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Visual Symptoms, Causes and Remedies of Bad Soil Structure

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INTRODUCTION

"Soil structure" refers to the arrangement of sand, silt and clay particles. How loosely or closely and firmly these particles are arranged influences the rates with which essential water and air move into and through the soil.

"Bad soil structure" refers to adverse physical condition of the soil as related to seed germination and root growth. Bad soil structure is usually associated with compact arrangements of sand, silt, and clay. On occasions, loose arrangements result in rapid drying and slow seed germination.

Bad soil structure may be a natural condition, especially with high-clay soils. However, bad soil structure more often reflects the activities of crop producers and the wet soil conditions that sometimes occur during field operations.

This report summarizes observations of crops grown both on field experimental plots and under farm conditions. It also explains why bad soil structures develop and briefly outlines what can be done to improve the structure of Michigan's agricultural soils.

Bad soil structure is frequently a major restriction on crop yields. In a 1974 survey of 99 navy bean fields, it was found that bad soil structure in the plow layer severely restricted root development and, therefore, yields in 67 fields. While other problems were diagnosed (root rot, insects, foliar diseases, nutrient deficiencies, etc.), none were more widely distributed than the condition of bad soil structure.

Symptoms of bad soil structure can be observed most easily when conditions are extreme. Both plants and soil display characteristics that can be visually identified. When such conditions are observed, steps can be taken to remedy the situation.

VISUAL SYMPTOMS IN PLANTS

The most obvious and frequently noted symptoms of bad soil structure visually displayed by field crops include: 1) slow plant emergence from soil, 2) plants shorter than normal, 3) off-colored leaves, 4) shallow root systems, and 5) malformed roots.

Each of these conditions is also a symptom of other problems such as dry soil, early planting, nutrient deficiency, high water table or nematodes, so diagnosis of the condition of bad soil structure must be made carefully.

Slow plant emergence may reflect the effect of low soil temperature, wet soil, soil crust or a cloddy soil condition, which can all be related to bad soil structure.

Associated with slow plant emergence are variable stands and low plant populations, even where adequate rates of high-quality seed were used (Fig. 1).

Fig. 1. Variable stands can result in poor quality and low yields. This soil was deeply compacted while harvesting sugarbeets in wet, plastic soil. After the beans were planted 3 in. of rain fell in three days. A thick, strong crust developed which not only retarded the emergence rate of some plants, but also reduced the stand.

Under wet soil conditions caused by bad soil structure, both seedlings and more mature plants are susceptible to damage by disease organisms. Root rots in navy beans (Fig. 2), phytophthora root rot in alfalfa and black root in sugarbeets are associated with this condition.

Fig. 2. Root rot on beans can be diagnosed only after digging the roots. The first clues include wilted, off-colored leaves (right) and new roots on the base of the stem. Several of the root rots thrive under low oxygen levels associated with high soil moisture levels caused by bad soil structure.

Shorter-than-normal plants may reflect nutrient deficiencies or diseases—or they may be a product of bad soil structure. Delayed emergence and slow growth result in shorter-than-normal plants. Short plants have been observed in cloddy seedbeds produced when wet soil was plowed in the spring. Such conditions are most common on fine-textured soils.

Off-colored leaves reflecting nutrient deficiencies or diseases have been observed under conditions of restricted root growth (Fig. 3).

Denitrification, which is common in waterlogged soil, is occasionally the product of bad soil structure. The use of more fertilizer may reduce the intensity of the problem and cause the color of the leaves to be normal, but yields are restricted. The best solution is to create a good structure where excessive water can rapidly drain out of the root zone.

Fig. 3. Visual nitrogen deficiency symptoms on corn growing on a compacted soil with a low water infiltration rate. Excessive water collected when exceptionally heavy rains fell on this overworked soil. Obviously, the nitrogen lost in denitrification resulted in decreased yields.

Shallow root systems are the most frequent symptom of bad soil structure. To classify a given condition as "shallow," it is necessary to know the characteristics of a normal root system (Fig. 4). The roots of most farm crops initially grow in a diagonally downward direction. By flowering time the roots tend to move more in a downward direction.

When the structure of a soil does not restrict root development, the depth on all crops, including navy beans, should be at least 2 ft. Single roots on long season crops, such as corn and sugarbeets, have been observed to penetrate deeper than 4 ft.

A close look at a root distribution pattern during the growing season provides valuable information about soil structure. While looking at root patterns, answer the following questions:

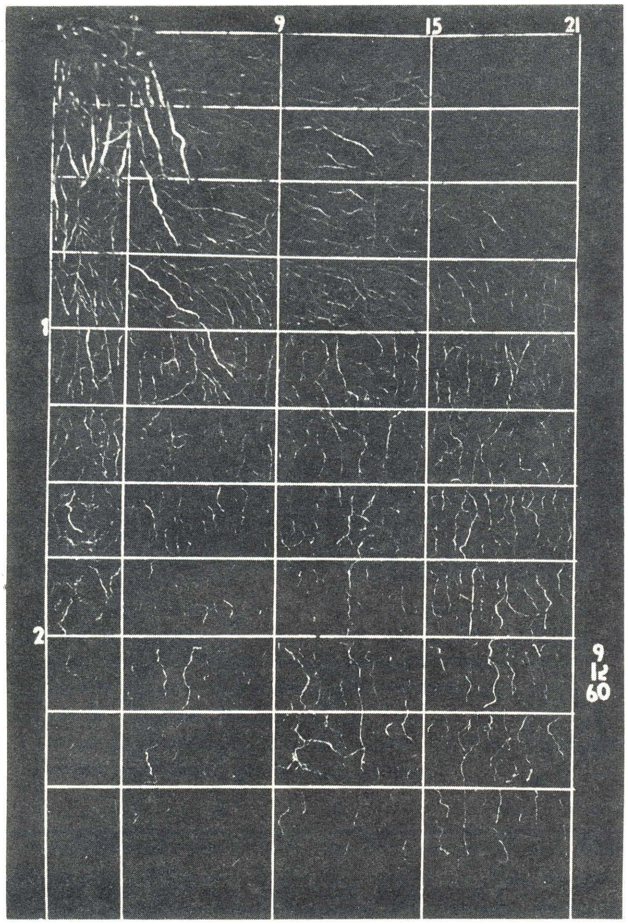

Fig. 4. With good soil structure corn roots penetrate to depths in excess of 3 ft. Single roots have been found at depths of more than 5 ft. The number of roots decreases gradually with depth. (Photo by H. D. Foth.)

1. Do the rootlets grow through the small aggregates (good) or do they grow around the aggregates (bad)?
2. Do the roots develop in a downward diagonal direction (good) or is there considerable lateral development (bad)? (Fig. 5).
3. Do the roots uniformly explore the plow layer (good) or are there large volumes of surface soil that contain no roots (bad)? (Fig. 6).
4. Are the roots uniformly distributed in the subsoil (good) or are they restricted to the plow layer (bad)?

Malformed roots suggest several problems, including bad soil structure. "Sprangly" roots and "dog legs" are common symptoms on root crops such as sugarbeets (Fig. 7). On beans, a shallow fibrous root system restricted to the surface few inches of soil is a definite symptom of bad soil structure. Root lodging on corn is a symptom of many problems, including bad soil structure. Numerous observations suggest that root rots are likely to be more damaging on crops grown on soils with bad structure.

VISUAL SYMPTOMS IN SOIL

There are five easily observable symptoms of bad structure in soil: 1) soil crusts, 2) subsurface compact zones, 3) standing water, 4) excessive erosion by water, and 5) increased power requirements for tillage.

Soil crusts are the most widespread and perhaps the first-noticed symptom of bad structure (Fig. 8). Interestingly, crusts develop on sandy soils (Fig. 9), although they are more common on soils with significant quantities of silt and clay (Figs. 10 and 11).

When wet, the pores in a crust are filled with water and the exchange rate of gases between the atmosphere and soil is reduced. When dry, crusts become strong and physically limit plant emergence.

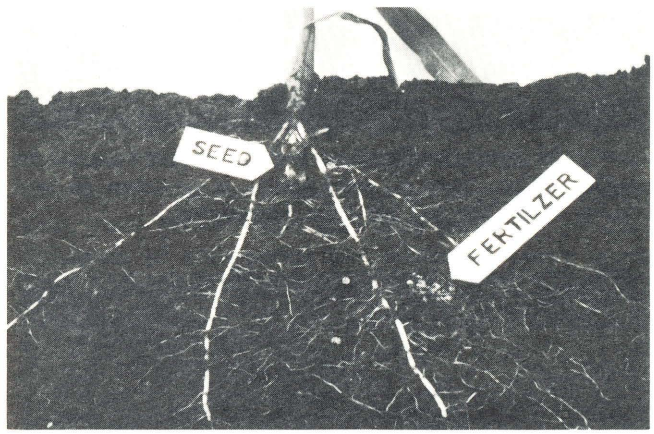

Fig. 5. Corn roots naturally develop in a downward diagonal direction. Extensive lateral movement of the major roots suggests problems associated with bad soil structure. (Photo by H. D. Foth.)

Fig. 6. Bean roots restricted to surface soil in an overworked field. Note the fine structure of the surface soil and the platy characteristics of the subsoil. The soil in this field was too wet when the seed bed was prepared.

Fig. 7. Sprangly sugarbeet roots grown in a bean-beet rotation. This type of root design is common in wet seasons where the soil has been compacted.

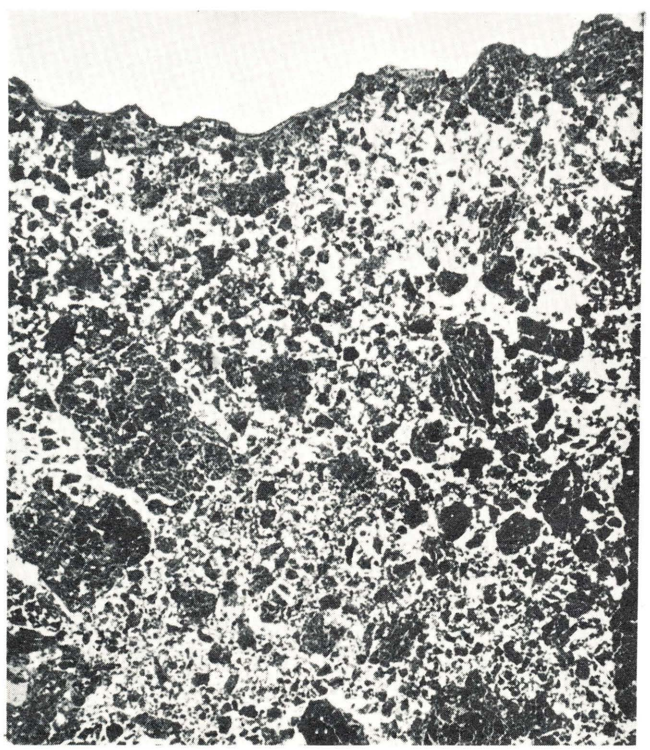

Fig. 8. A microphotograph of a soil crust. The light areas represent air space. The darker areas represent sand granules or soil aggregates. Notice the continuous nature of the crust which interrupts the natural movement of both air and water into and out of the soil.

Subsurface compact zones can only be observed after digging into the soil. Compact zones may be a natural condition or can be caused by farming operations. Crop roots, as previously discussed, aid in identifying compact conditions. Without a growing crop, only the most extreme conditions can be correctly interpreted.

The data in Table 1 illustrate several points that have already been made, as well as the effect of subsurface compact zones. The Charity clay soil of these plots is naturally compact. It is also a soil in which excessive compaction easily occurs.

Table 1. Yield, plant height and root distribution of navy beans as affected by tillage treatments.

	Tillage Treatments			
	Conventional Tractor Compacted Soil	No Tillage	Minimum Row Tillage Only	Shallow Overall Tillage
Yield cwt/acre	8.4	15.7	16.1	17.2
Plant height, in. 7/19	5.1	9.8	9.8	9.4
Root depth, in.		% of total		
0 - 2¼	75.9	40.0	42.2	67.3
2¼ - 4½	9.2	22.1	19.5	9.3
4½ - 6¾	11.2	10.7	22.7	6.7
6¾ - 9	3.7	10.4	5.2	4.5
9 - 11¼	0.0	9.0	5.1	5.9
11¼ - 13½	0.0	7.6	5.1	5.2

The 1973 treatments included one that was labeled "conventional" because, as on the average bean farm, four passes were made over the plots with a tractor before the beans were planted. The minimum tillage treatments involved only one or no passes over the plots before the beans were planted.

With conventional methods, which resulted in compact soil conditions, navy bean yields were reduced from the highest yields more than 8 cwt/acre.

Fig. 9. A thin crust on a Kalamazoo sandy loam. The crust was strong enough that alfalfa plants could not grow through it, and the alfalfa had to be replanted. In this photo, notice how few cracks there are in the surface soil. Air cannot easily move into the soil. In this field the soil was fall plowed. Crusting problems are likely to be greater on fall-plowed than on spring-plowed land.

Fig. 10. Crusts formed after raindrops destroyed the natural structure of this overworked, fine-textured soil. Greatly reduced tillage would have allowed more water to penetrate the soil and would have resulted in a more stable structure. Notice the smooth surface of the crust in the depressions caused by a chisel plow. This is where water collected and stood for several hours.

Fig. 11. A close-up of the soil crust shown in Fig. 10. Notice how much thicker the crust is in the depression where water collected. Any steps that can be taken to prevent water from standing in the field are likely to reduce opportunities for crust formation. If water can rapidly enter the soil, erosion will also be reduced (see Fig. 13).

The color of the beans on the conventional tillage plots was different from the color of the beans on the other plots. Furthermore, the plants were only half as tall.

In this project there were great differences in rooting depths. On the conventional tillage plots, three-fourths of the roots were located in the surface 2¼ in. This is not a natural condition. Also, there were no roots below 9 in. With this root distribution pattern, the beans are subject to great stresses in both wet and dry weather. The crop is not utilizing the moisture or the nutrients below a 9-in. soil depth.

Standing water may be a symptom of bad soil structure (Fig. 12). If water infiltration rates are slow due to soil crusts or deeply located compact soil materials, plant growth rates and crop yields are reduced. Evidence of compaction by wheels of heavy implements are observed more frequently than in the past, especially in fields of very early planted crops, such as oats, barley, sugarbeets and corn.

Excessive erosion by water may also be a symptom of bad soil structure (Fig. 13). When rain or irrigation water does not rapidly enter the soil due to crusts or compacted conditions, it either collects on the sur-

Fig. 12. Ponded water in tile-drained fields is likely to be a good indication of bad soil structure, especially if water does not collect in adjacent fields of similar soil. This field of soybeans was severely damaged by the standing water.

Fig. 13. Accelerated soil erosion by water occurs even on the relatively level lake bed soils of the Saginaw Valley. If the rain water had been able to penetrate the soil, the erosion in this bean field would not have occurred.

face or runs off to another site. If the runoff rate is high enough and the volume is sufficient, accelerated erosion occurs.

Increased power requirements for tillage may also be a symptom of bad soil structure. Many farmers have not recognized this symptom because most farms now have the larger 100+ hp tractors.

CAUSES OF BAD SOIL STRUCTURE

The development of bad soil structure is a phenomenon associated with frequent tillage operations. The most common causes of bad soil structure include: 1) inadequate drainage, 2) excessive tillage, 3) intensive cash cropping systems, 4) untimely field operations, and 5) design of farm implements.

Inadequate drainage, both surface and subsurface, is perhaps the major cause of bad soil structure in fields that are wet during field operations. With relatively high soil moisture levels, many soils become plastic. Under these conditions, compression by farm implements is excessive.

Compaction occurs at tillage, planting and harvest times. When the soil is wet, granules are crushed and oriented so that the soil volume contains less pore space for both water and air. Rain and irrigational waters further decrease oxygen levels and oxygen diffusion rates. Thus, crop yields are adversely affected (Figs. 14 and 15).

Excessive tillage increases the opportunity for deep compaction to occur. However, the real problem is that of aggregate stability. Excessive tillage produces a large number of very small-sized aggregates, which are less stable than large ones. Opportunities for aggregate decomposition crust formation and accelerated erosion by both wind and water are great. If there is not an obvious reason for a given tillage treatment, it should not be done.

Cropping systems that do not produce relatively large amounts of crop residues are considered a major contributing factor on many farms experiencing soil structure problems, especially in the Saginaw Valley region. Many farmers no longer use green manure crops or cover crops and do not produce hay and have livestock manure. Some farmers do not even grow corn, which produces large volumes of crop residues. Others bale and sell small grain straw. Soil structure problems are becoming more apparent on farms that produce only sugarbeets and beans. These crops produce smaller amounts of crop residues than others. Rapidly decomposing organic matter tends to stabilize the soil structure.

Cash cropping systems involve more tillage operations than other systems. Any tillage treatment opens the soil so that it is better exposed to air. Under such conditions, the organic matter in the soil is oxidized, which results in lower organic matter levels and less material present to act as binding agents for a stable soil structure.

Untimely field operations, whether they be tillage, harvesting or even hauling manure or fertilizer, result in a deterioration of the physical condition of the soil. On occasions, it is necessary to be in a field when the soil is wet. However, waiting until the soil dries so compaction does not occur is frequently best, at least from the standpoint of producing and maintaining good soil structure.

Farm implement design can easily lead to compaction. Dual wheels on farm implements and tractors are considered to be less damaging than tandem wheels. Plowing with tractor wheels in the furrow causes deeper compaction than keeping the wheels on the land. The use of some of the most modern super-large tractors and implements results in fewer trips across the field and, therefore, less surface compaction, even though the compaction may be deeper. While the larger special flotation-type tires are expensive, their use on farm implements results in less compaction.

IMPROVING SOIL STRUCTURE

The causes of bad soil structure have been considered and the remedies to such problems implied. Therefore, only a brief list of methods that prevent deterioration of the physical condition of soil and promote the formation of a stable structure is necessary. The following methods for improving soil structure may not apply to every situation, but they will all improve soil structure.

1. Provide adequate water drainage, both surface and subsurface.
   a. Maintain ditches so they can rapidly transport excessive snow, rain and irrigation water.
   b. Inspect and repair tile drains each year.
   c. Smooth the surface of fields to eliminate opportunities for the collection and ponding of surface water.
   d. Till the soil in such a way that low areas do not develop. In some instances, it may be desirable to provide outlets for dead furrows or use sod waterways.
2. Use the minimum tillage principle, which states that no more tillage than necessary should be done to create conditions essential for rapid seed germination, a good stand and rapid plant growth.
   a. Test the moisture content of the soil at the greatest tillage depth before attempting any tillage treatment. If soil is wet, postpone field activities.
   b. Vary plowing depth from season to season. Don't plow the soil any more deeply than necessary.
   c. Use the chisel plow primarily in the fall when low soil moisture levels are most likely to occur.
   d. Where compact soil conditions occur, plow only deep enough to loosen the soil material in the compact zone.
   e. Plow with the wheels of the tractor on the land rather than in the furrow.
   f. Keep the plow well repaired and adjusted.
   g. Combine field operations to reduce trips across the field. Where more than one trip across a field is required, follow the tracks from a previous trip.

Fig. 14. Inadequate drainage is a major cause of bad soil structure. Spreading fertilizer and manure and plowing and planting when the soil is plastic results in compact soils. This picture was taken after 4 in. of rain had fallen in 6 days. The last rain totaled 1.4 in. Surface drainage into a ditch adjacent to this field would have helped this crop. With water outlets to the ditch, soil moisture levels would be lower, thus reducing opportunities for soil compaction.

Fig. 15. Ditches plugged with brush and trash retard the rate of water removal. This situation increases opportunities for soil compaction and crust formation.

h. Where necessary, broadcast fertilizer and lime before plowing.

3. Maintain and improve organic matter levels in the soil.
   a. Use green manure and cover crops wherever possible.
   b. Prevent accelerated soil erosion by wind and water.
   c. Use crop residues as the source of soil organic matter.
   d. Use livestock manure as a soil amendment and not a valueless byproduct.
   e. Include in a rotation at least one crop, such as corn, which produces large amounts of crop residues.
   f. Control insects, diseases and weeds so that both high grain yields and crop residue yields are produced.
   g. Have the soil tested at regular intervals in a modern laboratory and follow the recommendations so that high yields of crops and residues are produced.

SUMMARY

The problem of bad soil structure appears to be more widespread in Michigan now than in the past. Methods for use by both farm advisors and farmers in identifying the problem have been outlined. The causes of bad structure include inadequate drainage, excessive tillage, intensive cash crop systems of farming, untimely field operations and the poor design of some farm implements. Methods for improving soil structure include providing for adequate water drainage, using minimum tillage principles so farm implements do not pack the soil excessively, and using organic matter to stabilize the structure of the soil.

On those soils that have bad soil structure, there is nothing better than to grow alfalfa or a clover grass mixture for two or more years. The grass stabilizes the structure of the surface soil while the deep-rooted alfalfa improves the structure of the subsurface horizons.

Bad soil structure has limited the yields of crops ever since man domesticated some of the original vegetation. Today, in most instances, there is little reason to have the condition of bad soil structure limit crop yields and profits.

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