EFFECTS OF NATURAL GAS WELL DEVELOPMENT, RECLAMATION, AND CONTROLLED LIVESTOCK IMPACT ON TOPSOIL PROPERTIES[1]

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Abstract. Stripping, stockpiling, and reapplying topsoil stimulates decomposition and loss of soil organic matter (SOM) by breaking apart soil structure and eliminating inputs of plant residues. Organic matter can be further decreased by stripping too deeply and diluting with subsoil. Studies of reclaimed coal mine sites in eastern Wyoming found an average of about 59 percent less SOM compared to adjacent undisturbed sites. Mixing of clays, salts, and sodium from subsoils into topsoil further reduces the ability of the plant community to recover once a site is reclaimed. Controlled livestock impact, achieved by confining and feeding hay to cattle, sheep, or goats at high stocking rates for short time periods on reclaimed areas immediately after seeding, may support reclamation success by adding organic materials of varying composition and improving seed-soil contact. Calculations of potential contributions of organic materials based on SOM levels of reclaimed coal mine sites in eastern Wyoming suggest about 412 cattle per ha per day would be required to bring SOM to predisturbance levels. Drier sites in southern and western Wyoming, for instance, with lower SOM contents would require about half that number. Hoof impacts are also reported to be beneficial, but the mechanism of the benefit is not clear. Packing the seed bed may improve seed-soil contact, but effectiveness of hoof impact compared to other methods is unknown. The number of accounts of the success of controlled livestock impact for reclamation warrants rigorous scientific study to define effects and mechanisms. This paper reviews literature on the effects of natural gas extraction activities (including reclamation) on soil properties and the potential impact of livestock activity on soil properties of these disturbed sites.

Additional Key Words: controlled livestock impact, soil restoration, soil degradation, soil organic matter.

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Introduction

Soils are complex, intertwined systems that determine the ecological productivity, resistance, and resilience of ecosystems. Soil systems develop over millennia of interaction with physical and biological environments to form soil horizons where the surface, or A horizon, is the most intensively altered by the environment through weathering, leaching, and inputs of organic materials.

The A horizon is generally the most fertile zone, but also the zone most vulnerable to erosion by water and wind (Hillel, 2004). Arid and semiarid soils are typically low in soil organic matter (SOM) and nutrients (Jenny, 1930). The A horizon contains greater concentrations of carbon and nutrients which are often lost through dilution when mixed with the B horizon (Ingram et al., 2005). Soil organic matter is an important component of soil quality as it determines many soil characteristics including nutrient mineralization, aggregate stability, water uptake and water retention properties (Doran et al., 1989). Well-developed A horizons facilitate infiltration of water and air that supports biological activity, but also slow decomposition and conserve organic materials by protecting them in stable soil structural units (peds) (Wick et al., 2009).

Subsoils, or B horizons, are typically zones of accumulation where clays, calcium carbonate, salts, and other materials that can be transported by water from the upper A horizon and deposited. In semiarid and arid regions, leaching of these ions into the subsoils produce horizons enriched in calcite or gypsum (Kraimer et al., 2005). Subsoils are important reservoirs for soil water but are much lower in nutrients and higher in clays and salts than A horizons.

Disturbances, such as those associated with natural gas extraction, severely alter physical, chemical, and biological soil properties. Reclamation goals are often set for re-establishing plant communities and rarely include repairing soils. Controlled livestock impact aims to improve soil properties to facilitate desirable plant establishment by increasing SOM pools and stimulating soil biological activity. This review will discuss how natural gas activities alter topsoil properties and the potential role livestock may play to negate these alterations.

Impacts of Stripping, Stock Piling, and Reclamation on Topsoil

Thin, nutrient poor topsoil, combined with potentially saline and calcite-rich subsoil reduce the resilience of arid and semiarid soil systems following drastic disturbances. Stripping and stockpiling topsoil, as is typically done during energy development activities, drastically disrupts the soil system and stimulates decomposition and loss of SOM by breaking apart soil structure that protects SOM. Removing and stockpiling topsoil has serious detrimental effects on physical, chemical, and biotic properties and usually results in a significant reduction in soil quality (Penderson et al. 1978; Severson and Gough 1983; Harris et al. 1989; Harris et al. 1993). Physical disruption of soil structure contributes to losses of SOM in much the same way that cultivation is known to degrade grassland soils: by exposing labile organic materials to decomposition that were previously protected from decomposition within aggregates (Six et al. 1998). Wick et al. (2009), found that C and N concentrations were impacted by the breaking apart of soil aggregates during topsoil stripping, leading to a significant decline of C and N in aggregate fractions.

Many studies show that stripping, stockpiling or hauling, and respreading topsoils significantly decreases soil organic matter content. Abdul-Kareem and McRae (1984) conducted research on soils stockpiled for 1.5 to seven years in the United Kingdom and found changes in the forms of available nutrients, increases in pH, greater bulk density, and lower organic matter content. Soil OM losses ranged from 26 to 63 percent based on contents adjacent undisturbed surface soils. They also reported lower microbial biomass carbon contents in stockpiled soils compared to adjacent undisturbed soils. In a study comparing management practices of soil stockpiling, Stahl et al. (2002) reported that stockpiling soils had a negative impact on SOM content, electrical conductivity (EC), total nitrogen content, mycorrhizal fungal spore content, and amounts of microbial biomass. Work by Stahl and others on recently reclaimed soils of eastern Wyoming coal mines shows that reclaimed sites have 44 to 79 percent based less SOM than adjacent undisturbed sites (Anderson et al., 2008; Ingram et al., 2002; Mummey et al., 2002; Wick et al., 2009). The time since reclamation did not have a consistent effect on the difference in SOM content between reclaimed and undisturbed soils. The most recently reclaimed sites of less than one year (Wick et al., 2009) and two years (Ingram et al., 2002) had 44 and 64 percent less SOM, respectively, than their undisturbed pairs, while a 20-year-old site showed a 67 percent reduction (Mummey et al., 2002). Ingram et al. (2002) found that reclaimed soils that had been hauled directly from a site being excavated to one being reclaimed, without stockpiling, lost more SOM than a nearby site reclaimed from stockpiled soils. This suggests that the physical disruption – stripping, loading, unloading, spreading, and cultivating – rather than stockpiling caused mush of the SOM loss. The length of stockpiling prior to reclamation is difficult to ascertain for coal mines that are disturbed incrementally and for long periods, but Ingram et al. (2002) estimate that the soil at their study sites had been stockpiled for periods ranging from several months to 20 years or longer. Stripping too thick a layer and diluting topsoils with SOM-poor subsoils may explain part of the measured difference between reclaimed and undisturbed soils. Other reasons include decreased plant organic matter input and decreased microbial activity (Mummey et al., 2002). Mummey et al. (2002) found elevated EC in stockpiled topsoils compared to undisturbed soil, which they attributed to mixing of subsoils into surface soils.

Successful restoration of a disturbed area is highly dependent on maintenance of soil quality, therefore, management practices that minimize destructive impacts of anthropogenic practices to the soil resource can prevent further site degradation and facilitate site restoration (Stahl et al., 2002). Controlled livestock impact has been described as one way to mitigate detrimental effects of stripping, stockpiling, and reclamation on topsoil, but the practice has not been scientifically evaluated.

Potential Role of Controlled Livestock Impact

While use of livestock grazing to maintain a desirable plant community is a relatively common practice used by both ranchers and surface mining companies (Popay and Field, 1996; Chapman et al, 1996), feeding hay to livestock on freshly reseeded reclamation sites is less common. In the controlled livestock impact approach, livestock are confined and fed hay for a short period immediately following reclamation and seeding of well pads. Unlike grazing, the animals are not consuming on-site vegetation and are removed prior to plant establishment. In Wyoming, the most common class of livestock, and therefore the most practical for this purpose, is cattle. Organic additions provided by controlled livestock impact include a wide range of materials of varying resistance to decomposition that provide nutrients necessary for plant growth. For example, fragments of hay (not consumed by the cattle), manure, and urine will all be added to the livestock-treated soil. These materials would be incorporated through trampling and hoof action. One benefit of this method may be replacement of SOM and associated nutrients lost during excavation, stockpiling, and reapplication of soil on disturbed areas.

According to the Natural Resources Conservation Service (NRCS), a typical 454-kg (1000-lb) beef cow produces 4.9 kg (10.7 lb) of manure per day (www.nrcs.usda.gov), which yields 1.1 kg (2.5 lbs) of dry organic material per animal per day (Van Vliet et al, 2007). Also, cattle typically waste about 30 percent of total hay fed on the ground, or as much as 8.2 kg (18 lbs) per animal per day for low-quality forage. This amounts to a total contribution of about 9.3 kg (20.5 lbs) of organic materials per animal per day.

Studies by Stahl and others show that eastern Wyoming sites reclaimed with topsoils stockpiled during coal mine development have an average of about 59 percent less SOM than adjacent undisturbed soils (e.g., Anderson et al., 2008; Mummey et al., 2002; Ingram et al., 2002, Wick, et al., 2008). These studies report soil bulk densities of about 1.3 g cm^{-3} and "native" SOM levels of about two percent in samples from the top 2.5 cm. For soils under mixed prairie in eastern Wyoming, this amounts to about 3.8 metric tons less SOM in the top 2.5 cm at reclaimed sites than undisturbed sites. Replacement of this amount would require approximately 412 cattle per hectare for one day (or about 167 cattle per acre per day). This stocking rate may be attainable on small well pads over several days. Over two days, for instance, the stocking rate would be 206 cattle per hectare (or 84 per acre). Larger pads may need to be divided into smaller paddocks, but this number of animals would create large costs for hauling them plus hauling feed and water.

The technique may be better suited for sagebrush-steppe and desert-scrub grasslands of the rapidly developing gas fields in south-central and southwestern Wyoming where undisturbed sites typically have about one percent SOM (Soil Survey Staff, 2009). Assuming similar magnitude of differences between SOM levels in reclaimed and undisturbed sites to the eastern Wyoming coal mine sites (59 percent), the amount of organic material needed and the number of cattle required would be half as much (206 cattle per hectare per day or 84 per acre per day).

Advocates of controlled livestock impact list other benefits, such as breaking soil crusts, improving seed-soil contact, mulching and fertilizing the soil, and helping to control weeds (e.g., Bengson, 1999; Horst, 1999; Tipton and Tipton, 1999), but offer no scientific evaluation of these attributes.

Many livestock managers and mine operators support the controlled livestock impact approach, but it has rarely been scientifically or economically evaluated or tested in different environmental situations. In one study, Vinson et al. (1999) report that treatments with 800 cattle days on soil-capped tailings in Arizona performed similarly to biosolid treatments with respect to biomass production, but had more planted plants that reached maturity and set seed. Lindemann et al. (1989) describe nutrient immobilization associated with straw amendments on coal mine spoils, topsoil, and stockpiled topsoil. The straw amendment resulted in a high C:N ratio immobilizing all soil nitrogen. Waste hay would likely have a similar effect and would immobilize a portion of available nutrients deposited in manure and urine. This may increase SOM in the slow pool and decrease weed and offsite nutrient pollution issues.

According to testimonials published it the texts *Beyond the rangeland conflict: toward a West that works* and *The Gardeners of Eden* (Dagget et al, 1998; Dagget et al, 2005), as well as those of land managers Tony and Jerry Tipton (Tipton and Tipton, 1999), livestock managers in arid and semi-arid climates restore native grasses on abandoned mine tailings using short periods of confined feeding at high stocking rates on seeded areas. A land manager for ASARCO, Inc., reports observations that high livestock impact for short duration on copper mine tailings breaks soil crusts, improves seed-soil contact, mulches and fertilizes the soil, and helps control weeds (Bengson, 1999). A recent article in the Canadian Farm Manager Newsletter (Cheater, 2008) describes winter feeding on dryland pastures to improve soils and increase production. The Wyoming Game and Fish Department (WGFD) cooperates with ranchers to successfully restore native forage on wildlife management areas using this technique. Observations by WGFD indicate improved soil conditions and greater success in restoration seedings (personal communication, Ryan Amundsen, WFGD). Related studies confirm the notion that controlled livestock impact has the ability improve soil quality. One study on cotton fields in west Texas found cotton fields that integrated livestock had higher SOC, soil microbial biomass, and aggregate stability than fields without livestock (Acosta-Martinez et al, 2004). All of these parameters suggest livestock improved the soil quality of these fields. A study in an east African savannah observed productive grasslands were often associated with historic cattle bomas (Augustine, 2003). Bomas are areas used to contain livestock overnight and usually enclose a high density of cattle for a short period of time (Augustine, 2003). There is substantial evidence regarding the role of livestock for maintaining and possibly improving SOM and nutrients, however little formal research has been conducted on the use of livestock for reclamation projects. High salt contents in manure may represent a limiting disadvantage for use in arid areas. Controlled livestock impact as a reclamation tool may warrant scientific and economic evaluation, especially for Wyoming natural gas well pads, which typically lie in long-term grazing permits and are small in extent so would facilitate high stocking rates for short periods. If it proved ecologically and economically beneficial, this approach could support local economies and improve relations between livestock permittees, energy companies, and leasing agencies by giving local livestock producers a stake in successful reclamation.

Summary & Conclusions

While changes in topsoil quality during stripping, stockpiling, and reapplication on reclaimed coal mines are well documented, those for natural gas well pads, which typically are stockpiled for much shorter periods, are much smaller in scale, and are handled somewhat differently, are not well documented. While the shorter stockpile duration may mean less SOM is lost, studies of coal mine chronosequences suggest that most SOM is lost to oxidation within a short time of disturbance. This means that SOM fractions lost are from active, readily decomposed pools that were protected from oxidation within soil aggregates prior to disturbance. Loss of around half the SOM from nutrient-poor, semiarid and arid soils may go far in explaining high failure rates for reclamation of natural gas well pads. The location of well pads within existing grazing allotments, as well as their small scale of around one to 10 ha in size, suggests that they might be good settings for using controlled livestock impact to replace SOM and nutrients and to benefit from other attributes that might enhance reclamation success. While many land managers and reclamationists attest to the benefits of controlled livestock impact for reclaiming drastically disturbed sites, the practice has seldom been scientifically or economically evaluated. Research that investigates biogeochemical mechanisms and economics of controlled livestock impacts in different production and environmental scenarios could verify usefulness of a reclamation tool that could benefit land resources and local agricultural communities.

Literature Cited

Abdul-Kareem, A. W., and S.G. McRae. 1984. The effects of topsoil on long-term storage in stockpiles. Plant and Soil 76:357-363. http://dx.doi.org/10.1007/BF02205593.

Acosta-Martinez, V., T.M. Zobeck, and V. Allen. 2004. Soil microbial, chemical and physical properties in continuous cotton and integrated crop-livestock systems. Soil Science Society of America Journal 68:1875-1884. http://dx.doi.org/10.2136/sssaj2004.1875

Augustine, D.J. 2003. Long-term, livestock-mediated redistribution of nitrogen and phosphorus in an East African savanna. Journal of Applied Ecology 40:137-149. http://dx.doi.org/10.1046/j.1365-2664.2003.00778.x.

Bengson, S. A. 1999. The Use of Livestock as a Tool for Reclamation of Copper Tailings in Southern Arizona. 16th Annual Meeting - American Society for Surface Mining and Reclamation: "Mining and Reclamation for the Next Millennium". 1999. The American Society for Surface Mining and Reclamation.
https://doi.org/10.21000/JASMR99010704

Brady, N. C., and R. R. Weil. 2002. *The nature and properties of soils*. Pearson Education, Upper Saddle River, New Jersey.

Chapman, R., J. Collins, and A. Younger. 1996. Control of legumes in a species-rich meadow re-created on land restored after opencast coal mining. Restoration Ecology 4:407-411. http://dx.doi.org/10.1111/j.1526-100X.1996.tb00193.x.

Dagget, D., and J. Dusard. 1998. *Beyond the rangeland conflict : toward a West that works.* Good Stewards project, Flagstaff, (Ariz.).

Dagget, D., and T. Bean. 2005. *Gardeners of Eden* : *rediscovering our importance to nature.* Thatcher Charitable Trust, Santa Barbara, Calif.

Doran, J.W., E.T. Elliott, and K. Paustian. 1998. Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. Soil & Tillage Research 49:3-18. http://dx.doi.org/10.1016/S0167-1987(98)00150-0.

Ghose, M.K, and N.K. Kundu. 2003. Deterioration of soil quality due to stockpiling in coal mining areas. International Journal of Environmental Studies. 61:327-335. http://dx.doi.org/10.1080/0020723032000093991.

Harris, J. A., P. Birch, and K.C. Short. 1989. Changes in the microbial community and physico-chemical characteristics of topsoils stockpiled during opencast mining. Soil Use and Management 5:161-168. http://dx.doi.org/10.1111/j.1475-2743.1989.tb00778.x.

Harris, J. A., P. Birch, and K. C. Short. 1993. The impact of storage of soil during opencast mining on the microbial community: a strategist theory interpretation. Restoration Ecology 1:88-100. http://dx.doi.org/10.1111/j.1526-100X.1993.tb00014.x.

Hillel, D. 2004. *Introduction to Environmental Soil Physics*. Elsevier Academic Press, San Diego, California.

Horst, S. A. Hoof, Mouth, and Manure Livestock and Mine Land Rehabilitation "Sustainable Mine Land Rehabilitation: The Overview". 16th Annual Meeting - American Society for Surface Mining and Reclamation: "Mining and Reclamation for the Next Millennium". 1999. The American Society for Surface Mining and Reclamation.
https://doi.org/10.21000/JASMR99010697

Ingram, L.J., G.E. Schuman, P.D. Stahl, and L.K. Spackman. 2005. Microbial respiration and organic carbon indicate nutrient cycling recovery in reclaimed soils. Soil Science Society of America Journal 69:1737-1745. http://dx.doi.org/10.2136/sssaj2004.0371.

Jenny, H. 1930. A Study on the Influence of Climate upon the Nitrogen and Organic Matter Content of Soils. College of Agric., Res. Bull. 152. University of Missouri, Columbia.

Kraimer, R.A., H.C. Monger, and R.L. Steiner. 2005. Mineralogical distinctions of carbonates in desert soils. Soil Science Society of America Journal 69:1773-1781. http://dx.doi.org/10.2136/sssaj2004.0275.

Lindemann, W.C., P.R. Fresquez, and M. Cardenas. 1989. Nitrogen mineralization in coal mine spoil and topsoil. Biology and Fertility of Soils 7:318-324. http://dx.doi.org/10.1007/BF00257826.

Mummey, D. L., P.D. Stahl, and J.S. Buyer. 2002. Soil microbiological properties 20 years after surface mine reclamation: spatial analysis of reclaimed and undisturbed sites. Soil Biology and Biochemistry 34:1717-1725. http://dx.doi.org/10.1016/S0038-0717(02)00158-X.

Natural Resource Conservation Service. "Section 4 Manure Production" Wyoming NRCS. www.nrcs.usda.gov .

Pederson, T.A., A.S. Rogowski, and R. Pennock. 1978. Comparison of morphological and chemical characteristics of some soils and minesoils. Reclamation Review 1:143-156.

Popay, I., and R. Field. 1996. Grazing animals as weed control agents. Weed Tech. 10:217-231.

Six, J., E.T. Elliot, K. Paustian, and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Science Society of America 62:1367-1377. http://dx.doi.org/10.2136/sssaj1998.03615995006200050032x.

Severson, R. C., and L. P. Gough. 1983. Rehabilitation of materials from surface coal mines in the western U.S.A. I. Chemical characteristics of spoil and replaced cover soil. Reclamation and Revegetation Research 2:83-102.

Soil Survey Staff. 2009. National Soil Survey Characterization Data. Soil Survey Laboratory, National Soil Survey Center, USDA-NRCS - Lincoln, NE. Monday, April 20, 2009.

Stahl, P.D., B. Perryman, S. Sharmasarkar, and L. Munn. 2002. Topsoil stockpiling versus exposure to traffic: a case study on in situ uranium wellfields. Restoration Ecol. 10:129-127. http://dx.doi.org/10.1046/j.1526-100X.2002.10114.x7.

Tipton T., and J. Tipton. Twenty-to-One: The Nevada Experience. 16th Annual Meeting - American Society for Surface Mining and Reclamation: "Mining and Reclamation for the Next Millennium". 1999. The American Society for Surface Mining Reclamation.
https://doi.org/10.21000/JASMR99010700

Van Vliet, P.C.J., J.W. Reijs, J. Bloem, J. Dijkstra, and R.G.M. de Goede. 2007. Effects of cow diet on the microbial community and organic matter and nitrogen content of feces. Journal of Dairy Science 90:5146-5158. http://dx.doi.org/10.3168/jds.2007-0065.

Vinson, J., M. Milczarek, D. Hammermeister, and J. Word. Vegetation Success, Seepage, and Erosion on Tailing Sites Reclaimed with Cattle and Biosolids. 16th Annual Meeting - American Society for Surface Mining and Reclamation: "Mining and Reclamation for the Next Millennium". 1999. The American Society for Surface Mining and Reclamation.
https://doi.org/10.21000/JASMR99010175

Wick, A.F., L.J. Ingram, and P.D. Stahl. 2009. Aggregate and organic matter dynamics in reclaimed soils as indicated by stable carbon isotopes. Soil Biology and Biochemistry 41:201-209. http://dx.doi.org/10.1016/j.soilbio.2008.09.012.