In her closing Lora explained the derivation of the farm name, Stonefen. Since New Hampshire was glaciated and has many outcroppings of bedrock, the stone part of it is easy to imagine. Fen is a bit different. It is an English term whose meaning is lost on most Americans. A fen is a low-lying wet land with grassy vegetation; usually it is a transition zone between land and water. They are characterized by their distinct water chemistry, which is pH neutral or alkaline, with relatively high dissolved mineral levels but few other plant nutrients. This is why grass grows so good on the farm and cattle do well on it. Most areas in New England are on acidic glacial till and need agricultural limestone added to them to produce good yielding, nutritious forage crops.

The Conference adjourned for the evening. It reconvened on January 16 at 8:00 AM with session 5.

Session 5 – Pasture Soil Compaction - Identification and Remediation

A. Fay Benson, Small Dairy Support Cornell Univ. SCNY Regional Team - Education Coordinator NY Dairy Grazing Apprenticeship & Project Manager NY Organic Dairy Initiative, Cortland, NY moderated this session and was its first speaker. The title of his presentation was “Identifying and Quantifying Pasture Soil Compaction”.

Fay covered four topics:

- Identify indicators of soil compaction.
- How does compaction affect soil functions?
- Review remedies for compaction, and
- Data from “Pasture Compaction Ratio”.

Grazing has major impact on soil health; it can be good or bad, as seen in the two pictures below.

The good: Tall grass with deep roots provides: Adequate Feed per bite reduces walking, soil protection from drying, and decreases water runoff and soil erosion. More rainfall infiltrates into the soil instead of running off during heavy rains. This increases available soil water to grow more grass. Rotational grazing allows for wildlife diversification since small parcels are grazed at a time instead of a whole pasture being grazed and treaded on. This all helps create an active biological cycle.

The Bad: Over-grazing along with heavy use areas at single gate entry points, under shade, near stationary feed bunks and mineral feeders on extensive pasture areas leads to exposed soil which inhibits water infiltration and produces less available forage per acre. Little rainwater infiltrates into the soil due to soil compaction from continual hoof traffic. The right picture above looks more like an exercise lot than a pasture. For sure, the "pasture" is not being depended upon very much for forage intake.

The concentrated animal feeding operation (CAFO) system is degenerative not just on-site but in the supply of its feed. The feed that is grown to feed cattle in feedlots is grown on cropland that can be soil degenerating depending on field conditions, such as slope, erosivity of the soil, ease of water infiltration, climate, and farm cropland management, such as amount of tillage used to plant the grain crop, the use or nonuse of contour farming and terraces on sloping ground, use of grassed waterways or not in concentrated flow areas. Additionally, methane gas related to manure pools is increased as CAFO's create a mix of fecal material and urine and this mix is likely to be anaerobic most of the time in wetter climates or in manure storage facilities.

Finishing meat-type ruminants on pasture using intensive rotational stocking can create similar average daily gains using a lot less energy and produce a less fatty meat. It can be done on perennial pastures where tillage is infrequently occurring and where annuals are used can be done with considerably less tillage or planted without any previous tillage (no-till planting). Soil structure is greatly improved when soils are tilled infrequently or not at all. Organic matter is higher where a dense sod with a fibrous root system exists. Belched methane may be similar in both systems, but methane generation from fecal matter separate from urine deposits will be less especially if dung beetles and other decomposers are active in well-managed pastures with healthy soils.

Fay had an epiphany to pasture compaction issues when he began looking closer at conditions under fences in pastured areas. He found that the:

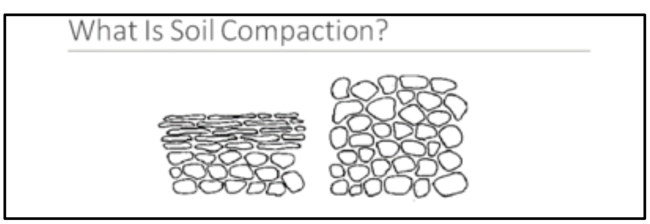
- Fence line soil level was 6-8 inches higher,
- Fence line had more pasture grasses,
- Pasture had more sedges, and the
- Farmer had not noticed the difference.

Compaction happens over decades. Most farmers do not realize that they have it. Not only the functions of the soil are impacted but also the types of plant which grow change. Sedges appear in the pasture due to the soil compaction lowering water infiltration into the soil. Water ponds on the surface creating a shallow wetland that favors the growth of sedges (a water-loving plant) over grasses with root systems that dislike growing in on-again, off-again water-saturated soils. Soil compaction makes it harder for roots to penetrate the soil and get enough nutrients, water, and oxygen to grow well so forage yields are reduced. Most noticeable difference in forage yield is to have a hayfield side-by-side with a pasture on the same soil type (especially a continuously occupied one), the grass in the hayfield will be noticeably taller in the spring at heading than the pasture where spot grazing allows some areas to grow ungrazed early in the season and sport seedheads (or a pasture not stocked immediately in the spring as the herd is elsewhere).

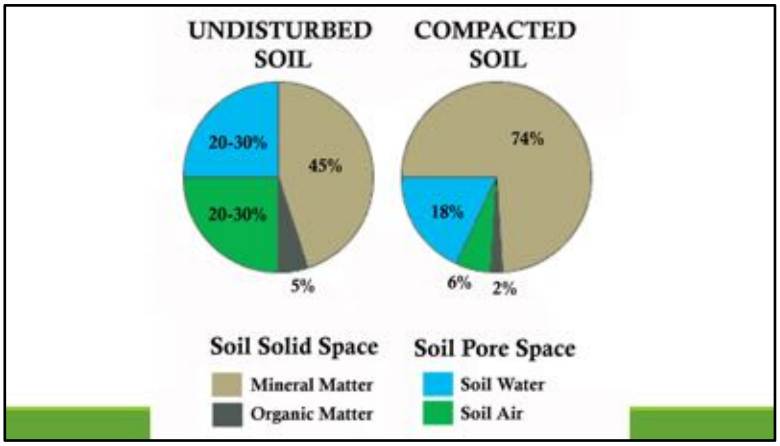
Below is a figure with a comparison of soil health between soil samples taken under-the-fence and in-pasture that Fay sent to Cornell to be tested and rated by the Cornell Soil Health Assessment. These samples were collected in April 2015. Some of the values were adjusted according to Version 3 of the Assessment that was published in 2016. In doing so, the under-the-fence soil was even more markedly different from the one in-pasture. The three worst rated soil indicators from the in-pasture sample were soil surface hardness (0-6 inches), subsurface soil hardness (6-18 inches), and soil aggregate stability. These are depicted in red on the assessment sheet for the in-pasture soil sample. The constraints column is filled out for these three indicators. These 3 factors greatly influence plant rooting depth and exploration, water infiltration into the soil and percolation through the soil, and nutrient and water access by the roots. Soil aggregation also affects soil air movement, soil surface crusting and sealing under intense rainfall, soil erosion, and water runoff. If the soil aggregates are not stable, all the things mentioned above get bad.

Comprehensive Assessment of Soil Health – The Cornell Framework (Version 3.2). Adjusted values entered and color coded for aggregate stability, organic matter, ACE soil protein index, and respiration for the under-the-fence report on the left and organic matter only for in the pasture on the right. The under-the-fence aggregate stability value was much higher than the in-pasture value so the rating was corrected. Medium textured soil curve used for appropriate indicators.

(Editor's Note: For people not familiar with some of the indicators, a few of them are explained as follows. The Autoclaved Citrate Extractable (ACE) Protein Index is an indicator of the fraction of the soil organic matter that is present as proteins or protein-like substances. This represents the large pool of organically bound nitrogen (N) in the soil organic matter, which microbial activity can mineralize, and make available for plant uptake. Respiration is a measure of the metabolic activity of the soil microbial community. It is measured by capturing and quantifying carbon dioxide (CO_2) released from a re-wetted sample of air dried soil held in an airtight jar for 4 days. Greater CO_2 release is indicative of a larger, more active soil microbial community. Active carbon is an indicator of the small portion of soil organic matter that can serve as a readily available food and energy source for the soil microbial community, thus helping to maintain a healthy soil food web [Moebius-Clune, B.N. et al., 2016].)



Compaction occurs when a force compresses the soil and pushes air and water out of it so that it becomes denser. Compaction is more severe when the soil is wet and less able to withstand compression.



When a soil is compacted air space is squeezed out of the soil which can be seen in the figure to the left. Root growth takes place in the air spaces around soil particles; therefore, soil compaction furthers mechanical resistance to root penetration, which limits the nutrient and water uptake. It also inhibits the emergence of seedlings and spreading of rhizomes. Clay textured soils are most easily compacted, while sandy soils are the least. Alluvial soils in bottomlands and fine textured silt loams are also easily compacted. With compacted soils, organic matter is reduced as well as overall soil health.

Measuring Soil Compaction using a penetrometer is a quick way to compare soil strength, but it has its weaknesses. It measures resistance to root penetration in soil in pounds per square inch. This resistance changes as soil moisture changes; the drier the soil, the greater the resistance. It is good for comparison on the same soil texture but different situations on the same day and time, such as under-the-fence and in-the-pasture. It is not useful as benchmarking tool as soil moisture conditions will vary considerably over time and on different soil textures. Measurements should be taken when the soil is near water-holding field capacity, but this is hard to judge without more instrumentation.

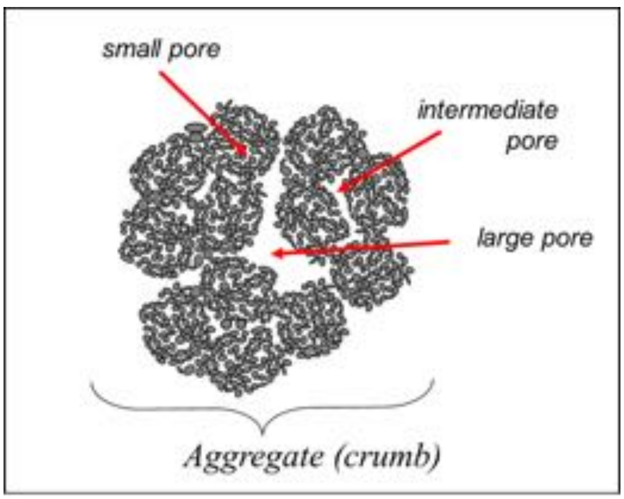
Soil penetrometer being pushed into the ground. A dial above the handles measures soil resistance. Lower inset shows the different tips than can be put on the business end of the probe.

Compaction and exposed surface soils

- Impede active root growth,
- Cause ponding, runoff, erosion, nutrient loss,
- Limit soil aeration and soil biology,
- Limit water infiltration: therefore, drainage and storage, raises drought frequency and severity,
- Cause stress for plants, leading to decreased yields and quality and greater input expense.

Poor nutrient management

- Limits forage growth in case of nutrient deficiencies and soil acidity, affecting the above
- Where livestock are allowed to camp near shade, permanently located water troughs, gates, and mineral feeders, soil nutrient levels can be too high at or near these spots.

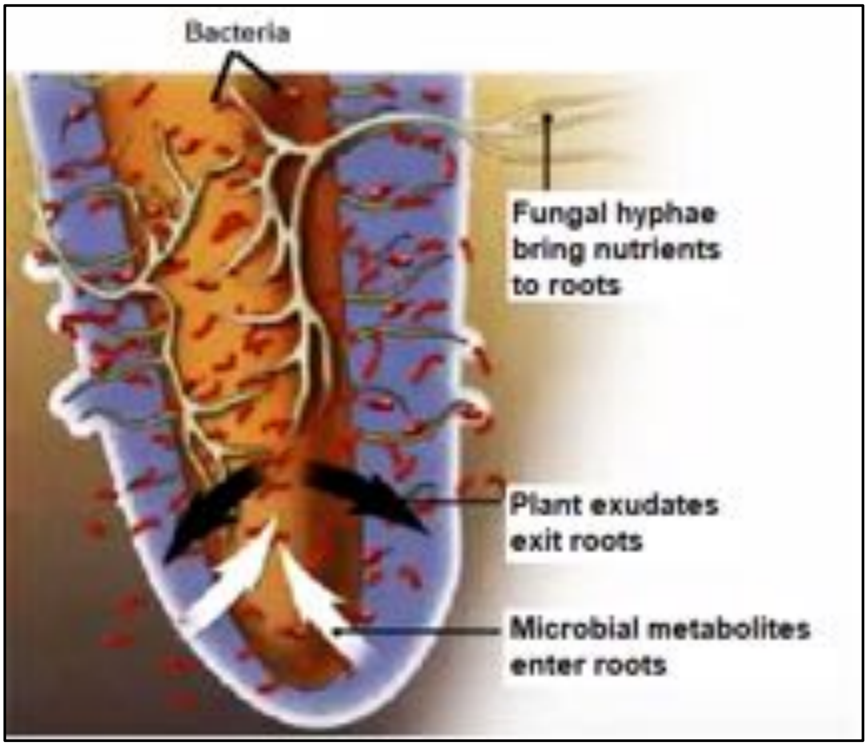


Soil aggregate or crumb schematic, soil particles glued together by root exudates to form a granular composite soil particle similar in appearance to coffee grounds.

Badly pugged pasture from cattle traffic; wet, slow to dry

Soil aggregates are key to a healthy soil. Large ones allow water and air to move freely throughout the soil. Small ones hold water for times of drought as they cut down on air space size so water can adhere to aggregate surfaces rather than move out of the root zone by gravitational forces. All aggregates keep the soil biology aerobic. When destroyed by compaction, the soil can turn anaerobic releasing methane and other undesirable gases. They aid soil porosity. Porosity is important for:

- Aeration,
- Permeability (the ability of a soil to allow gases or water to circulate through it),
- root growth,
- Water availability, and
- Biological habitat (plant roots and microorganisms).



Root tip schematic showing its rhizosphere where the root interacts with soil bacteria and fungi. Legume roots interact with soil bacteria called Rhizobia as a mutualistic host providing food for the bacteria while they fix nitrogen, a plant food, for the host legume.

The rhizosphere is where roots and microbes exchange nutrients. Soil compaction inhibits nutrient exchange between plants and microorganisms in the soil, harming plant growth. As seen in the schematic above, roots give off exudates which feed soil microbes and are the glue that forms soil aggregates. As the roots explore the soil and grow, they create just enough pressure to compress these aggregates into water stable ones that can resist being dissolved and suspended in water.

Pasture soil compaction remediation: Nature vs Machine. Nobel Research Institute report said five out of seven studies showed no difference from aeration. (Editor's Note: Some research papers I have seen on this were poorly designed. In one case, not done on a pasture and the soils were not compacted very much to begin with. I suggest doing this work with on-farm studies.)
https://www.noble.org/news/publications/ag-news-and-views/2000/april/some-thoughts-on-soil-aeration-of-pastureland/
The Yeoman Plow debate:
University of Georgia: "Most research has shown that aeration is, at best, a temporary solution. Studies comparing fields with aerated vs. non-aerated areas tend to only show a difference in performance for 1-2 years."
As with row crop farming, to choose mechanical means to alleviate compaction is like taking the first drug, and eventually becoming addicted to tillage. It is trying to alleviate the symptom, but not cure the problem: pasturing livestock on soils too wet to have traffic on them, machine or

animal. Perhaps it means sacrificing a paddock or two when it gets rainy, but when there is no rotational grazing system, large pastures can be affected greatly either in localized areas or all over. If the ground is subject to frost heave in winter, some of this compaction can disappear on its own. Better to have only a few acres with compaction issues than on large pasture areas.

Preventing pasture compaction is a better alternative. The old adage that an ounce of prevention is worth a pound of cure is very apropos here. Flexible Management or Adaptive Grazing can be prevention strategies, such as:

- When soils are wet, move animals from sensitive soil types if possible. (Clay, Silty)
- Increase rest period if soils are low in OM.
- Decrease animal density if soil is prone to compaction.
- Alternate pasturing with hay harvests on pastures with compacted soils where machine work can be done easily. This will allow deeper root penetration.

Infrastructural means of preventing pasture compaction are:

- Good laneways confine compaction to a specific area (dairy cows – main laneway to milking parlor).
- Drainage will decrease time soil is wet and prone to compaction (Random or system depending on soil conditions: swales versus entire field stays wet for prolonged periods.)
- Increase watering areas and move often, not same spot each time paddock is grazed.
- Look into “No-Gate” system (beef and other meat animals, perhaps dairy).

How you feed your livestock can either reduce or heighten soil compaction. Feeding large round bales either in a feeder, or not, concentrates livestock activity around a rather large feed source that invites a lot of hoof traffic in a small area. Rolling out large round bales and limit feeding them with a hot wire would spread hoof traffic over a wider area as each bale can be rolled out in a different spot and spreading hayseed around more. This is shown in the picture at left below.

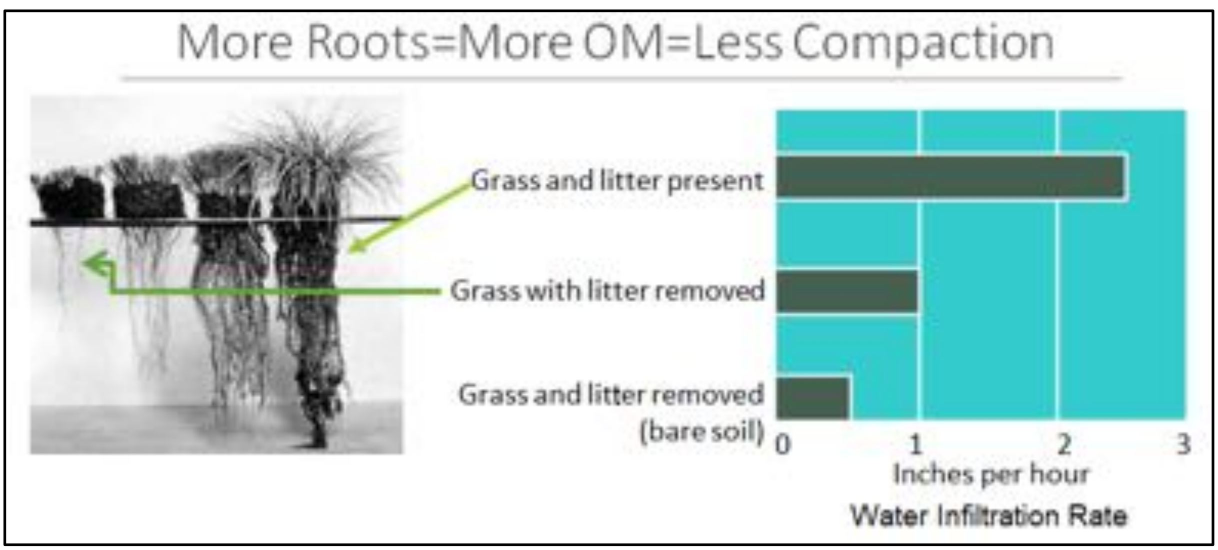
A portable oiler and mineral feeder being moved to the next paddock to be grazed. Locate at opposite side of paddock from water.

Removing leaves also affects the plant below the ground. If too many leaves (too much of each leaf) are removed, most of the stored energy to make new leaves is lost; the roots do not grow. As a rule, “taking half and leaving half” OF THE LEAF VOLUME allows some leaves to be removed

Grazing Management

% Leaf Removed	% Root Growth Stopped
10	0
20	0
30	0
40	0
50	**2 to 4**
60	**50**
70	**78**
80	**100**
90	**100**

while not stopping root growth significantly. Source: Dietz, 1999. (Editor's Note: Care must be taken on how this data is interpreted. Root stoppage alone is not a problem as long as once the grass is grazed, the grazing livestock are moved to another area with another ration of grass to consume and will not return to graze the grazed area again for 3 weeks to 6 weeks. Continually grazing the same grasses over time, will mean more than 50% of the grass is likely to be removed and root growth will be stopped for a longer period of time. Eventually this leads to the sloughing of dead roots as the plant can no longer sustain top and bottom growth simultaneously, especially for those grass species that store carbohydrate reserves to restart leaf or root growth in their leaf sheaths (orchardgrass and tall fescue). To replace carbohydrates means the grass must grow more leaf instead of roots since the leaves are needed to capture sun energy to produce carbohydrates during the growing season. Once leaf removal gets to 70%, it is likely some of the leaf sheaths are being bitten off with a loss of stored carbohydrates. Root stoppage is more complete, then. At 80 and 90 percent leaf removal, the stored carbohydrates will almost be completely consumed or the leaf sheaths damaged greatly. Rhizomatous or stoloniferous forage crops will be less damaged, this is why Kentucky bluegrass (rhizomatous) and white clover (stoloniferous) can proliferate in a closely grazed pasture while the more productive grasses and legumes will disappear over time. Their carbohydrates are stored in these underground stems (rhizomes) and on-the-ground stems (stolons). They are protected from grazing, but treading damage is a whole other matter. Soil compaction or excessive treading damage can end up hindering or ending their survival as well. Bare ground and goosegrass are at heavy use gate openings.)



More roots deeper into the soil improves soil organic matter with depth. Good ground cover improves infiltration rate. As soil permeability increases throughout the rooting depth due to the better soil structure that more organic matter and roots create, this keeps water moving downward to greater depths wicking it away from the soil surface - No backup (ponding) as if the drain pipe of the soil was plugged. With grass and litter removed, the surface soil seals shut, if it is silty or clayey, so little of the water infiltrates into the soil. Most will run off in a heavy downpour. If tilled recently, it will be loose and easily washed downslope. In a compacted pasture soil, bare soil will not erode much; it will almost be pavement, but any fecal material on it will easily be washed off downslope.

Fay cited a research paper on a 12-year sheep pasture grazing intensity study done in France entitled “Grazing triggers soil carbon loss by altering plant roots and their control on soil microbial community”. It had an interesting finding concerning how soil microbe fauna changed when the intensity of grazing increased. High disturbance grazing led to a decrease of soil fungi and a proliferation of Gram(+) bacteria that accelerated decomposition of old particulate organic carbon. (Editor’s notes: However looking back at a previous paper on the same study [Louault, F. et al., 2005] to get a full look at the methods and conditions underlying the study, the plant species of the pasture studied were mostly low-growing grasses and forbs due to their being grazed by sheep since the 1940’s. Quackgrass (couchgrass) was a dominant species unless under high disturbance, defined in this study as 3 grazing events about 2 months apart after a June hay cutting and 1 grazing event in mid-April before a June hay harvest each year. Sheep were removed once grass height was down to about 2.5 inches, measured daily until achieved. Bent-grass, velvet-grass, perennial ryegrass, and Kentucky bluegrass made up most of the grass ground cover in the high disturbance pasture while dandelion and Dutch white clover were the dominant forbs. If relating this to US conditions, this would be similar to a long-time continuously grazed naturalized pasture made up of European grass species and forbs. Short duration grazing where livestock are moved within 3 days or less and do not return for 3-6 weeks depending on grass growth or age (beginning of senescence) would be lax grazing compared to this study due to the shortness of the residual stubble left (~2.5 inches) when the sheep were moved. Low disturbance in this study was a single spring grazing by sheep in early spring each year until getting down to the 2.5-inch stubble height. A single yearly grazing is not going to be done on a commercial farm. Research and anecdotal findings here in the eastern US comparing organic matter in pasture soils in rotationally short duration grazed pastures and typical heavily-grazed continuous pastures has shown an increase in organic matter in the rotational pastures over that of continuously grazed pastures. Put and take continuously grazed research farm pastures do not capture what goes on commercial farms where no taking of livestock takes place, just more hay is taken to the pasture, or supplemental-feed back at the dairy barn or dry lot replaces pasture forage. A 2010 research paper by Franzluebbers and Stuedemann conducted in the southeastern US concluded “Contrary to nutrient source (organic or inorganic), how forage was utilized had an enormous impact on the temporal development of soil properties. When forage was hayed continuously, surface residue was low, soil bulk density was high, and soil organic C and N remained relatively unchanged. When forage was grazed by cattle, surface residue was low to moderate, soil bulk density was low to moderate, and soil organic C and N were sequestered at high rates. We tested two grazing pressures and found that surface residue C and N contents declined, soil bulk density increased slightly, and soil organic C and N sequestration rates remained unchanged with high grazing pressure compared with low grazing pressure. When forage was unharvested (similar to a Conservation Reserve Program management scheme), surface residue was highest, soil bulk density was low (similar to low grazing pressure), and soil organic C and N sequestration rates were intermediate between haying and grazing. Soil organic C sequestration at a depth of 0 to 6 cm (linear regression across 12 years) followed the order: *haying (0.04 ± 0.04 Mg C* ha^{-1} yr^{-1}*) < unharvested (0.23 ± 0.18 Mg C* ha^{-1} yr^{-1}*) < low grazing pressure (0.65 ± 0.05 Mg C* ha^{-1} yr^{-1}*) = high grazing pressure (0.67 ± 0.04 Mg C* ha^{-1} yr^{-1}*)*. Rates were lower than reported earlier in this (12-year) study due to a drought period that caused a temporary decline in soil organic C. Although broiler litter added significant organic C throughout the course of this study (2.4 ± 0.6 Mg C ha^{-1} yr^{-1}), its decomposition was high, resulting in statistically undetectable changes in soil organic C. Cattle grazing of mixed bermudagrass–tall fescue pastures can be considered a viable strategy to rehabilitate degraded cropland in the southeastern United States. Our data negate the perspective that only non-utilization of land will be the best strategy for rehabilitating degraded land." One could add rehabilitating long-abused pastures too.)

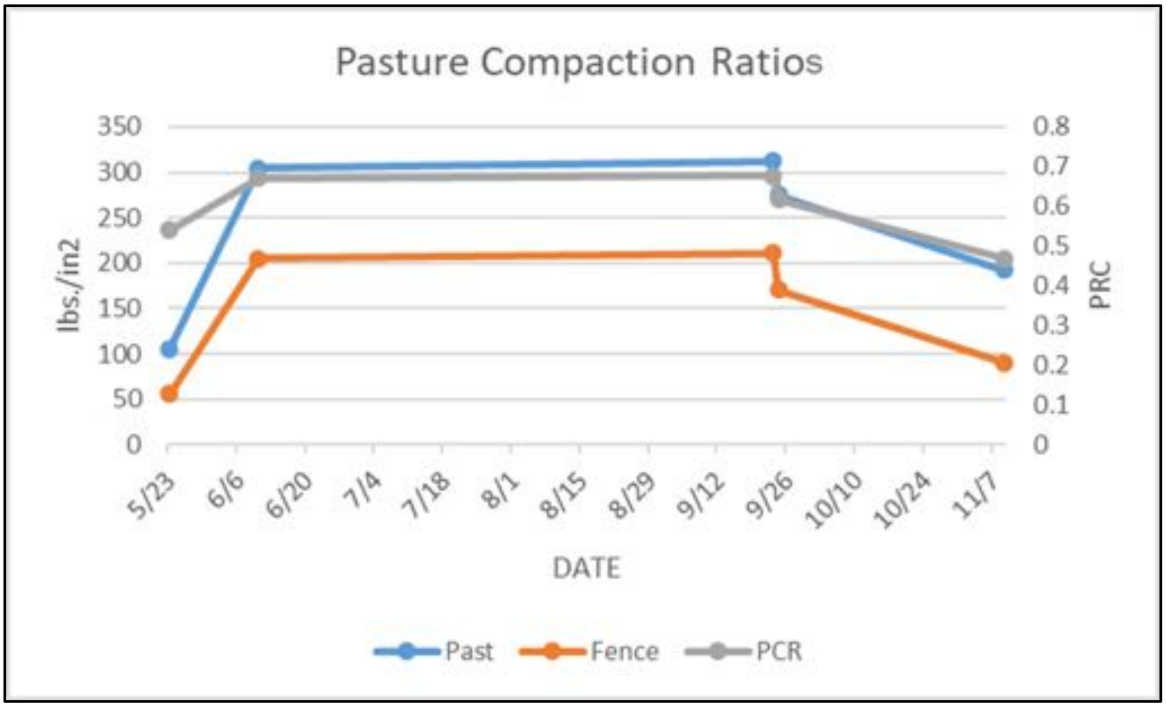
The reason for discussing soil carbon is in overgrazing or haying pastures there are effects below ground as well as the obvious stresses on forages. Negative changes in soil particle aggregation, bulk density, and soil carbon occur. As soil carbon and water stable aggregates decrease and bulk density increases, pasture soils are more prone to compaction. It worsens with more livestock traffic and allowing them access to pastures with soils wet enough to be easily squished.

A Northeast SARE grant project "Identification and Remediation of Compaction on Northeast Pasture Soils" is headed up by Fay. It seeks to accomplish these tasks:

- Convene educators from the Northeast for a Train the Trainers on soil compaction
- Provide educators with funds and equipment (Soil Health Trailer) for on farm education on soil compaction, and
- Enlist farmers and educators to collect data for Pasture Compaction Ratio (PCR).

New York Soil Health Trailer

Pasture compaction ratio to determine the difference in soil compaction between under-the-fence and in the pasture is being stressed as part of the train the trainers on soil compaction after they are made aware of the problem and its causes. The ratio between fence line and pasture is a definitive indicator that livestock traffic in the pasture is compressing the soils there even when invisible. The trainers are taught to retest as soil conditions change going from dry to wet and back to dry depending on the season and rainfall.



Here is an example of grazing season-long pasture compaction samples taken every two weeks. The pasture compaction ratio (PCR) shown as the gray line on the above graph is remarkably consistent even though the soil strength changes with time as soils become drier and then once summer is over and fall rains and cooler temperatures begin the soil strength decreases. For this pasture, the fenceline soil is always easier to penetrate with a soil penetrometer than the soil in the pasture. The PCR runs between 0.5 (half) to 0.7. This indicates soil compaction is occurring from hoof traffic. This may disappear overwinter with frost action if the pasture is not occupied during the winter months. The more sample times, the more precision there is in getting a true picture of how the PCR changes with time. Less frequent samplings will not give the amount of detail there is in the above graph.

What is the "Correct" Amount of Compaction? Silty and clayey soils are going to compress some if at all wet enough to be molded. When hoof prints become noticeable, serious compaction is beginning to take place. If hoof prints (pugs) hold water for more than a few hours, the soil at the bottom has sealed shut (no pore spaces) due to compression of the soil. This is serious compaction not readily solved and usually worsens. Prevention is a better solution. Soil drainage might be in order if it is a chronic problem and the field cannot be left ungrazed (deferred) due to the lack of drier pastures elsewhere to graze while the wet one dries out or forage quality at that pasture suffers too much in the meantime.

For the new year, Fay (afb3@cornell.edu) plans to engage more educators for on-farm presentations, collect more data points for PCR, and determine the repeatability of the PCR, and measure soil strength on an enclosed area to determine how time changes soil compaction.