations in stratified soils, roots do not grow uniformly in them. Roots often will not penetrate downward through a layer of contrasting texture, even though it may be less than an inch thick.

The primary purpose of deep tillage in stratified soils is to mix the layers and make a soil profile with a more uniform texture and porosity. Since the soils are not usually dense, loosening is only a minor objective. Even sandy soils in which water percolation is rapid will benefit from mixing sand layers of different degrees of coarseness.

Deep plowing with moldboard (Fig. 5) or disc plows (Fig. 6) does the best job of breaking up and mixing stratified layers. Once over does a fair job but twice over is much better. A second time over freshly plowed soil may not be possible with a moldboard plow, so complete mixing may require two plowings a year or more apart. Some disc plows will do a good second plowing on freshly plowed soil. Either type of plow is normally limited to a depth of 18 to 30 inches depending on size. A few old four foot moldboard plows are still used in parts of the state. If deeper mixing is desired, a slip plow (Fig. 7) can be used to go five to six feet deep. However, a slip plow only mixes that soil in the trench it makes, normally around 15 inches wide at the bottom widening to four or five feet near the surface. This may only be 15-25% of the total soil profile, and the mixing job is not as good as that of the moldboard or disc plows. Nevertheless, if stratified layers extend to six feet deep, slip plowing followed by moldboard or disc

plowing may be a significant improvement over either treatment alone. Deep ripping, however, is the least useful treatment because it mixes very little soil.

Dense Clay Subsoils

These soils are called "developed" soils, or in the extreme cases, "claypan" soils (Fig. 2). They are the result of aging and weathering of alluvial soils over thousands of years of time (Table 1). Clay formation and migration have concentrated these smallest of soil particles in the subsoil. The surface 10 to 20 inches of developed soils are typically a coarse to medium texture, for example, sandy loam, loam, silt loam, or clay loam. The subsoil is always higher in clay, often a 10 to 30 percent increase over that in the surface. The older and more weathered the soil, the greater the percentage clay increase and the more abrupt its boundary below the surface soil. The added clay particles largely occupy pore space that was once open, so their effect is to decrease total porosity, reduce the number of large pores, and thus increase soil density and strength. The particles are not cemented together and subsoils will soften when moistened. In this way they differ from hardpans, discussed later.

Developed soils behave similarly to stratified soils in reducing water percolation and aeration, but in addition are dense so that roots grow poorly or not at all in them. To grow in soils, roots must be able either to enter pores between soil particles, or to push particles aside to make space to grow. Pores in clay subsoils are so small that roots enter with difficulty and the soil strength is so great that particles cannot be easily pushed aside. Roots in claypans are only found following those cracks that develop as the clay dries and shrinks. When the clay swells on rewetting these roots become pinched and it is common to find flattened roots in these soils. Even though these roots may persist for several years, they are not very effective at obtaining water or nutrients from the bulk of the clay subsoil.

In addition to the root inhibition by limited porosity and increased soil strength, increased clay in subsoils slows downward water movement and restricts aeration, similar to some stratified soils. In fact, it's often difficult to determine which effect inhibits root growth the most: poor aeration or porosity/strength relationships. Probably both are at work, with their relative importance depending on the soil physical makeup. In any case, the objective of deep tillage in developed soils is to lower the density of the subsoil layer of increased clay content, and thus both deepen the effective root zone, and improve its water percolation and aeration properties. The clay content goes through a maximum, usually in the two to four foot depth range, and then decreases with further depth, so it is desirable for deep tillage to extend well below the point of maximum clay content. Mixing of the subsoil with the surface might be desirable if by so doing, a sandy surface soil was improved in both water holding capacity and nutrient supplying ability. But a loam soil could suffer reduced workability if too much subsoil clay was brought up and mixed with it.

Deep ripping (Fig. 8) or slip plowing (Fig. 7) are the operations available to try to lower the density of developed subsoils. Even under the best circumstances, they only partially accomplish the job. This is because the shanks only directly displace a small percentage of the soil, while the major volume of soil between channels is only cracked and largely retains its original density between the cracks. Nevertheless, a thorough deep tillage job may significantly improve the crop potential of a developed soil. Slip plowing displaces and cracks more soil than ripping, and requires a correspondingly higher energy input. Slip plowing is particularly beneficial in soils that have permeable soil material beneath the clay subsoil layer.

The spacing between shank channels, their depth, and the pattern of ripping or slip plowing make a big difference in the amount of improvement that is accomplished. Depths of three feet or less usually do not accomplish very much. Neither do single shanks spaced eight feet or more between channels. Ripping in one direction at four foot widths is better than ripping and cross ripping at an eight foot spacing. A really thorough ripping job would be five feet deep with ripping and cross ripping at four foot spacings. If slip plowing were substituted for the cross ripping, the power requirement for slip plowing would be reduced because of the initial ripping.

Cemented Hardpans

Hardpan soils are thought to be even older and more weathered than claypan soils (Fig. 3). Like claypan soils, they have formed on ancient alluvial fans and are now found on terraces, mostly on the east side of the Central Valley, and occasionally in coastal valleys and in southern California (Table 1). Most hardpan soils have formed from granitic parent materials. A few have developed on old lakebed sediments in northeastern California. Typically the cemented layer starts abruptly at some depth from a few inches to a few feet below the surface. By cemented it is meant that the soil particles are glued together by hard mineral matter and will not soften even when wet. The shallower the layer the greater the restriction to root growth, but also the easier it may be to break it apart.

The hardpan is an absolute barrier to water percolation and root growth. Soils with hardpan at a depth of two feet or less are useful only for pasture or dryland grain. Often a claypan has developed on top of the hardpan, further limiting the depth of root zone. Water will perch above the hardpan for long periods during the rainy season and will do the same thing if irrigation water is not applied very carefully. Therefore the objectives of deep tillage are not only to deepen the root zone but also to provide a means for any buildup of rain or irrigation water to escape downwards.

Ripping five to six feet deep with a single shank is the standard practice for breaking hardpan (Fig. 8). A spacing of eight feet between channels is a minimum job and four foot spacing with cross ripping also four feet apart is much better. Slip plowing has generally not been done in hardpan soils, partly because of the high power requirement and partly because chunks of the pan brought to the surface could be objectionable. Recently some ripping contractors have tried cross slip plowing with the slip plate set so its far end remains about two feet below the soil surface. This produces a wider channel and more fracturing than a ripper and still does not bring hard chunks to the surface. Some hardpan materials break up more easily than others if brought to the surface.

SALINE AND SODIC SOILS

Saline and sodic (black alkali) soils may contain any of the restricting layers described earlier. The purpose of the deep tillage in these soils is to facilitate leaching of salts. So any treatment that improves downward movement of water through and out of soil profiles will help rid them of salts. Sodic soils are a special problem because the sodium present reduces water percolation even more than would be the case with that same soil texture and density if the sodium were not present. Furthermore, the sodium is not leachable with just water, but must be replaced by soluble calcium. The usual ways to provide soluble calcium are to add gypsum - which contains calcium and will dissolve - or to add sulfuric acid (or other acid forming chemical) to dissolve the soil calcium that occurs as insoluble carbonate in some soils. Deep tillage may be required, not only to physically break up and mix restricting layers, but to get the soluble calcium to the place where it can replace the sodium.

CLAY SOILS

Soils that consist of clay from the surface downward are not generally favorable for the growth of deep rooted crops. Although the surface of many clay soils granulates nicely under proper management, with depth they become increasingly dominated by small pores, slow water movement, and poor aeration. Root diseases are always a hazard. Deep tillage does not provide as great a benefit to clay soils as it does to those with other kinds of restricting layers.

SOILS WITH ARTIFICALLY INDUCED RESTRICTING LAYERS

Stratification and Compaction by Land Leveling

Land leveling can create several conditions which need further tillage to make them suitable for plant production. If subsoil restricting layers are present before leveling, they will be shallower in the cut areas and deeper in the fill areas after leveling. To make sure that fill areas do not become undrained basins, those restricting layers should

be ripped before leveling. The leveling process then may cause stratification because materials of varying texture may be brought in to make the fill. In addition the fill particularly, and to some degree the cuts become compacted because of the large amount of wheel traffic running over them. So after the final grade is achieved, the appropriate deep tillage (ripping, slip plowing, disc or moldboard plowing in some combination) will be needed to loosen compacted soils and mix stratified areas.

Soil Compaction by Agricultural Practices

Some soil compaction seems to be an inevitable partner to agricultural production. No soil is completely immune but some soils compact more easily than others. While the susceptibility of a soil to compaction is not always easy to assess, certain soil characteristics and agricultural practices make soils more resistant or more susceptible to compaction. To examine all of the possible variables is beyond the scope of this paper, but we know that high organic matter or calcium carbonate content, low moisture content, and strong granular structure are soil characteristics that resist compaction. Agricultural practices that promote compaction are: working wet soils, driving equipment over moist soils or freshly cultivated soils, increasing equipment weight to apply more power or traction, and repeated cultivation of dry soils to make a smoother seedbed.

Whether compaction becomes a limiting factor in plant growth depends on how it directly affects water percolation, aeration, and root extension, and indirectly affects nutrient uptake, plant diseases, and rate of growth. Sandy soils are susceptible to compaction because of their single grained structure and lack of aggregate stability. But water percolation and aeration usually remain adequate because of relatively large pore spaces in sands. The effect of compaction is to interlock the sand grains so that roots can neither enter the pores nor push the particles aside. This effect is called root "impedance". Finer textured soils (loams, clay loams, silt loams, clays) also may cause root impedance because of small pore size and increased soil strength, but in addition may promote slow water percolation and poor aeration, and it is often difficult to decide which effect is most responsible for poor root growth.

The serious effects of soil compaction are usually found between the surface and 15 inches deep, but in some cases the effect can be found as deep as 24 inches (Fig. 4). Since it is shallower than the natural soil layering discussed earlier, it should be easier to remove by tillage. The problem lies in the fact that it needs to be dealt with repeatedly because our present farming practices rather quickly recompact soil that has been loosened by tillage (Fig. 9). There is some hope for the future in the form of new equipment now being developed. The concept is a wide spanning combined tractor and tool carrier unit that performs all cultural operations for a crop but only bears on a small percentage of the field. This is called "controlled traffic", since the unit always uses the same field tracks.

Tools available for loosening compact soils are large moldboard (Fig. 5) and disc plows (Fig. 6), and various kinds of rippers and chisels. Since the plows move all of the soil to a depth of 18 to 24 inches, they have the potential to loosen most of the compaction, providing the moisture content is such that the soil will crumble rather than come up cloddy. At the same time, this loosened soil is especially prone to recompaction if equipment is driven over it. If possible, freshly plowed soil should not be disturbed for several weeks. Alternate wetting and drying, particularly by rainfall, will allow the soil to settle gradually and help strengthen its structure.

Rippers and chisels come in a wide variety of sizes and shapes (Figs. 10, 11). For loosening compaction, a depth capability of two feet is desirable. Curved or "parabolic" shanks require less draft than straight shanks to loosen the same amount of soil (Fig. 12). Soil moisture content and spacing of ripper shanks are also important considerations for doing the most effective job of shallow ripping. Rippers pull more easily through moist soils but do a less effective job of loosening (Fig. 13). Ripping moist soils may even be harmful to plant growth if slicking of walls inhibits water movement or creates a favorable environment for disease organisms. Ripping dry soils usually results in more effective loosening (Fig. 14). Shank spacing should be equal or less than the depth of ripping. Ripping never breaks the soil straight across between the points of adjacent shanks. There is always a hump between two channels (Fig. 15). The further apart the shanks the higher the hump. In extreme cases the hump may come clear to the surface (Fig. 16). Cross ripping can lower the hump some but parallel ripping at a narrow shank spacing does a more efficient job than ripping and cross ripping at double the spacing.

Table 1. Some California soils with stratified layers, developed (clay enriched) subsoils, or cemented hardpans.

Stratified*	Developed Subsoils		Hardpan
	Moderate	Claypan	
I <u>Sacramento Valley Soils</u>			
Columbia	Chualar	Artois	Anita
Cortina	Harrington	Corning	***Landlow
Honcut	Marvin	Hillgate	Moda
Lang	Perkins	Keefers	Redding
Laugenour	Plaza	Kimball	Rocklin
Maywood	Pleasanton	Newville	San Joaquin
Merritt	Ramona	Positas	***Stockton
Millrace	Red Bluff	Riz	Tuscan
Molinos	Rincon	San Ysidro	Yokohl
Orland	Ryer		
Ramada	Tehama		
Reiff			
Soboba			
Tujunga			
Tyndall			
Valdez			
Vina			
Yolo			
II <u>Eastside San Joaquin Valley Soils</u>			
Anderson	Borden	Cometa	Academy
Cajon	Chualar	Corning	Alamo
Chino	Pond	Modesto	** Dinuba
Columbia	Ramona	Montpellier	El Peco
Foster	Ryer	Positas	Exeter
Grangeville	Snelling	Waukena	Fresno
Hanford			Keyes
Hilmar			***Landlow
Honcut			***Lewis
Tujunga			Madera
Visalia			Pozo
Wunje			Redding
Yolo			** Ripperdan
			Rocklin
			San Joaquin
			Whitney
			Yokohl
III <u>Westside San Joaquin Valley Soils</u>			
Camarillo	Avenal	Herdlyn	** Dinuba
Columbia	Lost Hills	Olcott	
Cortina	Ortigalita	Positas	
Mocho	Pleasanton	Solano	
Panoche	Rincon	Waukena	
Ramada	Rossi		
Salado	Stomar		
Sorrento			
Vernalis			
Zacharias			

- * Stratification can be highly variable within any soil series and some of these soils are typically more stratified than others.
 ** Unrelated siltstone substratum has same effect as hardpan.
 *** Clay soil throughout above pan.

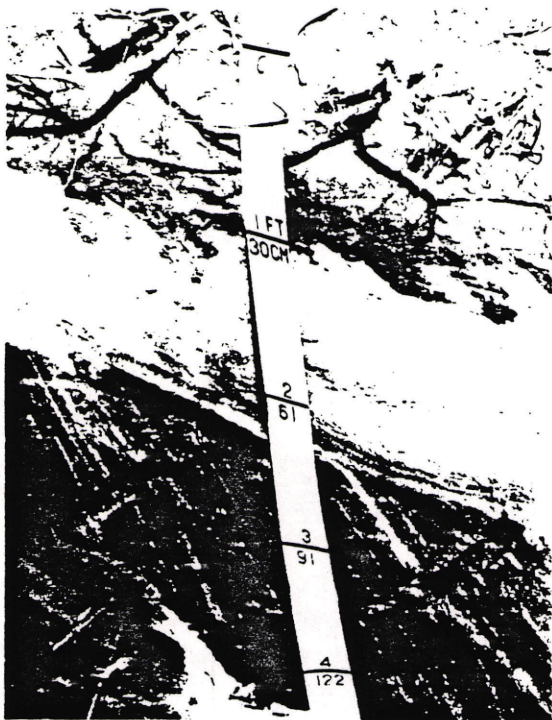


Figure 1. Stratified soil; sandy loam/sand/silt loam. Young pear roots grew only in the top foot. Mixing layers allowed deep root growth.

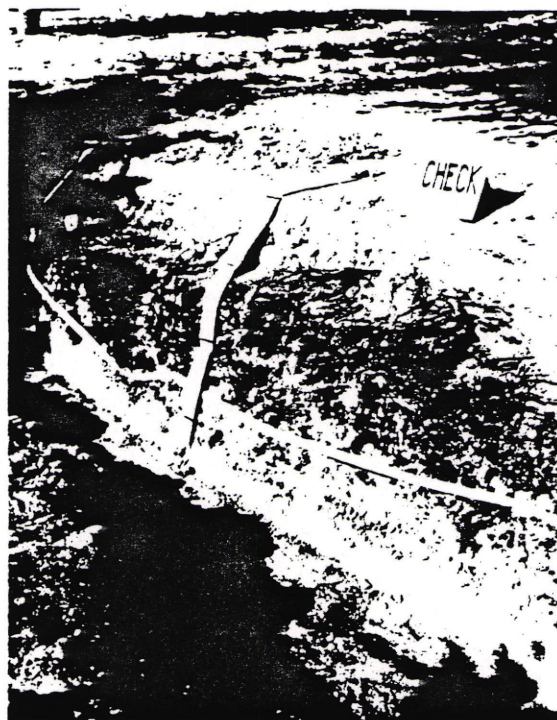


Figure 2. Claypan soil; abrupt clay layer at 1 foot. A few roots grow in cracks in clay, but none below 2 1/2 feet. Slip plowing improved root depth and drainage.

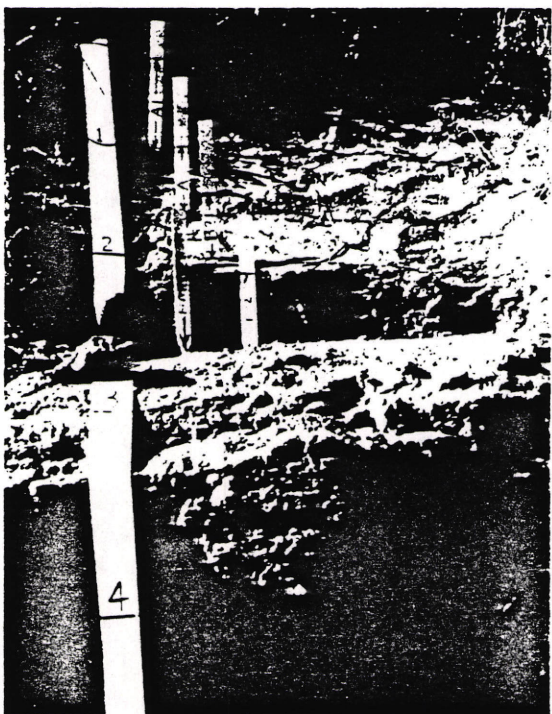


Figure 3. Hardpan soil; 2 feet sandy loam/6 inches clay/1 1/2 feet cemented pan/sandy loam. Deep ripping significantly increases productivity.



Figure 4. Soil compacted by row crop farming. Grape roots struggled but eventually reached loose soil at 2 feet. Deep plowing would have improved early root growth.



Figure 5. Moldboard plowing three feet deep in stratified soil. Pre-ripping is sometimes necessary in hard soil.

Figure 6. Disc plowing 20 inches deep. 30 inch depth attainable with larger discs. Furrow wheel enables replowing of loose soil.

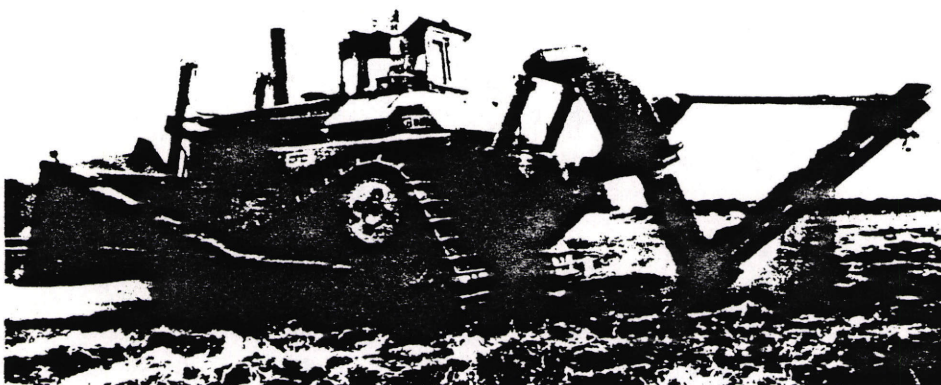
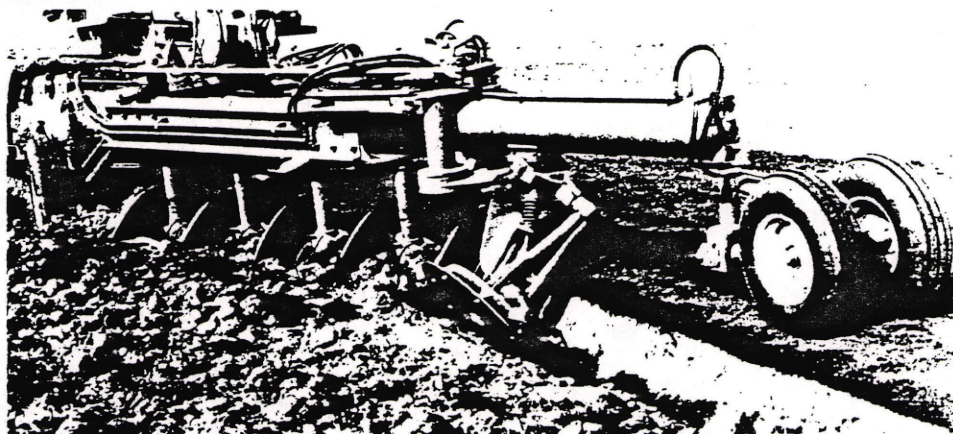


Figure 7. Slip plow; can operate six feet deep. 14 inch wide slip plate causes more heaving and displacement of layers than a ripper shank.

Figure 8. Deep ripper quad unit; up to 4 tractors pull and push a single shank 5 to 6 feet deep in hardpan soils.

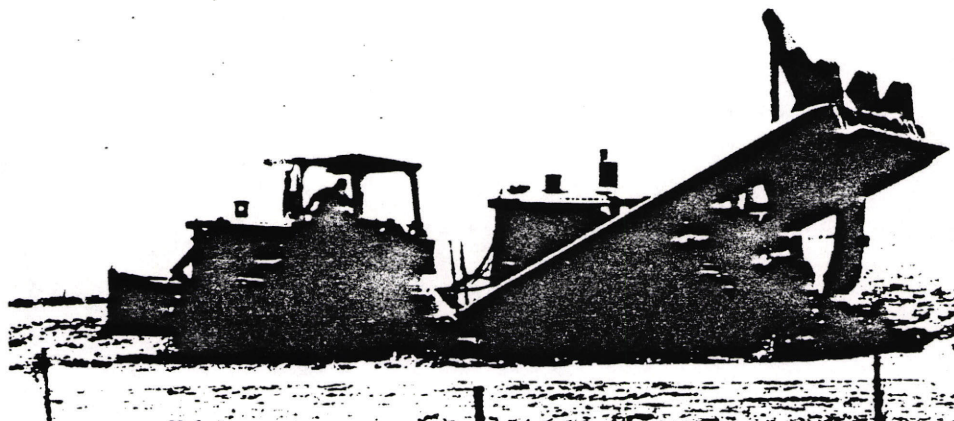




Figure 9. Ineffective shallow (24") ripping; 36" ripper spacing was too wide. Soil that was loosened was recompactd by discing and land planing.

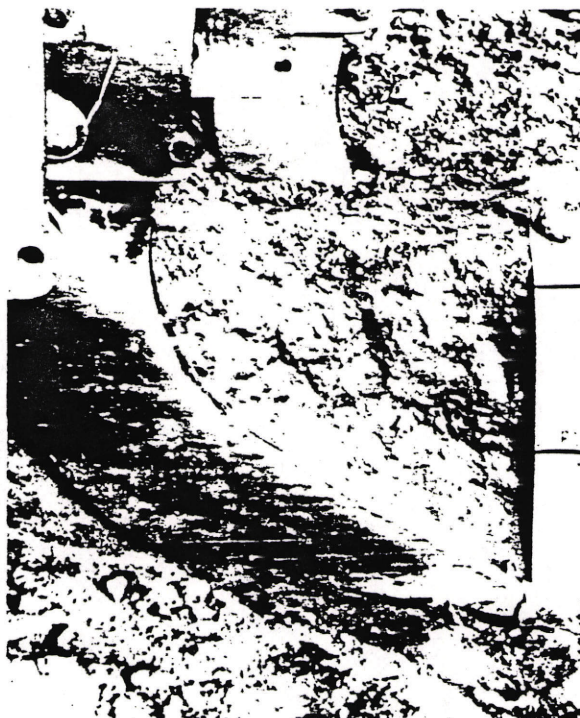


Figure 10. Parabolic ripper shank rips 2 feet deep. This design provides the least draft requirement for the same soil loosening.



Figure 11. Straight and curved rippers tested at the National Tillage Machinery Laboratory. See Figure 12.



Figure 12. In soil test bins, curved subsoilers loosened same amount of soil as straight ones using 14% less draft in sandy soils, 28% less in clay.

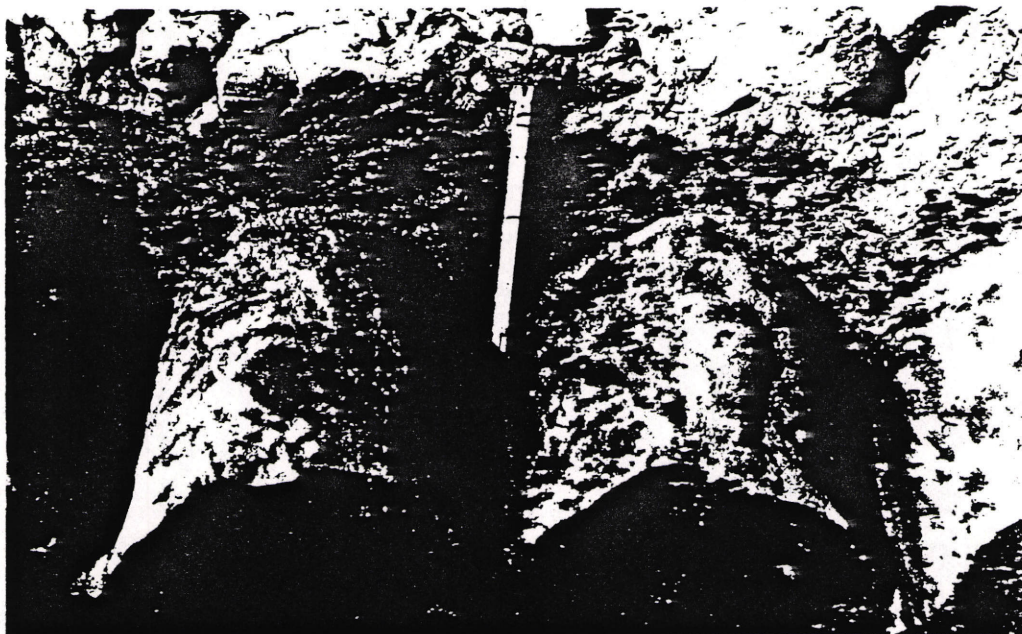


Figure 13. Fine sandy loam soil after ripping 16 inches deep at 13% moisture. Note unloosened humps between shanks, spaced 20 inches apart.

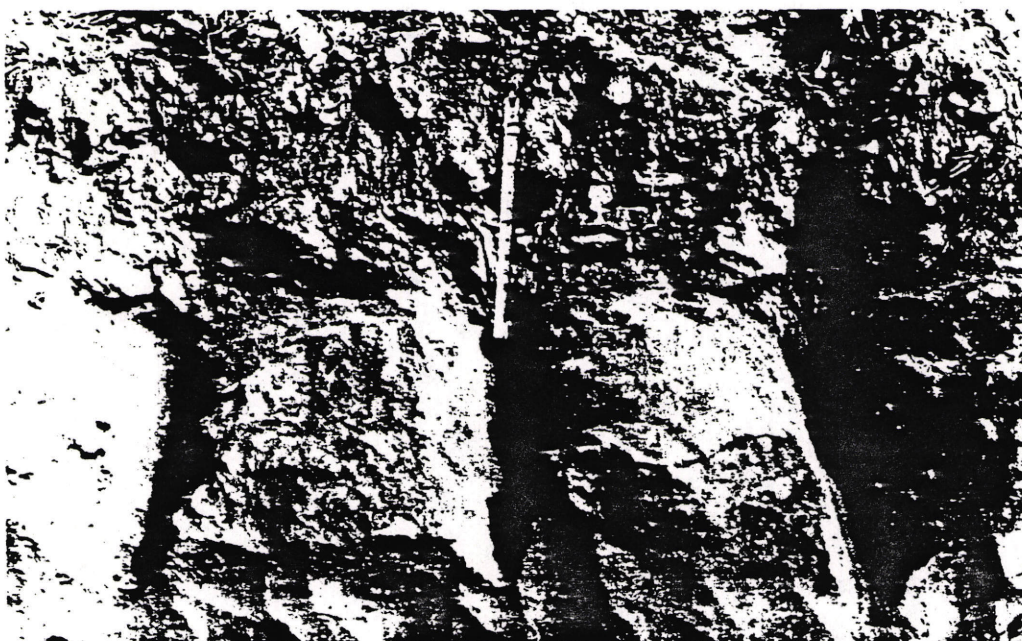


Figure 14. Same soil as Figure 13 at 4.6% moisture. Greater shattering and lower humps resulted from the lower moisture content.



Figure 15. Another sandy loam soil ripped 16 inches deep at 20 inch spacing. Compare with Figure 16.



Figure 16. Same soil as Figure 15 ripped at 30 inch spacing. Loosened soil does not overlap between shanks. Moisture content 4.5% on both.