Soil
FACTSHEET

Order No. 613.100-1
Revised December 2015
Created October 1990

Soil Compaction
A Review of its Origin and Characteristics

INTRODUCTION

Soil compaction refers to the disruption and reduction of the large pores within the soil. The presence of excess soil moisture at the time of any field operation is the main factor leading to soil compaction. Once a soil is compacted, the bulk density and the strength of the soil are increased. For construction purposes, a compacted soil is ideal but under normal crop production, a compacted soil can be a serious problem. Penetration into the soil by tillage implements and crop roots is restricted. The movement of air and water through the soil is hampered causing the soil to remain wet and cool long into the growing season.

Many areas in British Columbia suffer from this debilitating condition which can be the main obstacle to good crop production. Because compaction is such a serious threat to good crop production, a closer look should be taken at ways to reduce or reverse its effects. However, this note will only deal with the recognition and effects of soil compaction.

HOW CAN YOU RECOGNIZE A COMPACTED SOIL?

Soil compaction occurs when a force compresses the larger soil pores and reduces the air volume of the soil (Fig. 1). The continuity of the pores from the surface of the soil to deeper depths is disrupted, and thus, the transmission of water through soil and gases between the crop's roots and atmosphere is reduced (Fig. 2).

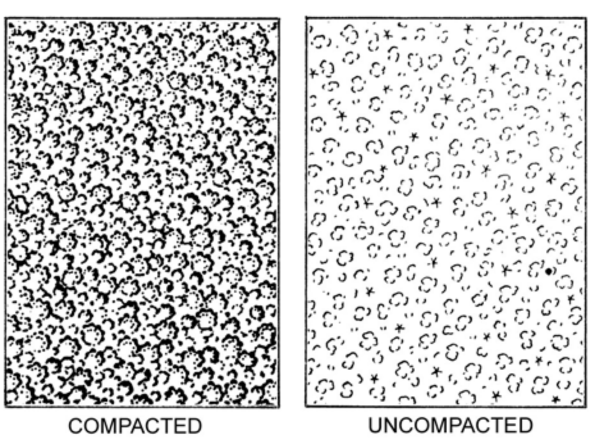

Figure 1 The effect of compaction on pore space

Figure 2 The effect of compaction on crop root growth

1. Bulk Density

The measurement of a soil's bulk density provides a relative value of soil compaction. The porosity of a soil can be related to the bulk density measurement with further laboratory procedures.

Bulk density is expressed as weight per volume of soil (usually in terms of grams per cubic centimeter). Variation in bulk density can occur on a year-to-year basis, as freezing and thawing, wetting and drying cycles and cultivation can alter the basic structure of a soil.

The bulk density of high organic mineral soils and peats is much lower than that of mineral soils. Table 1 gives some examples of soil bulk density measurements.

Table 1 EXAMPLES OF AVERAGE MINERAL SOIL BULK DENSITIES

	(g/cm^3)*
Well structured high organic loam soil	0.9
Silt loam	1.1
Medium to fine textured loam	1.3
Sand	1.5
Compacted soil or clay subsoil	1.3 – 1.6

*** (1 g/cm^3 = 62.43 pounds force per cubic foot)**

2. Penetrometer Method

Another method of measuring soil compaction is using a penetrometer. Penetrometers can give quick results in the field and many measurements can be taken in a short time. However, the use of penetrometers and interpretation of the results requires considerable skill especially if soils are in the initial stages of compaction. Penetrometers are useful in finding hard layers that will obviously obstruct root development or water flow through a soil.

Penetrometers measure soil strength and their movement through the soil that has been related to the soil's resistance to root penetration. Plant roots, however, grow around obstacles and can exert tremendous local pressure on soil pores so that penetrometers can only provide a relative root resistance value.

Factors which affect penetration resistance as measured by penetrometers are cone angle, cone diameter (surface area) and rate of soil penetration; soil factors which affect soil strength or resistance are water content, structure and bulk density.

The effects of compaction are dependent on the amount of root zone that is compacted, continuity of compacted zone and susceptibility of crops to compaction.

Table 2 is a rough guide to penetrometer resistance values (in megapascals – MPa) and soil compaction through the rooting zone. These penetrometer readings are averages and were obtained using a penetrometer with a 60-degree cone angle.

Table 2 EXAMPLES OF SOIL RESISTANCE VALUES ON CROP YIELD

	(MPa)*
Low Compaction Effects	<1.0
Medium Compaction Effects	1.0 – 1.5
Severe Compaction Effects	2.0 – 3.0

* **(1 MPa = 1450 pounds force per square inch)**

Although using penetrometers is much easier and quicker in the field, the number of factors that come into play in interpreting their results makes them as difficult to use as the bulk density method. If proper sampling techniques are used, the bulk density method may give a more accurate result for any particular site in the field. Because both technical methods have limitations, the visual method may be the quickest and best alternative.

3. Visual Method

Often the best method of determining soil compaction is visual observation of both the soil and crops. Cloddy seedbeds, increased surface water ponding, loss of granular soil structure and reduced pore spaces through the soil are good visual indicators of compaction. Digging an observation hole in the field and observing rooting depths and patterns helps to determine if the crop is exploring the total soil volume or is restricted. Probing soil layers with a knife can indicate compacted zones and help determine where rooting or water flow has been curtailed.

Depressed crops, stunted or contorted root systems, a tendency to show yellow colouring especially during or after large rainfalls (poor aeration), indicate compacted soils. Shifts in weed or crop type or population are also good indicators. In addition, root rot diseases may increase with surface compaction.

WHAT EFFECT DOES SOIL COMPACTION HAVE ON THE CROP?

A reduction in yield or yield potential is the most significant effect that soil compaction has on crops. The inability of roots to penetrate compacted soil layers will result in decreased yield. With less root penetration into the soil, root mass is reduced and a plant's ability to take up nutrients is reduced. As a result of surface soil layers having lower water storage capacities, plant roots remain closer to the surface and are therefore more susceptible to drought. Compacted soils often have higher subsurface soil moisture contents because soil water is unable to drain away freely and air movement in the soil is restricted. This reduction in internal drainage generally leads to surface ponding which may drown the crop.

As a result of the reduction in the size and number of macropores in the soil and the subsequent reduction in aeration, microbial activity is reduced. Soil microbes play an important role in the breakdown of organic matter and fertilizer into useable plant nutrients so soil fertility may be reduced. Poor quality, low fertility organic matter accumulates on the soil surface because soil microbes are not present to breakdown crop residues. Well decomposed organic matter (humus) levels in the upper soil layers will decline with a reduction in microbial activity. With this loss of humus, soil aggregate stability is reduced.

Mechanical pressure and manipulation from equipment and loss of aggregate stability lead to further degradation of the soil structure. Compacted soils also tend to warm more slowly resulting in slower crop growth and higher moisture contents. Compacted soils remain cool and wet into the growing season resulting in conditions that favour the growth of soilborne pathogens such as Pythium or Rhizoctinia root rot. Plants under stress are also much more susceptible to root rots and other diseases.

If compacted layers are present in the soil, the risk of soil erosion is increased. The movement of water into and through the soil is reduced resulting in greater overland flow and subsequent surface erosion.

FACTORS INFLUENCING COMPACTION

The potential of any soil to compact is dependent upon its physical properties, water content and the nature of the force applied. The physical properties influencing compaction include the original bulk density and structure, as well as the texture and organic matter content. In general, soils with fine textures (silt and clay), low organic matter contents, high porosity and weakly aggregated structure are more susceptible to serious compaction. From a soil management stand point, all soils should be considered as capable of being compacted.

The two major management factors that influence the soil's ability to compact are the soil moisture content at the time of any field operation and the contact pressure exerted by the implement or vehicle involved in the operation.

THE CAUSES OF SOIL COMPACTION

Natural

Compaction is the result of either natural soil formation processes and/or cultural practices. Natural compaction resulting from soil formation processes is found in many areas. This compaction is usually related to chemical transformations below the surface of the soil. It may also be related to the texture of the subsurface material and how it was deposited. Natural compaction may take the form of hardpans or cemented subsoils. Because some natural compaction continues as the soil formation processes continue, there is little or nothing that can be done to prevent its occurrence. Cemented layers or shallow natural hardpans may be disturbed by deep cultivation.

Other management practices, such as drainage, may reduce the effects of the hardpans or reverse the soil formation processes that lead to cemented layers.

Cultural Practices

Most soils in their undisturbed state have porous surface layers, but after years of cropping this porosity is often significantly reduced. This reduction in pore space and size is the result of several cultural practices either alone or together. Some cultural practices that cause reduction in porosity and compaction are untimely or excessive tillage, repeated tillage at the same depth, pulverizing of soil aggregates by tillage equipment and excessive or untimely access to fields by farm vehicles. The process of deformation of randomly placed soil particles into a dense layered mass is known as puddling. A 'puddled' soil has a greatly reduced infiltration rate (Fig. 3).

Drainage

The presence of excess soil moisture is the main cause of soil compaction. The cultural practice with the greatest potential to reduce soil compaction in much of British Columbia is the use of subsurface drainage. The whole soil is more easily deformed and soil particles can be forced together when subjected to external pressure when they are wet. In saturated soils, the soil particles are dislodged and subsequently redeposited in a dense, layered form. Wheel ruts and tillage pans formed in soft wet soils can be seen to have an effect on crop growth long after any excess soil moisture is gone. Drainage systems are designed to prevent saturated soil conditions thereby alleviating soil compaction problems (Fig. 4).

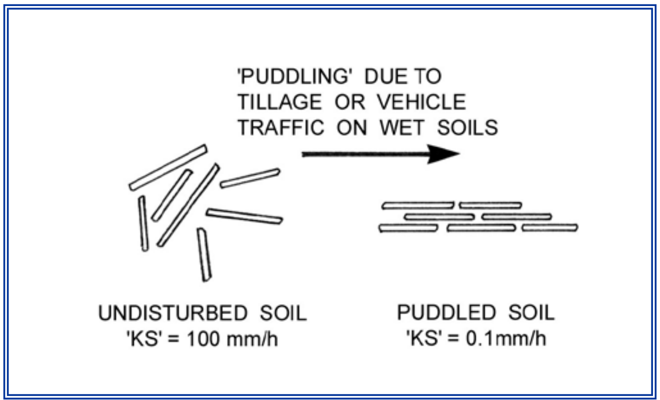

Figure 3 Puddling of Soil Particles. The term 'KS' refers to the steady state water infiltration rate of a soil.

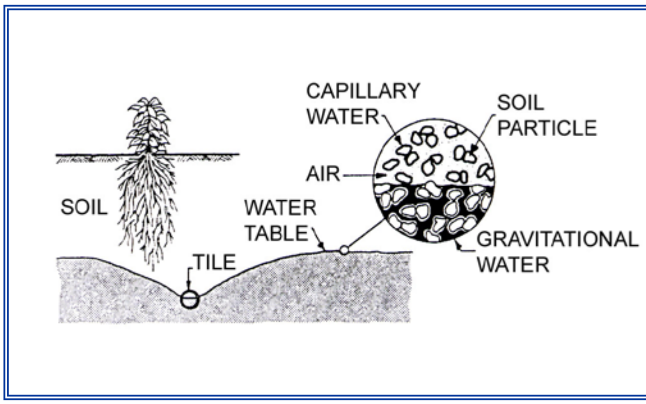

Figure 4 Effects of drainage on soil moisture

Tillage

Tillage breaks apart soil aggregates, permitting soil particles to move apart or be forced closer together. Exposure of the soil particles to air also causes more rapid decomposition of soil organic matter which is important for soil aggregate stability. In wet soils, tillage does not break apart soil particles, but rather smears the particles together to form clods. Tillage, depending on the implement used, also exerts downward pressure on the soil layers below the surface leading to deep compaction and the formation of “plow pans”. Thin layer smearing by implements such as moldboard plows or rotovators plus the compaction on the bottom of the furrow slice resulting from the contact pressure or any slippage of the tractor wheel cause deep tillage related compaction (Fig. 5).

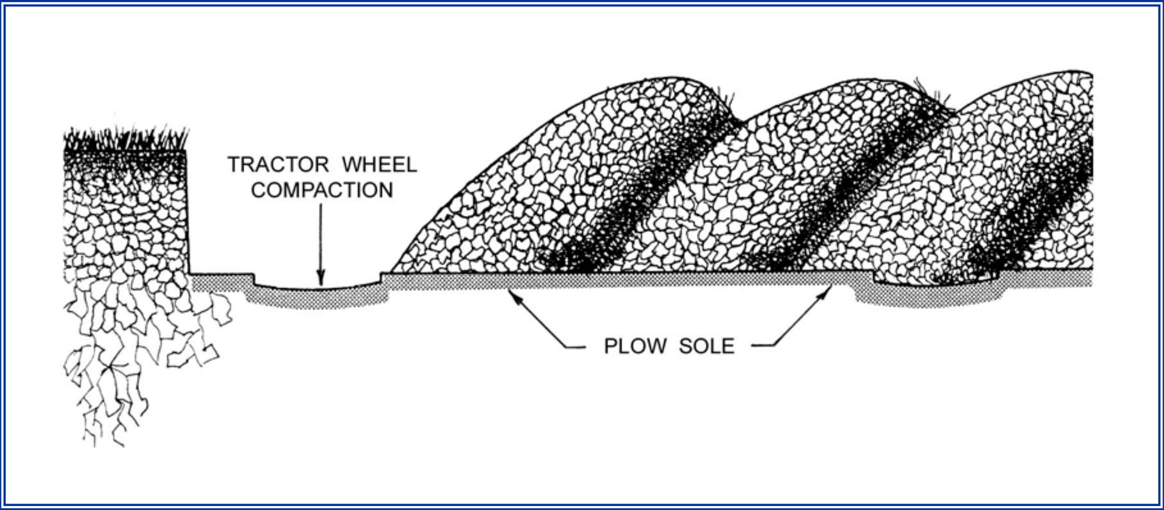

Figure 5 Schematic drawing of the effect of plowing on soils

Traffic

Traffic from vehicles such as forage wagons, farm trucks or manure vacuum tankers exerts force on the soil (Fig. 6). The degree of compaction caused by vehicle traffic is dependent on two main factors that can be controlled by the crop producer. The first is the contact pressure of the vehicle which is determined by the overall weight of the vehicle and the footprint of the vehicle tires or tracks. The greater the contact pressure and/or the more frequently the vehicle passes over a particular area in the field, the greater and deeper will be the resulting compaction (Fig. 7). The second factor is the soil moisture content at the time the vehicle is in the field. The greatest amount of compaction occurs when the soil is wet. It has been estimated that up to 80% of the soil surface of a field can be exposed to wheel traffic at least once in any field season; this is particularly true in the case of fields used for forage production.

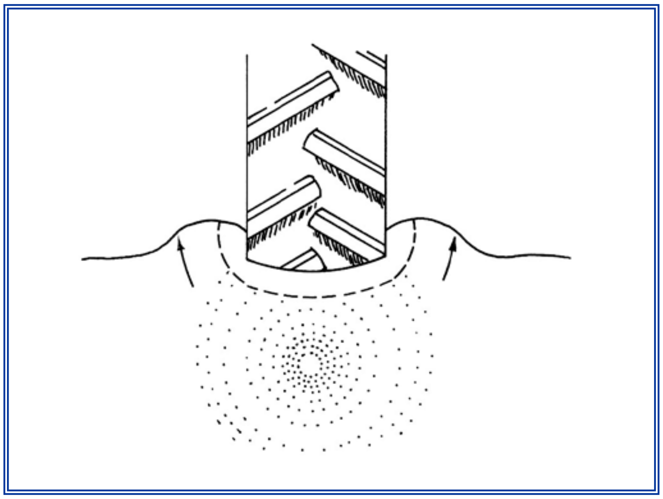

Figure 6

Effects of wheel traffic on soil. Dotted and dashed lines indicate zones of compaction.

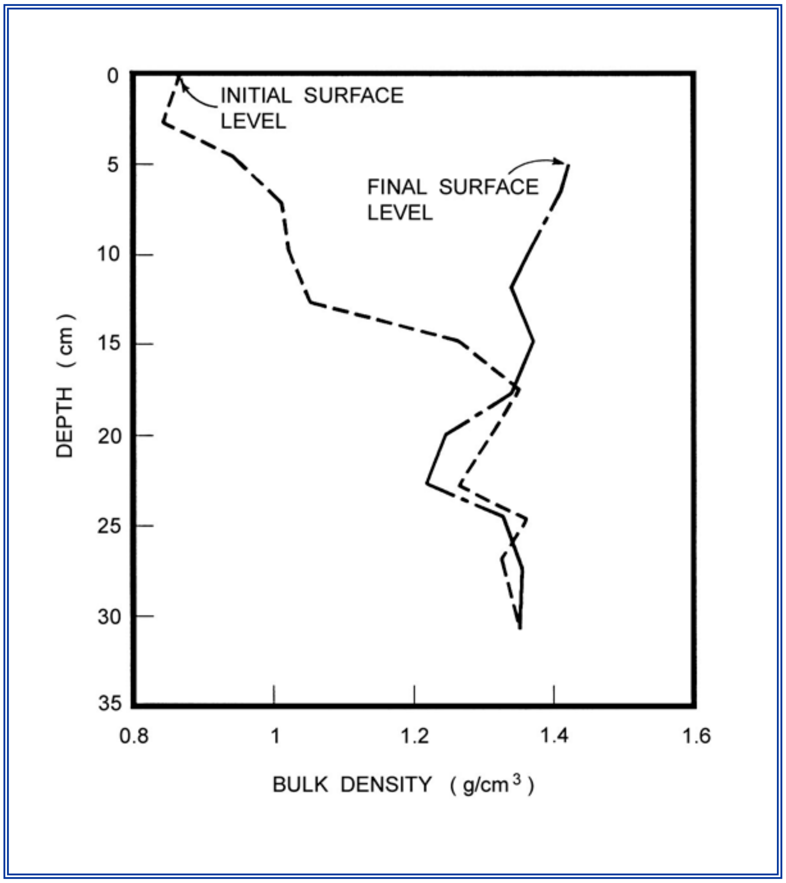

Figure 7 Bulk density profiles before and after tractor wheel passage

Other Cultural Practices

Other cultural practices that lead to compaction are soil surface exposure, organic matter depletion and the use of some crop nutrition and protection products. The exposure of soils due to lack of vegetative or trash cover allows raindrop impact to disperse soil particles leading to "puddling" of the soil and ultimately compaction. One use of tillage is to incorporate organic matter. However, it is also possible for the simple act of tillage to accelerate the breakdown of some types of soil organic matter that are required to bind soil particles together.

However, in reduced tillage and forage production systems, soil structure is improved by microbial decomposition of organic residues without the benefit of tillage. Soil compaction can also be the end result of excessive applications of fertilizers or pesticides. Because many of the binding agents that maintain a soil's structure are the result of the activity of living organisms, excessive applications of fertilizers or pesticides could be harmful to those organisms. This would lead to a decline in the breakdown of organic matter into products that bind soil aggregates.

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