Soil Organic Matter and Native Plant Production on the Missouri Coteau

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Mollisols (grassland soils) are among the most productive soils in the world. This productivity is largely a result of the effects of grassland vegetation on soil development. The dominant process in Mollisol formation is the darkening of the soil by organic matter additions (melanization). Additions to soil organic matter are mostly due to plant materials inputs from above and below ground. Climate, landscape position, and parent material, including soil texture, influence organic matter accumulation because of its influence on drainage, botanical composition, and productivity.

Stevenson (1982) explains the relationship between soil-forming factors and organic matter. In particular, he lists the reasons currently accepted for organic matter differences in grassland soils (e.g., Mollisols) and forest soils (e.g., Alfisols): "1) larger quantities of raw material for humus synthesis are produced under grass, 2) nitrification is inhibited in grassland soils, thereby leading to the preservation of nitrogen adn carbon, 3) humus synthesis occurs in the rhizosphere, which is more extensive under grass than forest vegetation, 4) restricted aeration occurs under grass, thereby contibuting to organic matter preservation, and 5) the high base status of grassland soils promotes the fixation of NH_3 by lignin." He believes a combination of these factors is involved but, humus synthesis by roots is most important.

The objective of this study was to compare the annual primary production to soil-landscape position and total soil organic carbon along with related soil parameters for plant communities of the Central Grasslands Research Station. Although much research has been conducted on North Dakota grasslands, little information is available on grasslands of the Missouri Coteau, upon which our study area is locate. The Coteau occupies 16 percent of the state and contains approximately 28 percent of the state's rangeland (U.S. Department of Agriculture, Soil Conservation Service, 1984).

DESCRIPTION OF THE STUDY AREA

The Central Grasslands Research Station was established as a branch station of the North Dakota Agricultural Experiment Station to be used as a range management research facility. It is located in Kidder and Stutsman counties in south-central North Dakota and consists of approximately 5,290 acres, most of which is rangeland. It lies near the eastern edge of the Missouri Coteau, an extensive glaciated highland which is part of the Missouri Plateau of the Great Plains Province (Flint, 1955). Climate is continental with a mean annual precipitation of 17 inches and a 120-day freeze-free period (Jensen, 1972). Vegetation of the study area is mixed-grass prairie and has been described by Lura (1985). Data presented here are from Lura (1985).

METHODS

Twenty-one stands were chosen for study covering the major plant communities of the study area. Wetland communities and communities occupying areas too small for managerial implications were not sampled. Production of each stand was estimated by the harvest method at or shortly after peak standing crop (mid August) for the years 1981-1983. Five randomly placed 400 square inches (0.25 squared meters) quadrats in each stand were clipped at ground level and oven dried. The soil type at each stand was identified. Particle size analysis of soil horizons was conducted on each stand using the Bouyoucos (1951) method. Plant available water capacity (AWC) was estimated from texture using the method of Wollenhaupt et al. (1982). Soil samples were taken at 6-inches increments to a depth of 36 inches where feasible for nutrient analysis from three randomly selected points per stand during the last week of August 1982. Increments were pooled by depth within each stand and analyzed by the North Dakota State University Soil Testing Lab for nitrate-nitrogen, phosphorus, potassium and organic matter. The methods are described in Dahnke (1980). The amounts of total soil organic matter and nitrogen in Table 1 were calculated from the laboratory data by assuming the surface increment (0-6 inches) had a bulk density of 1.3 grams per cubic meter and the rest of the profile to a 40-inch depth had a 1.5 grams per cubic meter bulk density. The ratio of stored total nitrogen is about 10 percent the amount of soil organic carbon (Shreiner and Brown, 1938).

RESULTS AND DISCUSSION

Quantifying below-ground productivity is difficult (Sims and Singh, 1971; Redmann, 1975). As a result, elucidating relationships between below-ground primary production and soil organic matter is difficult. By comparing organic matter distribution and annual primary production, however, a measure of the influence of root production on soil organic matter may be estimated. Soil and vegetation data are summarized in Table 1.

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Table 1. Selected plant and soil parameters from Lura (1985). Bulk density was assumed to average 1.3 to 1.5 T m^{-3} to 1.0 m, C:N ratio was 10:1, and organic carbon was 60 percent of organic matter.

Plant community	Range Site	Soil Series	Soil drainage class	Soil texture class	AWC Est. Avg.	OM Avg. Prod 1981 to 1983	OM Minimum Prod 1981 or 1982	OM Maximum Prod depth	Soil OM to 1.0 M N	Estimated Total Available	NO_3-N
					%	T/ac					lbs/ac
Bogr-Stco-Cafi	Very Shallow	Sioux	Excessive	S.L. S	3	1.08	0.84	1.47	134	8.1	16.8
Bogr-Stco-Cahe	Silty	Williams	Well	S.L. C.L.	13	1.62	1.48	1.85	165	9.9	35.0
Bogr-Cahe-Ansc	Thin Upland	Barnes	Well	L	15	1.71	1.28	2.27	151	9.1	24.2
Bogr-Cafi-Mucu	Thin Upland	Barnes	Well	L	15	1.20	0.77	1.89	107	6.4	22.8
Popr-Agre-Sori**	Silty	Vida Bowbells	Mod. Well	L	16	1.85	1.35	2.16	216	13.0	26.9
Bogr-Agsm-Popr	Shallow to Gravel	Arvilla	Mod. Well	S	5	1.78	1.50	2.12	112	6.7	20.6
Ansc-Popr-Stsp	Limy Sub-irrigated	Hamerly	Somewhat Poor	L	16	2.06	1.83	2.96	187	11.2	39.8
Cast-Juba-Caco	Wet Meadow	Vallers	Poor	C	15	2.15	1.86	2.40	176	10.6	58.8
Poar-Disp-Hoju	Saline Lowland	Lallie	Poor	C	15	1.04	—	1.04*	179	10.8	70.7

*Saline: data averaged and adjusted for 40% bare ground. **Plowed in the 1920's and not an original prairie.

***Bogr-Stco-Cafi = *Bouteloua gracilis-Stipa comata-Carex filifolia*; Bogr-Stco-Cahe = *Bouteloua gracilis-Stipa comata-Carex heliophila*; Bogr-Cahe-Ansc = *Bouteloua gracilis-Carex filitolia-Andropogon-scoparius*; Bogr-Cafi-Mucu = *Bouteloua gracilis-Carex filifolia-Muhlenbergia cuspidata*; Popr-Agre-Sori = *Poa pratensis-Agropyron repens-Solidago rigida*; Bogr-Agsm-Popr = *Bouteloua gracilis-Agropyron smithii-Poa pratensis*; Ansc-Popr-Stsp = *Andropogon scoparius-Poa pratensis-Stipa spartea*; Cast-Juba-Caco = *Calamagrostis stricta-Juncus balticus-Carex*; Poar-Disp-Hoju = *Poa arida-Distichlis spicata-Hordeum jubatum*.

Production of a range site is a function of many factors, including soil available water holding capacity (AWC), drainage, and quantity of salts. We assume that the primary plant productive factor is the amount of water available for plant growth. Most of the communities had good plant available water capacity based on soil textures (Table 1).

The Sioux and Arvilla soils, however, are droughty and are classified as very shallow and shallow to gravel range sites, respectively. Botanical composition differed between the two sites and production on the Arvilla soil was 60 percent greater than on the Sioux soil. These differences result from the fact that the Arvilla soil occupied a landscape position that received additional soil water from higher elevations while the Sioux soil was an excessively drained site on an outwash terrace.

Characteristics of the Lallie soil (saline lowland range site) are influenced by topographical locatin. Approximately 40 percent of the ground surface is devoid of vegetation (Figure 1) due to accumulation of salts. This salinization occurs as a result of deposition of salts from inflowing soil water. As a result, production is relatively low.

Landscape position tends to override other factors which influenc primary production here and elsewhere in North Dakota (Mack, 1981; Wollenhaupt and Richardson, 1982; Butler et al., 1986). We conclude that landscape position is the single most important parameter influencing production on these soils, followed by salinization and available water capacity of the soil.

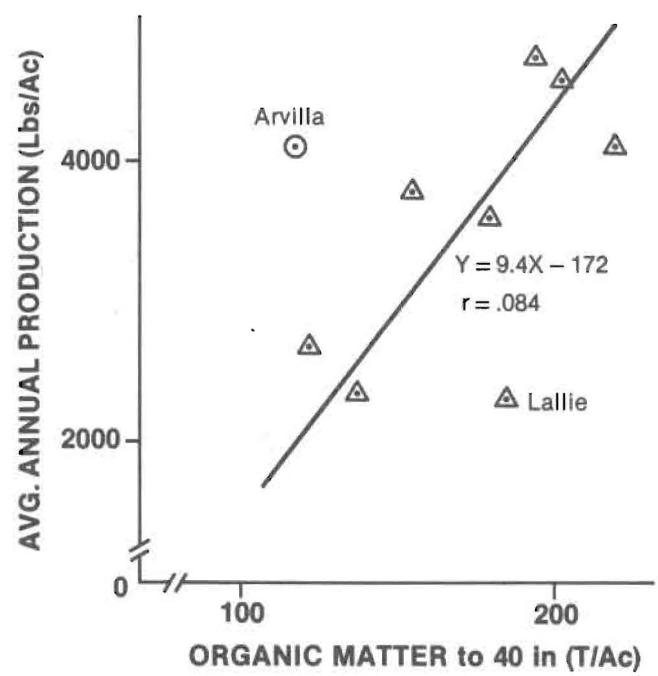

Figure 1. Soil organic matter observed in soils under various range plant communities on the Central Grasslands Research Station.

Production was relatively consistent between years for this study. The greatest variation in yearly production occurred on those communities occupying well drained soils on upland till (Barnes and Williams series). The greater variation in production on these sites is partially a result of variations in timeliness of summer rains. Microrelief, as usual, is also an important factor influencing production.

The relationship between mean and above-ground production and soil organic matter to 40 inches in our sstudy was statistically significant (Fig. 1) with $r=0.84$ (p 0.05). Data from communities on Lallie and Arvilla soils are not included in the regression. Because of topographical location, these soils are subject to much lateral water flow through the solum or are saline. As a result, the relationship between soil organic matter and production is atypical. In Figure 1, the Arvilla is the outlier above the regression line with less organic matter and higher production and the Lallie is the outlier below the line with more organic matter and lower production. The other sites are systematic (Fig. 1). From these data we conclude that there is a close correlation between production and soil organic matter with the exception of those sites receiving large amounts of lateral water flow through the solum. Assuming typical drainage conditions, the relationship is expected to be closely related to AWC.

The silty range site and Bowbells/Vida soils with *Poa pratensis-Agropyron repens-Solidago rigida* had abundant organic matter on the surface and in the upper portion of the soil profile (Lura, 1985 and Fig. 2). The profile distribution may reflect the accumulation of material from microrelief, however (Fig. 2). The distribution of organic matter in the Bowbells which classifies as Pachic Udic Argiboroll is similar to the organic matter distribution in other series in the Pachic subgroup (Richardson, 1984). The "Pachic" subgroup means these soils have an extra thick A-horizon. The nitrate nitrogen in the Bowbells soil varies little with depth compared to the other silty range site (Fig. 3). The other silty range site (Williams series) displays the typical decrease in

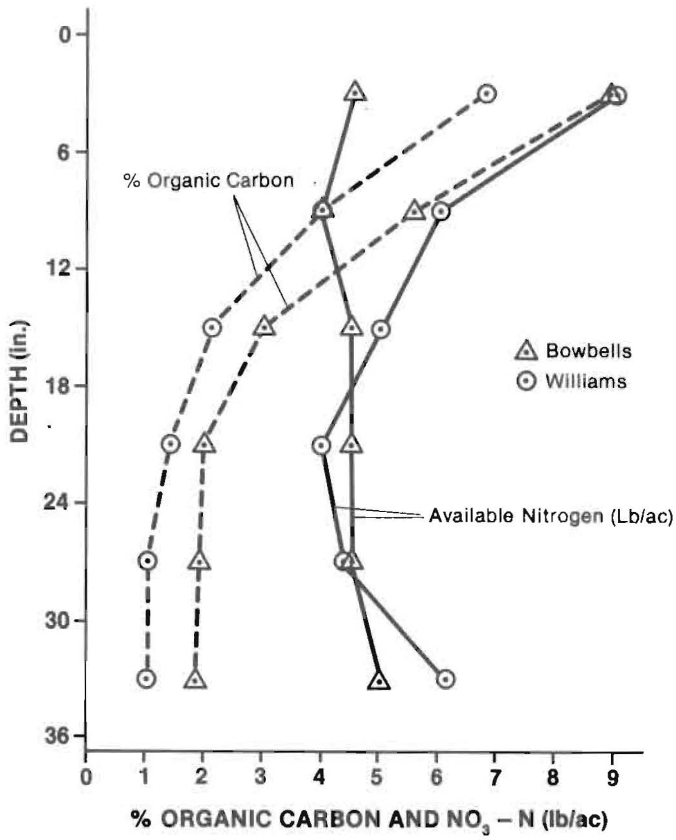

Figure 3. Comparison of organic matter distrubtion and plant avaiable N in an unplowed and previously plowed soil.

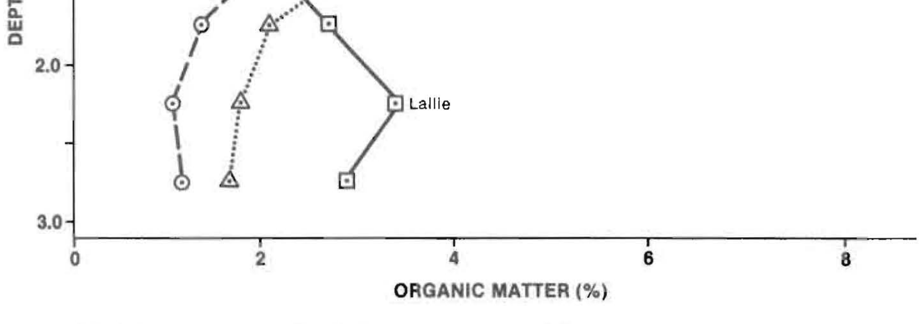

Figure 2. Organic matter depth distribution of a Pachic Udic Haplaboroll (Bowbells), a Udic Haplaboroll (Williams), and an anomalous distribution in a saline soil (Lallie).

organic matter with depth (Fig. 2) expected in upland soils. In contrast the saline lowland range site (Lallie soil) has a distribution that is anomalous with irregular organic matter changes with depth (Fig. 2). Much of the organic matter may be from deposition and/or preserved from soil wetness.

The amounts of annually produced above-ground dry matter compared to soil organic matter is less than 2 percent. Production values for the years of the study may be above average, and maximum yields were used in calculations presented in Table 1. In a Barnes loam from South Dakota, Broecker et al. (1956) dated the age of the organic matter as 350 years old using carbon 14. Based on data from Foss et al. (1985) we do not believe it would be older. Assuming that this is a reasonable estimate for Missouri Coteau soil horizons, organic matter would accumulate at a rate of about 0.5 tons per acre per year. Sim and Singh (1971), Abouguendia (1973), and Dziadyk (1981) found that underground production ranged from 60 to 80 percent of total production. Therefore we can speculate that 10 percent of the total annual production would be needed to create the amount of organic carbon observed in these soils. This would be much greater than the amount suggested by Jenkinson (1965). Also, this suggests that high amounts of plant material are synthesized to resistant forms of organic matter.

Approximately 75 percent of the total primary production on grazed mixed grass prairie is below ground (Marshall, 1977), and 25 percent of the root biomass is recycled annually (Dahlman and Kucera, 1965). These values would be most comparable with the silty range site, which is also the most extensive range site on the study area and would best typify the soils of the Missouri Coteau.

Based on these assumptions, the root production on the silty range site would average 10,800 pounds per acre, and 2,700 pounds per acre of root biomass would turnover annually. A large portion of the carbon would likely be removed from the soil as carbon dioxide from the decomposition process. A greater portion of nitrogen however, would tend to remain in the soil or within the living components of the soil (Clark, 1977). Assuming 1 percent of the root dry matter is nitrogen (Porter, 1969), approximately 27 pounds per acre of nitrogen would be released from root tissue on these sites annually. The total nitrate nitrogen in these soils is 9,000 pounds per acre, which is equivalent to 2,000 pounds per acre elemental nitrogen. As nitrogen exists in the soil in other forms, total soil nitrogen is undoubtedly much larger.

In Table 1 using the 10:1 C:N ratio, we estimated a range of total nitrogen in these soils from 7.5 to 14.5 tons per acre. Schreiner and Brown (1938) compared soil nitrogen in various regions of the United States. The Prairie and Chernozem soils (Mollisols) averaged 9 tons per acre total nitrogen to a depth of 40 inches. This compares to only 3.7 tons per acre for Brown Forest soils (Alfisols). The soils in this study average just slightly higher in total nitgrogen than those of Schreiner and Brown. The plant available nitrogen in these soils is not linear as can be seen in Figure 3 and the last two columns in Table 1. The Bowbells was plowed in 1930s and the Williams is native range. Most of these differences in these silty range sites appear to be due to disturbance. Losses of plant available nitrogen during plowing may be serious in a range site because these are not usually fertilized with commercial fertilizers.

The kinds of crops that can be grown on these soils are severely limited due to the nature of the topography. Many of these soils are subject to severe erosion if converted to cropland. Unfortunately, these and other similar fragile soils have been converted to cropland. Erosion may be degrading the productive potential of previously plowed range lands and may be threatening their future economic viability.

Dormaar and Smoliak (1985) studied natural old-field succession following cultivation on the mixed-grass prairie of southern Alberta. They estimate that over 55 years are required for soil organic matter and associated soil parameters of old fields to approximate conditions on native range if grazed moderately throughout the period. Reseeding old fields to native vegetation would be expected to speed the recovery process, although to what extent is presently unknown. Economic factors in combination with losses of soil fertility may make reseeding of marginal cultivated lands back to native vegetation desirable. More research is needed to understand how best to restore the productivity of these lands, which are so important to North Dakota agriculture.

SUMMARY

Productivity of Missouri Coteau rangelands is closely correlated with soil organic matter. Those soils on landscape positions subject to lateral movement of soil water may deviate from this correlation. The soils studied support a very productive native vegetation and contain a large reservoir or nitrogen and carbon. Accumulation rates for soil organic matter may average 0.5 tons per acre per year and total nitrogen in the soil may range from 7.5-14.5 tons per acre. Conversion of these soils to cropland may result in erosion and losses of soil fertility and reduce the future economic viability of these soils. More research is needed to better understand the soil-vegetation relationships on these soils.

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dramatic changes were seen in 1981. The effects of a one-time harvest on an entire plant community seems to have a favorable effect on the basal cover of blue grama although it is at little or no expense of other species or goups. Holderman and Goetz (1981), reporting on the first two years of this study, showed clipping to have no signficant changes in basal cover of blue grama. Long term indications are that the basal cover of blue grama is increased under one-time harvests in a growing season. Although this clipping treatment was of high intensity, the short duration of the treatment could have lessened its severity by giving plants considerable time for recovery.

CONCLUSIONS

Results from this study, spanning five years, indicate that clipping has long term effects on the mixed grass prairie of western North Dakota. Early season harvests generally increased composition and yield of forbs and blue grama, the warm season grass component, while somewhat reducing the cool season graminoid component. Western wheatgrass initially increased from clipping treatments as reported by Holderman and Goetz (1981). Gains in yield by this species were eventually negated as treatment continued and in some instances yields were drastically reduced.

Most changes in the plant communities due to clipping treatments did not occur until the final years of the study. In contrast to yield, basal cover of species from year to year was relatively stable. Therefore, changes in basal cover would be a more permanent fixture of the plant community. In addition, range improvement relying on changes in basal area would be slow to achieve in this mixed grassland type.

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