Soil Compaction during Forest Grazing

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Livestock grazing in forests and woodlands is much more common than many people realize. About ¼ of all U.S. forest and woodlands are grazed by livestock. This is about 13% of the total land grazed in the U.S. and roughly equals the total area of improved pastures and grazed croplands, combined. Foresters have often discouraged livestock grazing in timber plantations because of fears that trees will be browsed, debarked, or stepped on. Once they are reassured that we can safely graze the plantations without damaging trees, the next silvicultural concern is often soil compaction. Although quite a bit is known about soil compaction from farm and logging equipment, much less is known about soil compaction by livestock in forests and pastures. Since trees often grow faster with well implemented grazing, and forage plants appear to regrow rapidly after livestock leave, many range managers have tended to dismiss the importance of soil compaction in grazed forests. A study from British Columbia, published in the Journal of Range Management (Krzic et al. 1999) caused me to rethink that proposition and, in the process, to refine my views of what soil compaction is, how it is caused, and how it effects plant growth.

What is Soil Compaction?

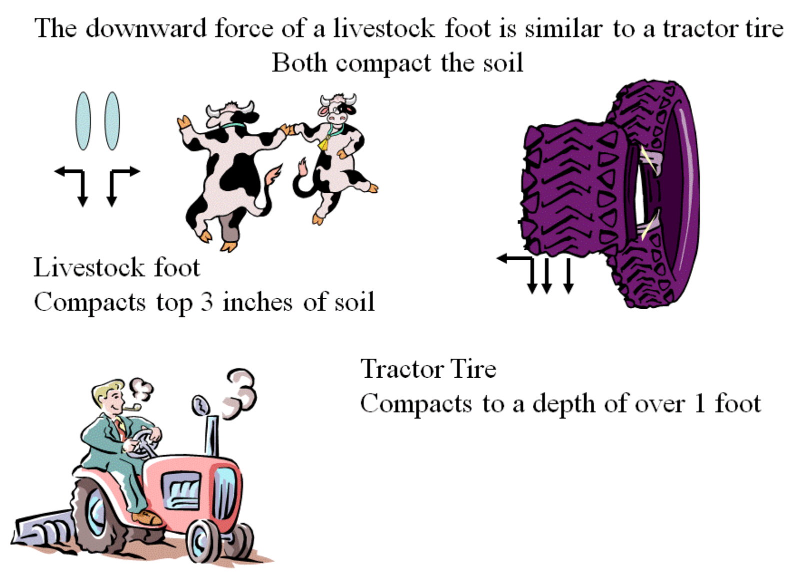
Cattle grazing in young B.C. lodgepole pine plantations increased soil bulk density and soil penetration resistance. We often use these two soil properties, along with soil porosity, to measure soil compaction. Soil is similar in structure to a piece of bread. It is mostly a series of holes (pores) joined by a matrix of mineral soil and organic matter. The holes are squeezed together as soil is compressed by gravity, animal foot pressure, or equipment wheels. The largest, air filled pores are the first to crush and be lost, while smaller, water filled pores are much more stable under pressure. Only very severe compaction will crush the small pores where water is stored, and actually squeeze water out of the soil. You can achieve this same effect by compacting a piece of bread. Initially, the bread just gets smaller and denser as large pores are crushed. Continued pressure begins to crush smaller pores, releasing their stored water. The bread now becomes wet and "doughy".

Movement of water and air into the soil is immediately reduced by loss of the large interconnected pores during initial compaction. This reduces water infiltration and soil aeration even under moderate levels of compaction. The loss of pore connectivity may be more important than the reduction of total large pore space in reducing water and air movement through the soil. Generally, once these large pores are crushed, they do not spring back after the pressure is removed. As air is squeezed out of soil, what remains is the heavier mineral soil and soil organic matter. So, the weight of soil per cubic inch of volume (soil bulk density) increases. It is unusual to compact soils to the point that even the smaller pores are crushed. So, compaction generally does not reduce soil water holding capacity. To the extent that larger, air-filled pores are squeezed down to become smaller water-holding pores, soil water holding capacity of soil may even increase with moderate compaction. Because roots must now try to growth through denser soil with fewer interconnected pathways to follow, soil resistance to penetration (soil strength) increases with compaction.

It is important to note here that we are talking about compaction of unsaturated soils. The water filled pores of saturated soils are less easily compressed than the air-filled pores of drained soils, so pressure is more fully transferred from the hoof to the soil matrix. When soil is saturated, even moderate pressure expels water from the larger flooded pores. The lower structural strength of wet soils, particularly those with considerable clay content, along with the expelled water that serves as a lubricant, allows even relatively small pores to collapse and the soil to flow around the hoof. The resulting creation of deep hoof prints in wet pastures has been called "poaching" or "pugging". Pugging is generally very undesirable because it reduces soil water infiltration, soil aeration, soil water storage capacity, and increases soil strength, all of which depress plant growth. The many hoof-sized holes punched into pasture soils during pugging tend to collect water. Making the soil surface wetter and more susceptible to continued pugging.

Are livestock heavy enough to cause soil compaction?

Evidently, the answer is yes. The issue of how much pressure is placed on the soil by animal hooves is surprisingly complicated. The simplest approach is to just divide the weight of an animal by the load-bearing surface of its feet. A more refined calculation takes into account that moving animals may have one or more feet off the ground as well as having a downward as well as forward motion of their body weight as they travel. The general result of such calculations is that cattle, sheep, and humans can easily exert as much downward pressure on soil as do agricultural tractors, and unloaded forestry harvest equipment. However, the total amount of pressure exerted is



not the whole story. The area over which the pressure is applied is also important. When the pressure is exerted over a very small area, such as a sheep or cow's hoof, some of the soil can respond by moving to the side as well as downward. This helps to dissipate the load near to the soil surface. Larger pressure sources such as a broad agricultural tire or a caterpillar track, predominately transfer their loads downward and can compact soil to a much greater depth. Therefore, soil compaction by livestock is generally concentrated in the top few inches of soil while heavy equipment compacts soils to a depth of well over a foot.

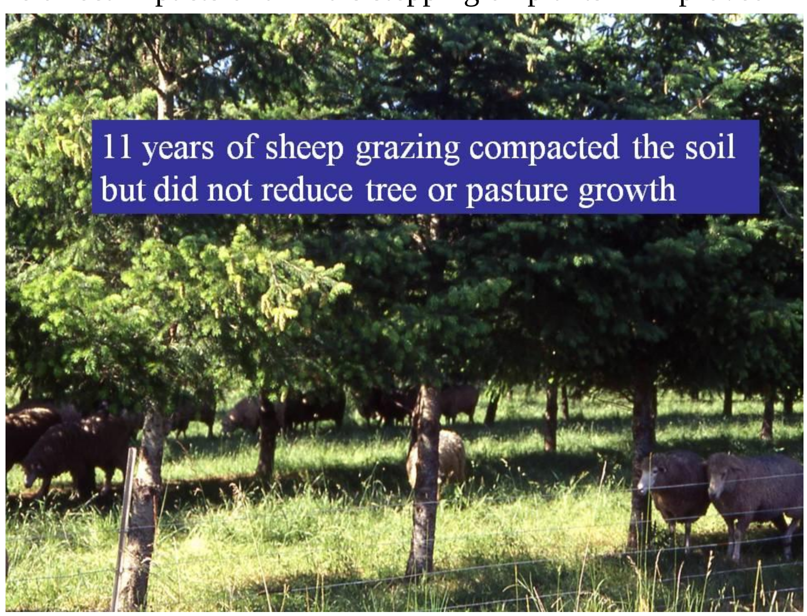
Is Soil Compaction a Bad Thing?
Soil compaction may be beneficial or detrimental depending upon how compact the soil is when you start. There is a widely held myth that plants roots grow downwards into moist soil because they are seeking water. In fact, roots grow along the path of least physical and physiological resistance. That may be down, it may be up, or it may be sideways. Physical resistance of a given soil to root penetration decreases as it becomes more plastic with increasing moisture content.

Roots prefer to grow through moist soil because it is easier for them to penetrate than drier soil. Roots need air to convert sugars into energy, just like the top. They may be excluded from very dense or seasonally flooded soil layers by lack of soil oxygen. A few plants, such as lodgepole pine, have solved this problem by developing interconnected voids within their stem and root tissues that allow internal movement of oxygen from the top to the roots of the plant. However, most plants have trouble rooting in poorly oxygenated soils. In most cases, soil compaction is a bad thing because it hampers root growth by increasing the physical resistance of the soil to penetration (increases soil strength), reduces soil aeration, and reduces the proportion of rainfall that enters and wets the soil (reduces infiltration). These problems are especially acute on clay soils. On the other hand, sandy-loam soils, sands, and newly plowed seedbeds may be too loose for optimal root growth. Such soils have lots of air filled pores, but few small water-holding pores. In such cases, roots do not have contact with enough water and nutrient containing pores to get the resources that the plant needs to grow. We compact the soil over seeds in plowed fields to improve contact between the seed and the soil and to form smaller water-holding pores from the numerous larger air-filled pores. Likewise, moderate compaction of sandy soils by livestock grazing may increase root and plant growth.

We should keep in mind that soil compaction is a **natural and dynamic process**. Gravity is the major force compacting soils. The weight of a layer of soil compacts the soil beneath it. The downward force of gravity applied to the soil surface by any object in contact with it compacts the soil. So, for instance, the weight of a tree is transferred down to the soil, which is compacted by the load. Interestingly, trees and other woody vegetation, also compact soil through root expansion. It is not unusual to see trees that have formed a pronounced mound under their trunk by simple expansion of roots over many years pushing the soil up and away from the trunk. This lateral compression compacts nearby soils. The current compactness of soil is a dynamic equilibrium between these compactive factors and restorative processes that uncompact soils. Restorative processes are rather poorly understood and documented. Shrinking and cracking of vertic clay soils, freezing and thawing, activities of ants, worms, and other soil microfauna, and the formation of fine root channels by plants are frequently mentioned restorative forces. The ability of these restorative forces to restore soil physical properties of rangelands after grazing is poorly documented and understood.

Does Compaction Reduce Plant Growth?

According to a extensive review of published literature by Greenwood and McKenzie (2001), grazing does indeed compact soil. However, it is unusual for livestock treading on drained soils to sufficiently compact soils to hinder plant growth. Indeed, many of the studies that showed increased soil strength, and increased bulk density after grazing failed to show any associated reduction in plant growth. Unless soils are very compact to start with, it takes considerable compaction to make them dense enough or poorly aerated enough to hinder plant growth. Grazing livestock may damage vegetation by physically stepping on plant crowns or surface roots as well as by compacting soils. There is not a lot of credible research that separates these two co-occurring events. However, it appears from the research available, that soil compaction is of minor importance compared to the direct impacts of animals stepping on plants in improved pastures. Treading immediately disrupts plant growth by breaking or kinking plant leaves, stems, or roots. Roots or stems that are not actually severed may be opened up to infection which then destroys the point of entry and can spread to nearby healthy tissue. The more open nature of semi-arid rangelands and open canopied dry forests should make direct trampling of plants much less common than in hay meadows, riparian strips, or other meadow-like vegetation. Likewise, the dense layer of fine roots which Douglas-fir and many other trees maintain very near to the soil surface may be particularly vulnerable to direct trampling damage. My experience in managing Douglas-fir agroforests, is that spring sheep grazing on clay soils, even at high livestock density, does not interfere with either tree or pasture growth (Sharrow et al. 1996), despite increased soil bulk density, reduced soil porosity, and lower soil water infiltration rate (all signs of soil compaction) under grazing (Sharrow 2007).



Should Soil Compaction be an Important Issue in Forest Grazing?
Soil compaction is a natural process. Livestock grazing contributes to this process by compacting soils near the surface where the restorative processes of plant organic matter addition, fine root growth, wetting/drying, freezing/thawing, and microfauna activities are most active. The net effect of periodically grazing unsaturated soils over a period of years is generally soils that are denser, more resistant to penetration, and have lower water infiltration rates. Forested rangelands in the western U.S. are most frequently used as summer-fall range, when soils are not saturated. It is unlikely that responsible forest grazing management practices will sufficiently compact soils to reduce tree or forage growth. Direct treading damage to shallow tree roots is much more of a concern than is soil compaction. The presence of a thick duff layer in older tree stands should be an effective protection for superficial roots. Care should be taken when grazing young stands, particularly on steep slopes to see that soil is not displaced by animal hoof action. However, grazing often increases tree growth in conifer plantations compared to ungrazed plantations. This suggests that either soil compaction and direct tredding effects are inconsequential, or that they are more than compensated for by the positive effects of weed control by livestock.

For further reading see the following articles:

Gifford, G.F., and R.H. Hawkins.1978. Hydrologic impact of grazing on infiltration; a critical review. Water Resources Research, Vol.14, pages 305-313.

Greacen, E.L., and R. Sands. 1980. Compaction of forest soils: a review. Australian Journal of Soil Research, vol. 18, pages 163-189.

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Krizic, M., R.F. Newman, K. Broersma, and A.A. Bomke. 1999. Soil compaction of forest plantations in interior British Columbia. Journal of Range Management vol. 52, pages 671-677.

Sharrow, S.H. 2007. Soil Compaction by grazing livestock in silvopastures as evidenced by changes in soil physical properties. Agroforestry Systems 71:215-223.

Sharrow, S.H., D.H. Carlson, W.H. Emmingham, and D. Lavender. 1996. Productivity of two Douglas-fir/subclover/sheep agroforests compared to pasture and forest monocultures. Agroforestry Systems 34:305-313.