

Avoiding Soil Compaction



PENNSSTATE



College of Agricultural Sciences
Agricultural Research and Cooperative Extension

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INTRODUCTION

Twenty-first-century farm economics stimulate farmers to increase the size of their operations. To improve labor efficiency, farm equipment usually increases in size. Tractors, combines, forage harvesters, grain and forage wagons, manure spreaders, and lime trucks are all bigger than they used to be. Twenty years ago, for example, 2.5-ton box-type manure spreaders were common in Pennsylvania, whereas today liquid manure spreaders may weigh 20 or 30 tons. The increasing size of farm equipment may cause significant soil compaction that can negatively affect soil productivity as well as environmental quality. This fact sheet focuses on ways to avoid soil compaction.

AIM OF SOIL COMPACTION MANAGEMENT

Our knowledge of soil compaction has increased substantially in the past two decades, especially after results of an international project of more than 20 soil compaction experiments in North America and Europe were published. Based on this work researchers have discovered that: (1) compaction in the topsoil is related to ground contact pressure only, (2) compaction in the upper part of the subsoil is related to both ground contact pressure *and* axle load, and (3) compaction in the lower subsoil is related to axle load only (Figure 1).

In a summary of the international soil compaction project, compaction due to axle loads of 10–12 tons reduced yields approximately 15 percent in the first year, decreasing to 3–5 percent 10 years after compaction. The lead researchers suggested that 10 percent of the yield loss in the first year was due to compaction in the topsoil and upper part of the subsoil. The effects of topsoil and upper subsoil compaction disappeared in approximately 5 and 10 years, respectively (Figure 2). Three to five percent yield loss was apparently due to deep subsoil compaction, which did not disappear during the period in which measurements were taken (12 years for the

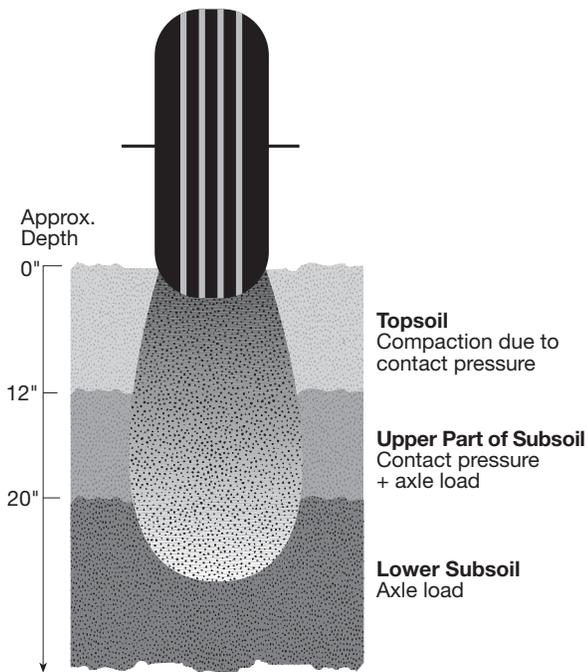


Figure 1. Topsoil compaction is caused by contact pressure, whereas lower subsoil compaction is caused by axle load.

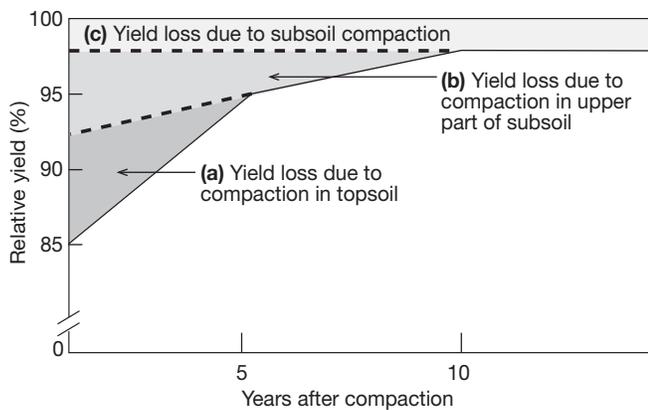


Figure 2. Effects of compaction in the topsoil (a) and upper part of the subsoil (b) are temporary, whereas deep subsoil compaction (c) is virtually permanent.

longest experiments). The conclusion is that lower subsoil compaction is, practically speaking, permanent and should therefore be avoided by all means, whereas topsoil compaction and upper subsoil compaction are temporary and should be limited as much as possible. Two other important observations from these studies are: (1) surface tillage (moldboard plowing in most experiments) did not completely alleviate surface compaction and (2) deep penetration of frost did not

alleviate lower subsoil compaction (most experiments were located in northern latitudes where soil is commonly frozen to 40–50 inches in winter).

KEYS TO SOIL COMPACTION AVOIDANCE

Axle Load

Axle load is the first factor that has to be considered in soil compaction. Axle load is the total load supported by one axle, usually expressed in tons or pounds. Farm equipment with high axle loads will cause compaction in the topsoil and subsoil, whereas low axle loads will cause compaction in the topsoil and the upper part of the subsoil only (Figure 3). Deep subsoil compaction can only partially be alleviated with subsoilers, and at considerable cost. Freezing/thawing and drying/wetting cycles have been shown not to remediate soil compaction at this depth. Finally, biological activity is concentrated in the topsoil and therefore also contributes little to alleviation of deep subsoil compaction. Therefore, avoiding deep subsoil compaction is critical. The key to

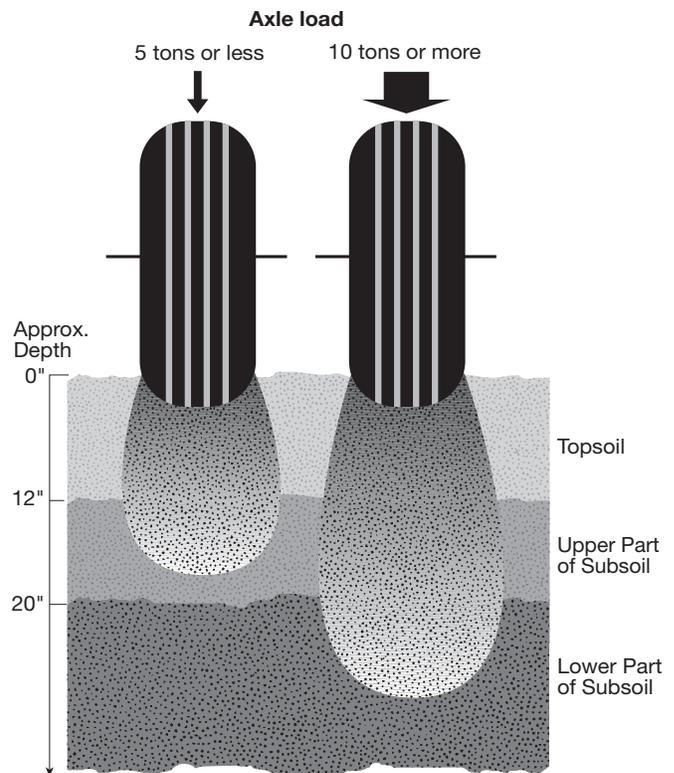


Figure 3. Low axle load causes compaction in the topsoil and upper part of subsoil only, whereas high axle load causes compaction in the lower subsoil as well.

Aims of Soil Compaction Management

1. Avoid compaction in the subsoil altogether.
2. Limit compaction in the topsoil as much as possible.

eliminating deep subsoil compaction is to keep axle load low.

The amount of top- and subsoil compaction caused also depends on the presence of a natural or traffic-induced pan close to the surface (Figure 4). In a uniform soil, stress will be transmitted from the surface deep down into the soil profile. In a soil with a pan or dense subsoil, soil stress tends to concentrate near the surface.

What is the critical axle load that is likely to cause subsoil compaction? Research has shown that a 10-ton axle load almost always causes deep subsoil compaction (more than 20 inches deep) under wet to moist field conditions. If the soil is dry, deep subsoil compaction is less likely, even with high axle loads. The 10-ton axle load is only a rough cutoff point, but limiting axle loads to 10 tons at the very most is advisable. Swedish

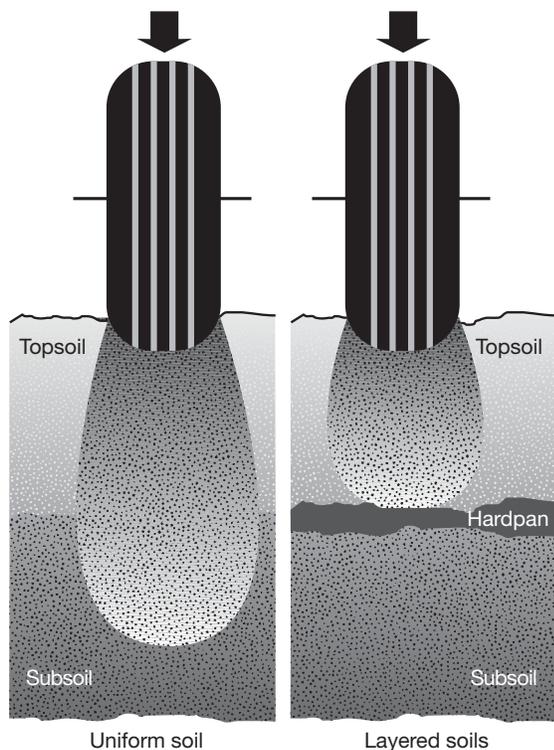


Figure 4. In a uniform soil, compaction is transmitted deep, whereas in a soil with a hardpan, compaction is concentrated above the hardpan.

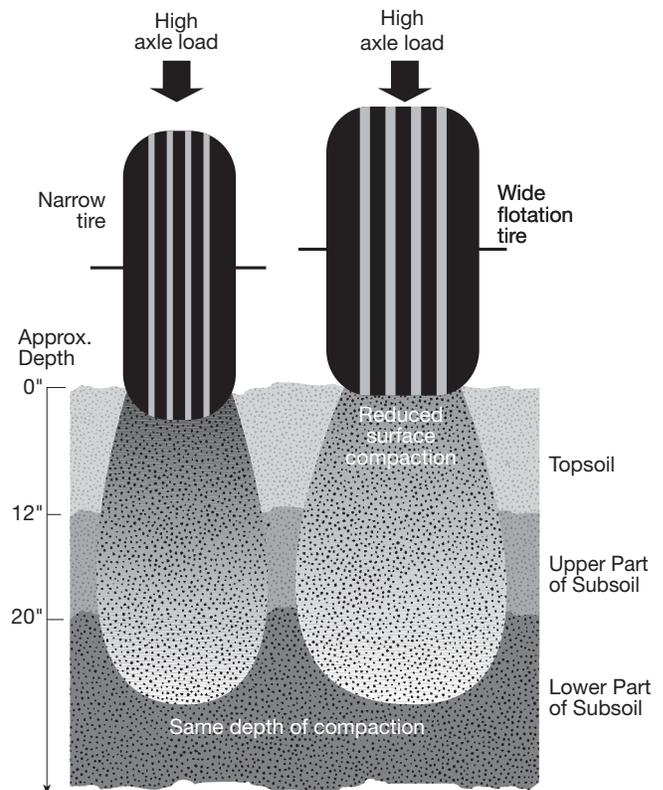


Figure 5. Increasing footprint reduces surface compaction but can still cause deep subsoil compaction if axle loads are high.

researchers stated some years ago that 6-ton axle loads contribute to subsoil compaction. Axle loads less than 5 tons are not likely to cause subsoil compaction, although they may create significant surface compaction.

To assess the danger of subsoil compaction, start thinking about the heaviest pieces of equipment on the farm. Typical candidates are the manure spreader, combine, and grain carts. The average axle load can be calculated by dividing the total weight of the loaded vehicle (for example, 16 tons) by the number of axles (for example, 2 axles), giving an average axle load of 8 tons. In general, however, the load is not uniformly distributed across all axles. In such a case the heaviest axle will determine if subsoil compaction occurs. Therefore, the best approach is to weigh each axle on portable or farm scales. The axle load can be decreased by lowering the load or by increasing the number of axles.

Strategies to Reduce Subsoil Compaction

- Reduce load
- Increase number of axles

Contact Pressure

Contact pressure is the pressure that is exerted by a tire or track on the soil surface, expressed in pounds per square inch (psi). Reducing contact pressures will cause less topsoil compaction (Figure 5). In completely flexible tires, surface contact pressure is similar to tire pressure. With most farm tires, surface contact pressure is about 1 to 2 psi higher than tire pressure due to stiffness in the tire. The best way to determine contact pressure is to calculate the load in pounds per wheel and divide it by the area of the tire that touches the soil (in square inches). This will give you the average contact pressure under that tire in psi. Lowering contact pressure will affect topsoil compaction but not subsoil compaction (Table 1). Table 1 clearly shows that tires run at 35 psi caused higher stresses at 14 inches depth and created ruts that were more than twice as deep as tires run at 12 psi tire pressure. However, at 22 inches, no difference was noted in measured stress between both tires because the tire load was the same.

Table 1. Experimental results of stress under tires (SR 20.0/70-20) inflated to different pressures (tire load was 3.6 tons).

Inflation pressure (psi)	Peak stress @ 14-inch depth (psi)	Peak stress @ 22-inch depth (psi)	Rut depth (in)
35	28	11	2.01
12	18	11	1.14

Adapted from J. J. H. van den Akker, W. B. M. Arts, A. J. Koolen, and H. J. Stuiver. "Comparison of stresses, compactions, and increase of penetration resistances caused by a low ground pressure tyre and a normal tyre." *Soil & Tillage Research* 29 (1994): 125–134.

Strategies to Reduce Topsoil Compaction

1. Reduce tire pressure to minimal allowable pressures
2. Use flotation tires
3. Use tracks or duals to replace singles
4. Adopt radial-ply tires instead of bias-ply tires
5. Install larger diameter tires to increase length of footprint
6. Use tractors with four-wheel or front-wheel assist or tracks to spread the load over larger footprint area
7. Properly ballast tractor for each field operation

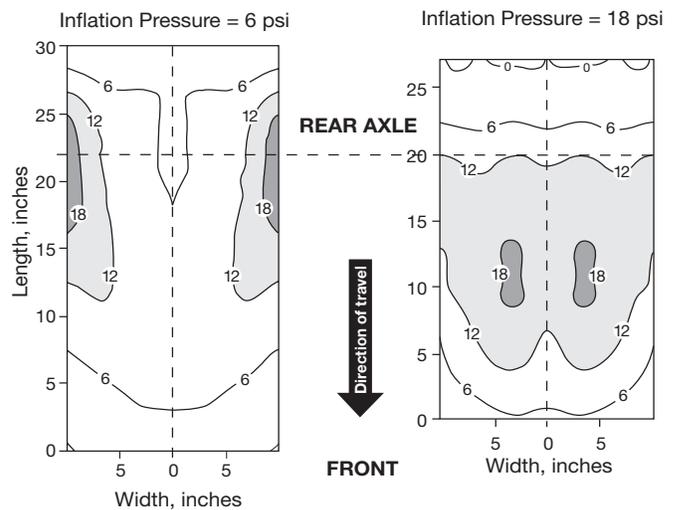


Figure 6. The same tire inflated to low and high pressures. At low tire pressure, highest stresses concentrate near the edge of the tire and represent a smaller area, whereas at higher inflation pressures, higher stresses concentrate below the center of the tire and occupy a larger area. From chapter 10: "Soil Compaction" by R. T. Schuler, W. W. Casady, and R. L. Raper, 2000, in *Conservation Tillage Systems and Management*, MWPS-45, 2nd ed., p. 74.

Contact pressure is not uniform under a tire due to sidewall stiffness (Figure 6). The area of high stress is greater when a tire is inflated to high inflation pressures and is concentrated under the center of the tire. In a properly inflated tire, the area of high stress is smaller, whereas the highest stresses are concentrated near the edge of the tire.

A common question is whether tracks are better than duals. The answer is that it depends on the tire inflation pressure in the duals. In an Ohio State study, a 310 HP tracked tractor was compared with a 350 HP tractor with duals. The duals were inflated to 24 and 6 psi, respectively. Total porosity was used as a measure of compaction. The tractor with overinflated duals caused most compaction, and least if used at proper inflation pressure (Figure 7). This shows that duals can do as good a job in avoiding topsoil compaction as tracks, provided the tire pressure is kept low.

Tracks offer some advantages such as a long but narrow contact area. The proportion of the field trafficked is therefore smaller than if using duals. Tracks are also known to provide better traction than tires. Very low average contact pressures under a track do not tell the whole story, however. The belt is flexible and there are pockets of high pressure under the axles of the belt that can be as high as those under a tire-mounted tractor (Figure 8). Each axle in a track represents a pass over the soil that causes a little more compression. Finally, tracks tend to increase the dwelling time of the load on the soil, which increases compaction. In conclusion, tracked

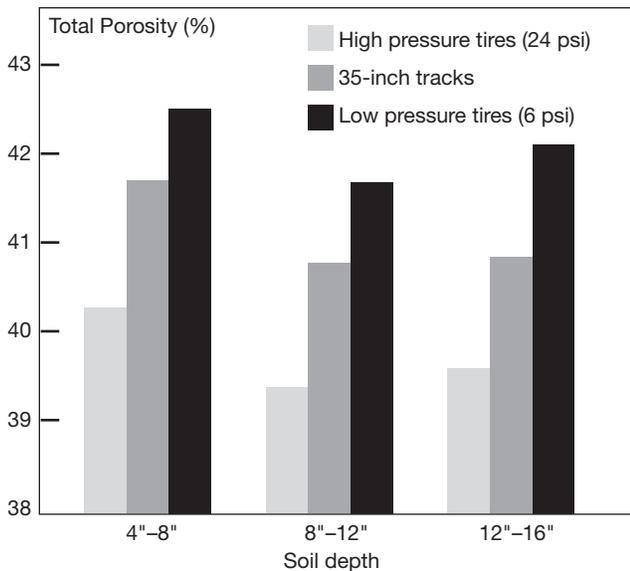


Figure 7. Duals inflated at high pressure caused more compaction than tracks, whereas the same duals caused less compaction if inflated at low pressure. From R. G. Hoelt, E. D. Nafziger, R. R. Johnson, and S. R. Aldrich. 2000. *Modern Corn and Soybean Production*. Champaign, IL: MCSP Publications.

tractors can cause the same compaction at the same total vehicle load as tire-mounted tractors.

Using larger diameter tires increases the length of the footprint and, therefore, decreases contact pressure without increasing the proportion of the field trafficked. Finally, front-wheel-assisted and four-wheel-drive tractors reduce topsoil compaction because the weight is more equally distributed (Figure 9). Remember, however, that the four-wheel-drive tractor might have higher axle loads than the two-wheel-drive tractor because of larger total vehicle weight, thus increasing the chance of subsoil compaction. Ballasting the tractor properly is a simple task that can dramatically reduce axle load as well as improve tractor efficiency.

Number of Passes and Travel Speed

Research in tilled soils has shown that approximately 75 percent of the increase in soil density and 90 percent of wheel sinkage is caused during the first pass. However, the compaction caused by subsequent passes may cause as much damage to a crop because the small changes to soil density are now in the high range, which is more likely to be detrimental to root growth. It has also been shown that the longer the dwelling time of a load on soil, the greater the increase in density. Therefore, (1) limit the percentage of the field trafficked, (2) concentrate repeated traffic in travel lanes so remedial action can be taken there, and (3) drive faster to shorten the load dwelling time.

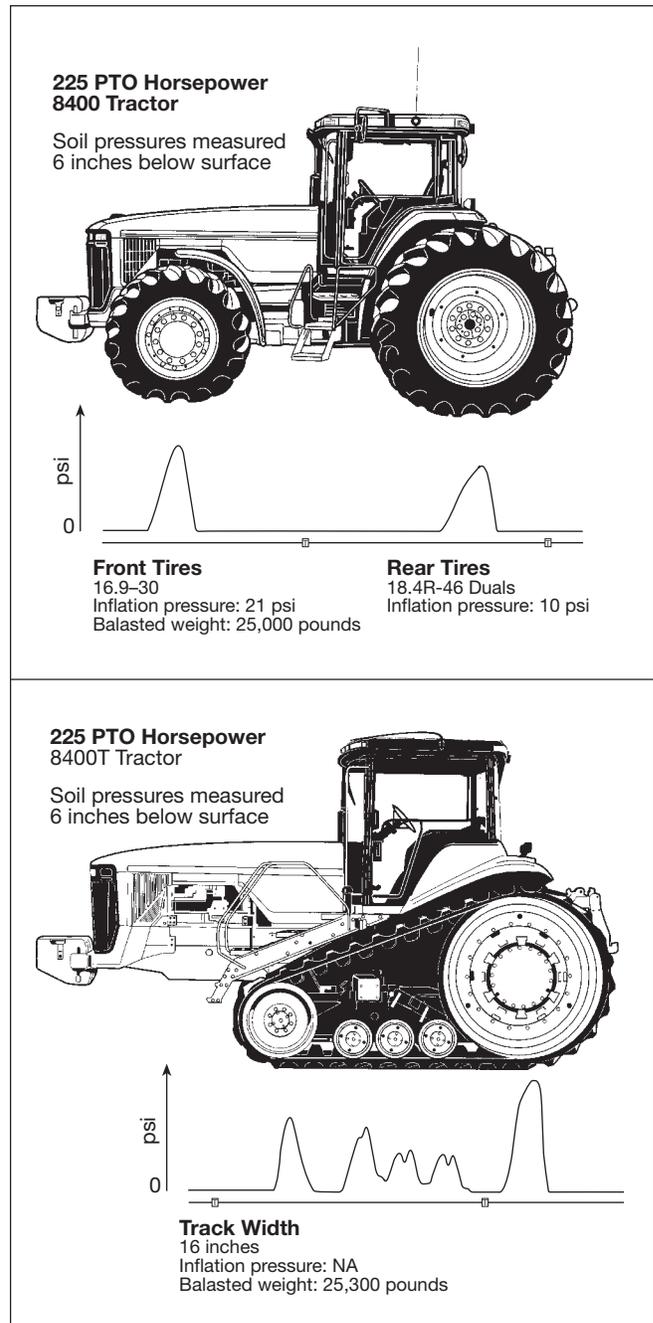


Figure 8. Although, on average, contact pressure is low under rubber tracks, there are pockets of high stress that can equal or exceed those under radial tires that are inflated to low pressures. From R. G. Hoelt, E. D. Nafziger, R. R. Johnson, and S. R. Aldrich. 2000. *Modern Corn and Soybean Production*. Champaign, IL: MCSP Publications.

Soil Moisture Contents

Monitoring soil moisture content is extremely critical to avoid soil compaction. Most compaction studies are performed at moisture contents near field capacity (approximately 24 hours after soaking rain) to simulate worst-case scenarios. If farmers can stay off their fields

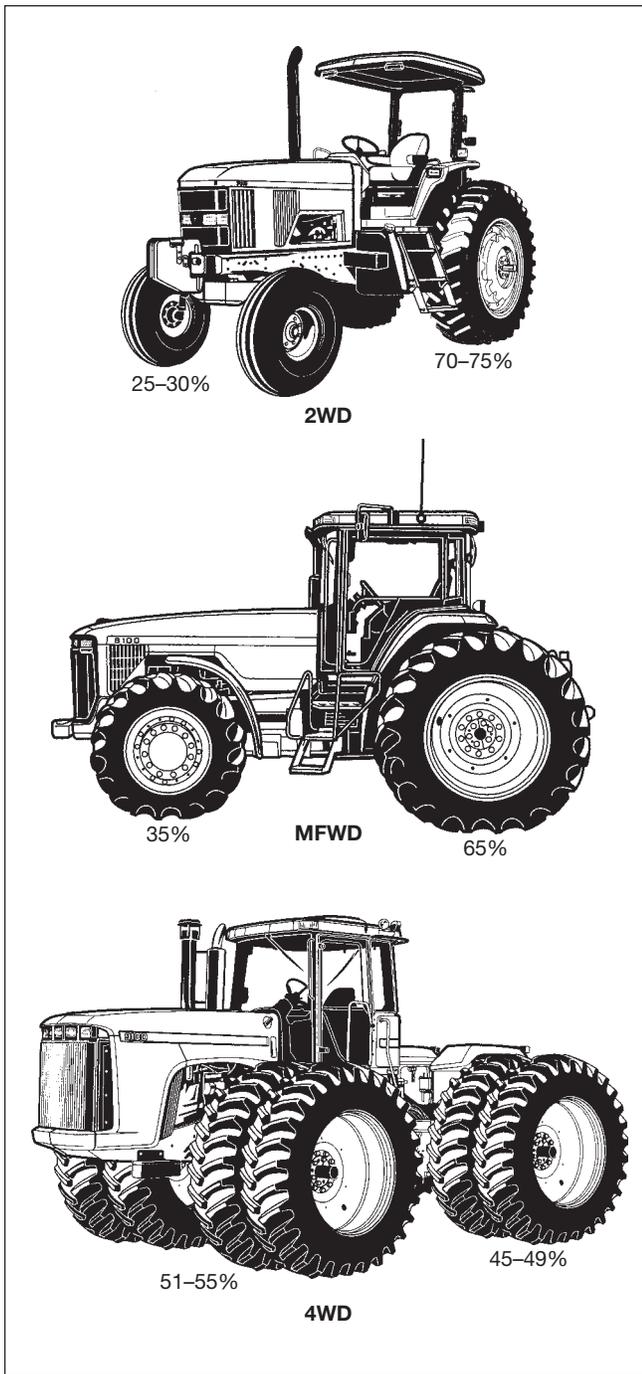


Figure 9. One advantage of four-wheel-drive or front-wheel-assisted tractors is that weight is more equally distributed. From R. G. Hoelt, E. D. Nafziger, R. R. Johnson, and S. R. Aldrich. 2000. *Modern Corn and Soybean Production*. Champaign, IL: MCSP Publications.

when soils are too wet, soil compaction is not likely to become a problem. Dry soil can sustain high axle loads and high contact pressures without adverse effects. The problem is, however, that factors such as optimum planting or harvest time often dictate that a farmer will be in the field at suboptimum soil moisture conditions for traffic.

Driving on wet soil causes rutting, slipping, and increased deep soil compaction. Dry soil cannot be compressed to as great a density as moist soil. However, at moisture contents above the “plastic limit” soil compaction decreases because all pores are filled with water that cannot be compressed. The Proctor density test is used to determine the plastic limit, or the optimum water content for compaction (Figure 10). Although this is a valuable test for road engineers, driving on agricultural soil that is wetter than the plastic limit has many problems. Rutting and slipping have devastating effects on soil structure that will be difficult to remedy.

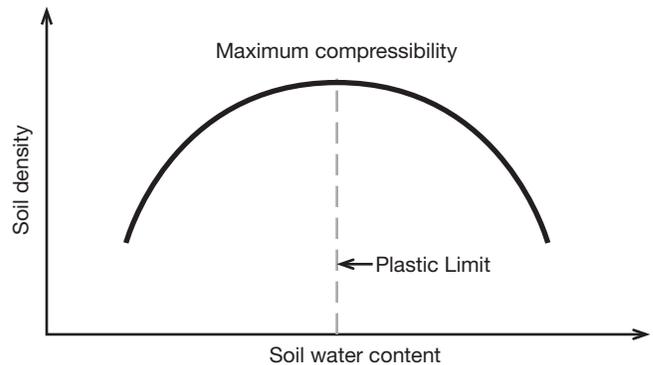


Figure 10. Engineers use the Proctor density test to determine the “optimum water content for compaction.” The Proctor curve shows that soil near saturation cannot be compressed as much as at plastic limit water content.

Trafficking very wet soil (especially with high loads and tire pressures) causes a “hydraulic ram” effect. The topsoil is compressed very quickly to saturation. Because water cannot be compressed, surface stresses are now directly transferred to the subsoil. Therefore, driving on very wet soil is very likely to cause subsoil compaction. Plowing with one wheel in the furrow also directly compacts subsoil.

CONCLUSIONS

Deep subsoil compaction is permanent and should be avoided at all costs. This can be done by keeping axle loads below 10 tons, and preferably below 6 tons. Compaction in the topsoil can be avoided by reducing tire pressure, using flotation tires, doubles, radial tires, or tracks, and by employing large-diameter tires. Reducing the number of trips over the field and reducing the total area per acre actually traveled are recommended. Driving on soil that is wetter than the plastic limit should be avoided at all times.

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