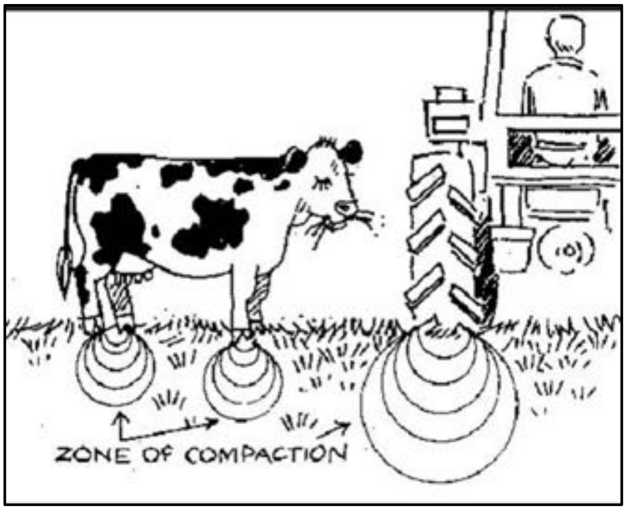
Lawrence D. Hepner Jr., Consulting Agronomist & Soil Scientist, Emeritus Professor of Agronomy & Environmental Science, Delaware Valley University, South Kortright, NY followed Fay. His presentation was on "Soil Structure Changes Resulting From Compaction and The Impact On Soil Health".



Larry covered three topics:

- What Is Soil Structure?
- How Do We Describe It?
- Impact Of Compaction.

Soil Structure is the aggregation of sand, silt, and clay particles and the fracturing of the soil along natural lines of weakness. Structure is a dynamic soil property having two kinds: Inherent properties that change little or not at all with management. They are texture, type of clay, depth to bedrock, and drainage class. And, dynamic properties that are affected by human management over the human time scale. They include organic carbon, structure, biological activity, and chemical activity. The terminology that we use to describe soil structure are type, grade, and size. One type of structure is granular. It is spheroidal in shape. Typically, it is found in the plow layer (Ap horizon) in pastures or cropland. In wooded sites, it is typically found in the surface A horizon. See picture below showing granular soil structure in the palm of a hand.

The next soil structure type identified was blocky. Blocklike in shape and denser, this type has two forms: Angular blocky found in higher clay soils has sharp edges and subangular blocky found in soils with less clay has rounded edges. Blocky is usually found in the subsoil (B horizons) that is directly under the topsoil. Both forms of blocky structure shown side-by-side below.

Angular Blocky

Subangular Blocky

The next type of soil structure described was platy. It is like a bunch of plates stacked on top of each other. Plate-like in shape, its horizontal axis is longer than its vertical axis which can be quite thin depending on its location in the soil. Platy structure is usually found in subsurface soils that have been subject to leaching or at the surface when compacted by animals or machinery. The plates can be separated with a little effort by prying on the horizontal layers with a pen knife. Platy structure impedes the downward movement of water and plant roots through the soil.

Platy soil structure, on the left platy structure in the topsoil and on the right platy structure in the C horizon

The next soil structure type discussed was prismatic with the opposite orientation of platy. Its vertical axis is longer than its horizontal axis. In the prismatic structure, the individual units are bounded by flat to rounded vertical faces. Units are distinctly longer vertically, and the faces are typically casts or molds of adjoining units. Vertices (Vertices are the corner points.) are angular or subrounded; the tops of the prisms are somewhat indistinct and normally flat. Prismatic structures are characteristic of the B horizons or subsoils. The vertical cracks result from freezing and thawing and wetting and drying as well as the downward movement of water and roots.

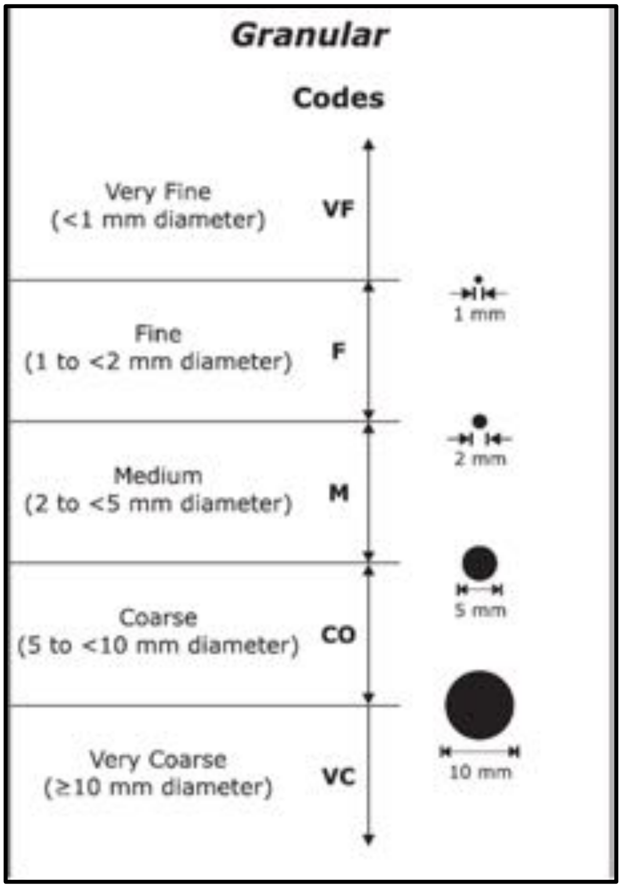
Note 4 white vertical cracks of the prisms

The term Grade was described next. There are 4 grades of how well the soil structure is formed. Strong structure is a sign of a healthy soil. As the grade number decreases, the soil is declining in health.

(SOIL STRUCTURE) - GRADE—

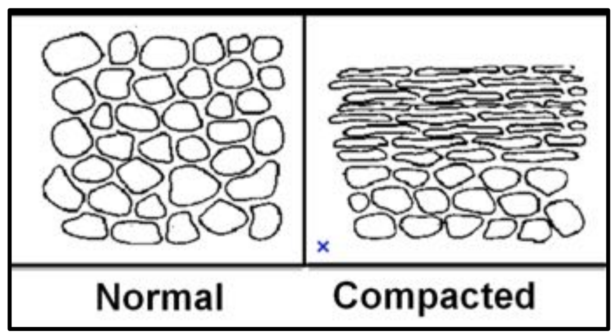
Grade	Code	Criteria
Structureless	0	No discrete units observable in place or in hand sample.
Weak	1	Units are barely observable in place or in a hand sample.
Moderate	2	Units well formed and evident in place or in a hand sample.
Strong	3	Units are distinct in place (undisturbed soil) and separate cleanly when disturbed.

The last terminology to describe soil structure is size. An example of size is illustrated in the figure below using granular type soil structure.



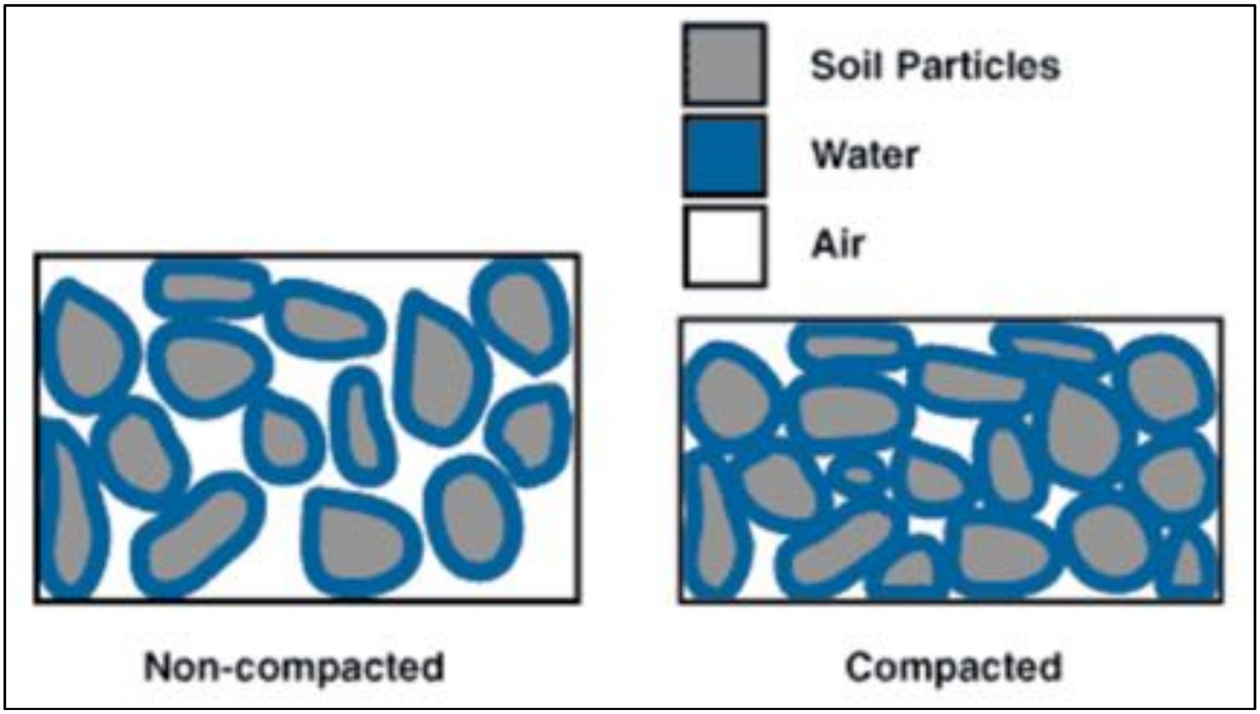
For the granular type of structure, the size ranges from very fine to very coarse as measured in millimeters. In a previous picture of a hand holding soil granules, they run in size from very fine to very coarse.

The impact of compaction on soil structure is shown in the schematic below. The compacted topsoil has a platy soil structure at its surface, as what was granular soil structure gets compressed into plates instead of being spheres like in the normal soil. There are also less air spaces between the soil aggregates.



Looking at two pasture soils, one normal and one compacted, note the normal soil has spherical granules of various sizes and is loose. The compacted soil has a platy structure and is dense.

When soil compaction occurs, soil macropores between soil aggregates are destroyed first, the normal granular structure of the topsoil is destroyed and becomes platy structurally, drainage and infiltration is slower, the soil becomes anaerobic, and it stays wet much longer.



Compacted soil has much less macropores for air, wetter, and is becoming platy as soil particles are being pressed together.

P. Tuohy *et al.*

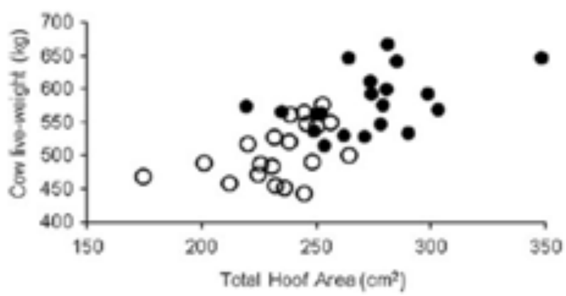


Fig. 3. Relationship between cow live weight and total hoof area for HF (•) and JX (○) cows. HF cows are heavier ($P < 0{\cdot}001$) and have larger hoofs ($P < 0{\cdot}001$) than their JX equivalents.

Table 4. *Mean weight, total hoof area and static pressure of subset of Holstein-Friesian and Jersey × Holstein-Friesian cows measured from the herd*

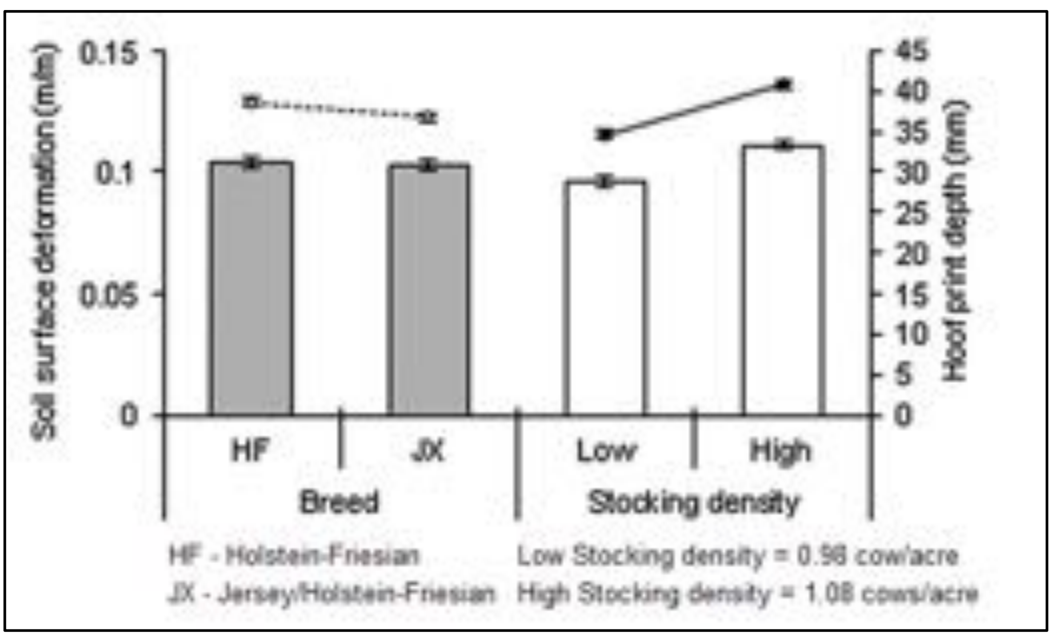
Breed	Mass (kg)	Total hoof area (m^2)	Static pressure (kPa)
HF	580	0·027	214
JX	506	0·023	218
S.E.	6·6	0·0005	4·2
P	<0·001	<0·001	NS

HF, Holstein-Friesian; JX, Jersey × Holstein-Friesian; NS, not significant

Larry presented some data from Irish dairy cow research on soil compaction that occurs on intensive rotational pastures that are wet (46% of Irish farmland is 'limited in agricultural use because of land wetness' [P. Tuohy et al., 2014]). They compared two dairy breeds, Holstein-Friesian and Jersey X Holstein-Friesian crossbreds, on their impact on soil properties when grazing pastures that are slow to dry in a climate that is cool and damp. In the second year of the study, they actually kept the cattle off the pastures when the pastures were deemed too wet to be grazed. The Holsteins have a bigger hoof than the Jerseys crosses. They were looking to see if grazing smaller cows on wet soils would cause less damage than larger cows. Although the Holsteins do leave bigger hoof prints in the soil surface and thereby leave more hoof area behind in the pastures (graph on left above), there is no significant difference in the static pressure created in the hoof print area of the soil (table on right above).

(Editor's notes: This piqued my curiosity. I used the citation information that Larry gave and did a search to get the whole research paper. I like Irish dairy cow pasture research as it fits very well with what our Northeast dairy graziers have to deal with, except our graziers are not as enamored with perennial ryegrass as they are (our winters are too cold and summers too dry/hot). Ireland has mild winters and rather cool summers. So, here is the rest of the story.

Although soil compaction was not affected much, poaching (pugging) of pastures was significant as seen in the figure below. What was interesting about this figure is the impact stocking density has on hoof print depth (HPD), hoof prints are deeper in paddocks stocked at a higher density. However, the annual stocking density is not that much higher, 1.08 cows per acre versus 0.98 cow/acre. HPD is quite different even though the stocking density is not. It actually is misleading to say low and high stock density based on the annual stock density. They also determined stock density based on the number of cows per hectare at 4 different times during the grazing season. These stock density numbers are much higher (2-4 times higher) in the spring and mid-summer of 2011 and 2 times higher in the spring of 2012 (a very wet year that caused cows to be pulled-off the pasture altogether at times). 2011 was a truer picture of day-to-day stocking density when cows were not pulled-off due to soils being too wet. It better reflects the true stocking density that the occupied paddocks received at those times.



Effect of breed, on SSD (grey columns, no significant difference) and HPD (dashed line, P < 0·01), and effect of stocking density on SSD (white columns, P < 0·001) and HPD (solid line, P < 0·001), error bars show the treatment S.E.M.

Soil surface deformation (SSD) was not significantly different between breeds, but the slight difference in stocking density did significantly deform the soil more at the higher stocking rate than the “low” one. SSD coupled with compaction at depth results in increased soil resistance and reduced pore space, which affects both shoot and root growth. Plant growth may also be reduced by direct effects of poaching (pugging) including plant injury, fragmentation, and burial. The resistance of soil to deformation is dependent on soil moisture; however, intensively grazed grassland is often situated in regions with high rainfall. The extent of soil damage in poorly drained soils is dependent on factors that are fixed (soil type and climate) and non-fixed (animal live weight, stocking density and grazing duration). The non-fixed elements may be managed to overcome soil and pasture damage [Tuohy et al., 2014]. In this experiment, Tuohy et al. found SSD was greater at the higher stocking density (P < 0·001, 0·11 v. 0·10 m/m, S.E. 0·0020 m/m) and was affected (P < 0·05) by an interaction between year and stocking density: Stocking density affected SSD in both years, but more so in 2012 (Table 3). SSD was significantly correlated with HPD (y=2·46x+ 12·29, R2= 0·75, P < 0·001). Mean SSD was lower (P<0·001) in 2011 (mean± S.D.), (0·07 ± 0·042 m/m) compared with 2012 (0·14 ± 0·056 m/m). Mean HPD was lower (P < 0·001) in 2011 (28 ± 11·9 mm) than 2012 (48 ± 17·1 mm). Soil surface deformation was not affected by breed but was affected (P < 0·05) by the interaction between year, breed, and stocking density.

Table3. The effect of dairy cow breed (Holstein-Friesian and Jersey × Holstein-Friesian), at two stocking densities (low; 2·42 cows/ha and high; 2·66cows/ha) and year on HPD (mm) and SSD (m/m)

	Dairy cow breed				Stocking density				S.E.M.						
	2011		2012		2011		2012								
	HF	JX	HF	JX	L	H	L	H	Year	Breed	Stocking density	Year × breed	Year × stocking density	Breed × stocking density	Year × breed × stockingdensity
Hoof-print Depth (mm)	29	27	49	46	26	30	43	52	0·5 (P < 0·001)	0·5 (P < 0·01)	0·5 (P < 0·001)	0·7 NS	0·7 (P < 0·01)	0·7 NS	1·1 (P < 0·001)
Soil surface deformation m/m	0·07	0·07	0·14	0·14	0·06	0·07	0·13	0·15	0·002 (P < 0·001)	0·002 NS	0·002 (P < 0·001)	0·003 NS	0·003 (P < 0·05)	0·003 NS	0·004 (P < 0·01)

HF, Holstein-Friesian; JX, Jersey×Holstein-Friesian; L, low stocking density; H, high stocking density; NS, not significant

Poaching damage in this experiment was described by Tuohy et al. as follows. “HPD as shown in the figure on the previous page was greater under the HF cows (P < 0·01, 39 v. 37 mm, S.E. 0·5 mm) and was affected significantly (P < 0·001) by the interaction between year, breed, and stocking density in table 3 above. HPD was deeper (P < 0·001) at the higher stocking density (41 v. 35 mm, S.E. 0·5 mm) and was affected (P < 0·01) by an interaction between year and stocking density. Stocking density had an effect on HPD in both years, but this was more pronounced in 2012.” This is shown in table 3 above, difference in HPD values under stocking density by year.

Tuohy et al. described the effect of treading on poaching damage in this 2-year experiment. “While there was no effect of breed on SSD and only a slightly higher HPD imposed by HF cows, there was a clear difference in poaching damage between the stocking density treatments, particularly in 2012 when it was rainy. This difference is due to the effect repeated loading had on soil strength. A higher stocking density resulted in a greater frequency of hoof-soil interactions and a higher amount of surface damage, which was further made worse by the wet conditions.

The repeated treading of wet soil increases the depth to which the soil is weakened (Mullins & Fraser 1980). Thus, partly poached soil is more susceptible to subsequent poaching as it is softer and wetter (Gradwell 1968). This process may also account for some of the difference in HPD recorded between breeds during the experiment. Since an HF hoof is 1.17 times larger than a JX hoof, HF treaded on 0.17 more of the pasture area than JX at each grazing. While the loading pressure is the same (see table below), the intensity of loading is increased, in much the same way as the intensity of hoof-soil interactions is increased with higher stocking rate. The higher poaching damage in 2012 was due to the soil being above its plastic limit throughout the grazing season. The plastic limit of a soil is the gravimetric water content (GWC) at which a soil changes from being friable to being plastic, and represents the lowest water content at which pugging and poaching may occur (Drewry et al. 2008). Analysis of the soil at 0·00–0·10 m. depth, found the plastic limit was 0·43 g/g GWC. In 2011 this threshold was not breached until November when mean GWC was 0·51 g/g. Soil samples taken in 2012 show soil GWC was continually well above the plastic limit, ranging from 0·56 (August) to 0·68 (November) g/g. In this scenario, soil deformation was the dominant effect of treading during grazing."

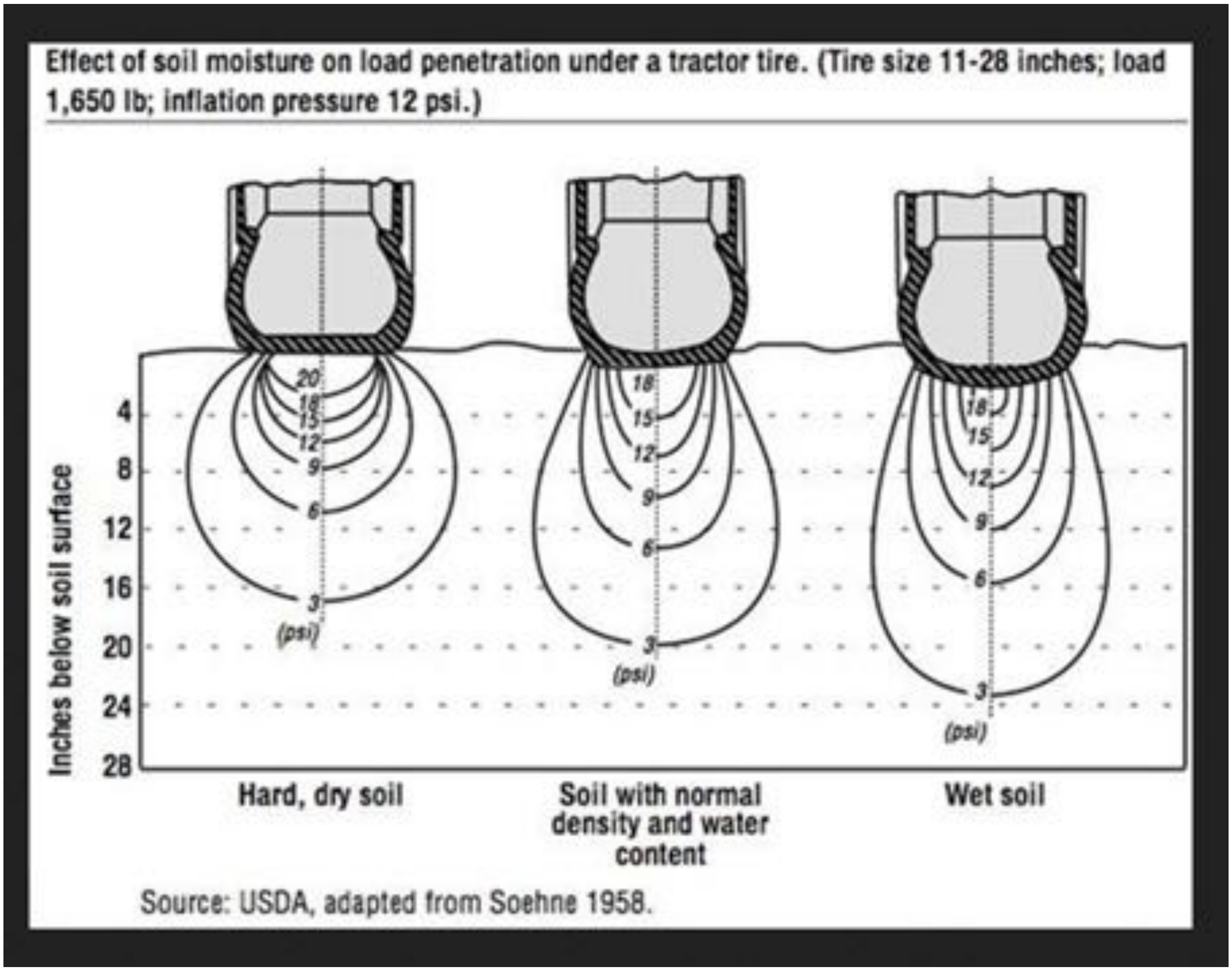
Cow weight 1,115 to 1,278 pounds

Total (kPa)	Total psi	psi per hoof Standing	psi per hoof Walking
214	31.0	7.75	15.5
218	31.6	7.9	15.8

From Tuohy et al., 2014

Note in the table above that an increase in cow weight of 163 pounds does not give the same commensurate increase in soil loading. However, there is a doubling of the pounds per square inch (PSI) exerted by a cow when walking instead of standing still. The more the cows have to walk around in search of forage to eat, the more pugging of the pasture soil surface. In larger pastures, this pugging can become more concentrated as a cattle trail when going back and forth to shade, water, feed bunk, or gate opening. The cattle trail becomes a smoother surface to walk on as it gets established and is then preferred over a tussocky pasture produced by pugging.)

The figure below shows three different load penetrations of a tractor tire as the soil moisture goes from dry to wet. The temptation is to harvest dry hay or haylage off pastures that are past their prime for grazing. This often happens after wet weather has stopped or slowed down cycling livestock through every paddock, especially during the spring flush of forage growth. Due to the time of year when there usually is excess pasture forage in relation to livestock demand, the better-laying pastures many be set-aside for mechanical harvest. They could very well be the ones that are the wettest. It is bad enough to have to harvest stored forage at that time with the risk of putting up poor quality forage, but deep soil compaction and rutting can occur as well when driving harvest machinery across the field if the soil is wet enough to be compressible.



Note that as going left to right in the figure, tire sinks deeper into the soil and soil compaction extends deeper into the soil.

Larry, in closing, summarized the impact of soil compaction on soil Health:

- Converts granular structure to platy structure in the topsoil,
- Loss of pore space – Macro pores destroyed first,
- Water infiltration reduced,
- Water movement through the soil profile reduced by deep compaction,
- Soil oxygen content is reduced,
- Soil microorganism activity is reduced,
- Carbon dioxide (CO_2) content rises,
- Gas exchange rate with atmosphere reduced, and
- Soil remains anaerobic much longer.