The effects of mechanical treatment on the soils and vegetation of a Natrargid-Paleargid complex in Northern Montana
by Marie Margaret Boehm

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soil Science
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Three Natrargid soils (Tealette, Elloam and Thoeny) and one Pale-argid soil (Phillips) in northern Blaine County, Montana were characterized and their vegetative productivity was measured with and without mechanical treatment (plowing or chiseling). Four treatments were studied: native vegetation, unplowed (control); native vegetation, plowed (cl930); crested wheatgrass vegetation, plowed (c!940); and native vegetation, chiseled (1972).

Plowing was found to be the most effective mechanical treatment. Grass, forb and total productivity increased significantly (p = .01), especially on Elloam and Thoeny, the most extensive soils in the landscape. Favorable response was attributed to increased infiltration of precipitation and spring snow melt due to clubmoss removal and fracturing of the impermeable B horizon, particularly on Elloam and shallow Thoeny soils.

The chiseled site showed an increase in total productivity, but the vegetative community was still in a serai stage of secondary succession as indicated by a large proportion of forbs, notably fringed sagewort. Measurements were made only 8 years after treatment with continuous grazing in the interim, so that little successionary progress would be expected.

The beneficial effects of plowing were still evident at least 50 years a ter treatment. A long residual effect is expected for these soils in which natric horizon development has ceased due to the dominance of a semiarid climate. The elimination of the prerequisite perched water table prevents the net upward movement of water and the reformation of columnar structure in the B horizon.

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by

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A thesis submitted in partial fulfillment
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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

LIST OF TABLES

LIST OF TABLES (cont'd.)

LIST OF FIGURES

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INTRODUCTION

Natrargid soils with slow permeability induced by soil texture and columnar structure occur intermittently in dryland areas of the continental till plain in northern Montana. Dense clubmoss (*Selaginella densa*) cover is frequently associated with these soils on heavily grazed rangelands. It reduces effective infiltration of precipitation and competes with preferred species for the limited moisture supply.

Historically, management intensity on these soils has been low. Economic factors on private land and public interest in better management of publicly owned rangeland has promoted an assessment of their potential productivity and the feasibility of renovation practices to increase their production.

A study of these soils in northern Blaine County was undertaken in 1979 as part of Interagency Agreement No. MT950-IA9-1442 between the Bureau of Land Management and Montana Agricultural Experiment Station. The objectives of the study were to:

1. Characterize four major range soils - Phillips (Paleargid); and Thoeny, Elloam and Tealette (Natrargids).
2. Evaluate their potential for forage productivity.
3. Evaluate the effects of two mechanical treatments, plowing and chiseling, on vegetative composition and productivity.

LITERATURE REVIEW

Mechanical land renovation has been practiced on western rangelands for more than 40 years in efforts to increase soil water storage, reduce runoff, and increase production of desirable forage (Neff, 1973; Branson et al., 1966). Climate, soil, grazing management, vegetation types, implements, and their use interact to determine treatment success (Branson et al., 1966).

Reports indicate that the most favorable response to mechanical treatments occur in arid and semiarid rangelands (Wight et al., 1978) with medium- to fine-textured soils (Branson et al., 1966). Sites in which soils are saline or sodium dominated tend to respond especially favorably to treatments which reduce run-off, providing a longer time for infiltration (Neff and Wight, 1977).

Implements most commonly used to treat rangelands are the moldboard plow, disc plow, ripper, pitter, chisel and contour furrower. There is consensus in the literature that contour furrowing is the most effective general method of treatment and that plowing tends to have the least long-term effect (Branson et al., 1966; Allmaras et al., 1977; Neff, 1973). Chiseling was only beneficial for treatments which required the fracturing of a "hardpan" layer in the soil to increase water infiltration and storage (Branson et al., 1966).

Effect of Mechanical Treatment on Soil Hydraulic Properties

Studies on the influences of chiseling and moldboard plowing on hydraulic properties of soils with an impermeable subsurface layer have shown that shallow chiseling improves water intake, soil water storage, and reduces soil water erosion more effectively than moldboard plowing (Lindstrom et al., 1974; Burwell and Larson, 1969; Allmaras et al., 1977; Sommerfeldt and Chang, 1980; Johnson and Moldenhauer, 1979). Burwell and Larson (1969) found that before runoff occurred, up to 50 percent more water infiltrated on chiseled plots than on counterparts moldboard plowed to the same depth. During the runoff phase, intake was not affected by tillage treatment when there were no residues on the surface. Water storage increases associated with chiseling have been attributed to improved intake from snowmelt and prevention of runoff due to the rough, trashy surface and fractured impermeable layer (Allmaras et al., 1977; Burwell et al., 1968).

Improved infiltration due to chiseling reported by Burwell et al. (1968) was inferred either from an increased proportion of large pores and increased permeability of saturated soil cores taken from problem subsurface layers, or when rupture of the problem subsurface layer was verified, even if changes in surface roughness were not great enough to affect surface detention and water intake. According to Allmaras et al. (1977) and Lindstrom et al. (1974) those observations would be insufficient to indicate any improvement due to chiseling. They propose that increased water holding capacity and greater downward distribution of water due to chiseling cannot be expected if the surface layer remains unchanged or if changes in profile water relations are unaffected by changes in water relations of the treated layer.

Allmaras et al. (1977) suggested that the beneficial effects of chiseling are related to increased water intake and redistribution down through the profile due to changed soil hydraulic properties. Reduction in water content of the upper layer of chiseled treatments due to more rapid drainage and redistribution would decrease surface evaporation, which decreases with soil water content (water diffusity), thus enhancing effective soil water storage. Increased hydraulic conductivity at constant water content due to chiseling and increased turbulent drying as the soil porosity is increased are both nullifying influences that must be considered in any net soil water storage projections.

Few researchers have studied the effects of chiseling or plowing on the water relations of sodium dominated soils. Branson et al. (1962) compared contour furrowing, trenching, pitting, plowing and ripping (chiseling) on 20 sites, one of which was a clayey saline-upland range site. They found that storage capacities of mechanically treated soils decreased rapidly during the first 5 years after treatment. Contour furrowing was the only treatment that caused a decrease in salts in the upper portion of the treated soil within that time. They postulated that although chiseling fractured the subsoil, it did not modify the soil surface sufficiently to allow maximum detention and storage of precipitation and snowmelt. Despite its relative inefficiency, chiseling produced to some degree all of the benefits of contour furrowing. For soils with a "hardpan" layer, they concluded that it may be the most mechanically efficient method of improving infiltration and subsurface drainage. Plowing did not significantly affect soil hydraulic properties at any of the sites for more than 3 years.

Several studies have examined the influence of contour furrowing on water relations of Natrargid soils of mixed prairie rangelands. Increased soil water was the major beneficial effect of all contour furrowing treatments (Branson et al., 1966; Soiseth et al., 1974; Wight et al., 1978; Neff and Wight, 1977). Overwinter recharge increased 157 and 162 percent, respectively (Neff and Wight, 1977), and available soil water, measured as cm-days, increased 36 and 107 percent, respectively (Wight et al., 1978) on treated saline-upland and panspot sites. Enhanced overwinter recharge increased spring available moisture which accounted (r = 0.89) for about 65 percent of increased herbage production in both studies. Branson et al. (1966) reported that even after treatment, panspot soils had lower infiltration rates and soil moisture percentages than saline-upland soils, although some soils that would have been classed as panspot soils before treatment were improved to saline-upland by contour furrowing. However, the fact that many furrowed panspots remained almost barren indicates that they cannot be completely reclaimed by mechanical treatment alone (Branson et al., 1966).

<u>Influence of Mechanical Treatment on Herbage Production</u>

Branson et al. (1966), in review of the influence of mechanical treatments on herbage production, reported that for panspot and saline-upland sites, beneficial biological effects persist for many years after enhanced moisture storage capacities of the soil have decreased. Wight et al. (1978) interpreted Soiseth's et al. (1974) data to indicate that any beneficial effects of contour furrowing should be autocyclic. As more water enters the soil, salinity decreases and herbage production increases, resulting in increased infiltration and nutrient availability, which, in turn, favors increased herbage production. In reference to panspot (Solonetzic) range sites, White (1969) observed increased herbage production 11 years after treatment and Soiseth et al. (1974) showed that improved infiltration, reduced sodium hazard and increased herbage production lasted for at least 10 years.

Yield responses of panspot range sites to mechanical treatment have varied from 0 to 100 percent or more (Wight, 1976). Wight et al. (1978) reported increased average herbage production of 165 percent (527 kg/ha) with thickspike-western wheatgrass (<u>Agropyron smithii</u>)

accounting for 64 percent of the increase. Basal cover of all other species was decreased. Rasmussen et al. (1972) and Branson et al. (1966) suggest that yield increases were generally 2.5 times greater on treated than check sites. Significant increases in litter, associated with increased forage production, were reported for all mechanical treatments (Branson et al., 1966).

It is generally agreed that re-establishment of major forage species requires about 4 years. Thickspike-western wheatgrass, Nuttall alkaligrass (Distichlis stricta) and, initially, foxtail barley (Hordeum jubatum) responded favorably to treatment. Crested wheatgrass (Agropyron cristatum) was generally not affected. Blue grama grass (Bouteloua gracilis), needle-and-thread grass (Stipa comata), and buffalo grass (Buchloe dactyloides) decreased on all treatment sites. Clubmoss response varied, tending to decrease with increased intensity of mechanical treatment. Fringed sagewort (Artemesia frigida) and other annual and biennial forbs increased with treatment intensity, but did not exceed 2.5 percent of total vegetation on any of the ungrazed study sites (Dolan and Taylor, 1972; Wight et al., 1978).

Influence of Grazing on Treatment Success

Restocking mechanically treated areas before forage species have become re-established has been shown to significantly reduce the beneficial effects of treatment. Branson et al. (1966) reported that infiltration rates on contour furrowed "slick and semi-slick soils" decreased with an increase in grazing intensity. They speculated that this was due to decreased mulch and increase in soil compaction due to trampling.

Branson et al. (1966) and Dormaar et al. (1977) found that blue grama grass dominated heavily grazed treatment sites whereas needle-and-thread grass eventually dominated ungrazed sites. Clubmoss increased with grazing intensity. Vegetation changes were accompanied by a change in dry matter of the root mass in the top 15 cm of the soil in each study site, which averaged 15 and 24 tons of dry matter on the ungrazed and heavily grazed sites, respectively (Dormaar et al., 1977). These findings concur with those of Smoliak et al. (1976) who also noted an increase in moss phlox (*Phlox hoodii*), prickly pear cactus (*Opuntia spp.*) and fringed sagewort on heavily grazed *Stipa-Bouteloua* mixed prairie rangelands.

Influence of Mechanical Treatment on Clubmoss

Dolan (1966) compiled a comprehensive literature review on the ecological role of clubmoss and its control by mechanical treatment. He concluded that despite its role as a stabilizer against water and wind erosion, "high clubmoss density is inimical to maximum range production." Because of its ability to intercept moisture which is then subject to rapid evaporation, it competes with desirable forage species for moisture. Removal of clubmoss competition for water and an increase in available nitrogen resulting from the decomposition of uprooted and buried clubmoss are partially responsible for increased productivity of preferred forage species on mechanically renovated range sites.

Dolan and Taylor (1972) observed that although clubmoss was still evident 40 years after mechanical treatment, its basal cover was reduced in proportion to intensity of treatment. Yield and ground cover contributed by forage species increased, as clubmoss decreased. Since no detrimental effects to the sites were observed in 40 years, renovation would appear to be effective in controlling clubmoss in areas where it is a problem.

LANDSCAPE ECOLOGY

Glacial History and Paleoecology

During the Wisconsin age, several major climatic changes associated with six distinct glacial advances and recessions occurred over the Northern Great Plains. In Montana, only the first two advances extended as far south as the Missouri River, each retreat marked by a deposition of glacial till material (Alden, 1932; Lemke et al., 1965). Meltwaters associated with the recession of the final four glaciations, flowed south to the Milk and Missouri Rivers, presumably carrying away much of the till. In some areas only a veneer of drift remains to cover the underlying, poorly consolidated Cretaceous shales, siltstones, and sandstones (Alden, 1932; Lemke et al., 1965).

Ice-age climate ended around 10,800 years BP (Bryson, 1975). The subsequent temperature trend was one of extensive warming in the mid-latitudes which culminated in a plateau of maximum warmth around the seventh millenium BP. The thermal maximum was maintained until the fourth millenium BP, after which cooling trends dominated with minor glacial advances around 3000 and 200 years BP (Bray, 1971).

Morrison and Frye (1965) have correlated climatic fluctuations during the Quaternary with soil-forming intervals in mid-latitude regions. They indicate that the rate of soil development varied exponentially, probably through several orders of magnitude, attaining greatest intensity during stronger soil-forming intervals of relative erosional stability and accelerated chemical weathering. Their research showed that intense soil-formation occurred during warm interglacial periods, with little pedogenesis during wetter and colder glacial intervals.

On the basis of climatic and soil data collected around 50°N latitudes, Bray (1971) concurs with their findings, but he contends that interglacial periods tended to be wetter, though drier in the summer, than during the glacial intervals. The researchers do agree that in the Northern Great Plains, a period favoring soil development was initiated by the humid environment associated with glacial melt and was intensified during the thermal maximum. It has been hypothesized (Morrison and Frye, 1965) that the rate of pedogenic development has been negligible over most of the Northern Great Plains during the past 4,000 years. This would infer that well-developed Natrargid/Paleargid soils in Wisconsin-age glacial till parent material can only be explained with reference to former paleoclimatic conditions.

Soils

Northern Blaine County is in a soil transition zone of Aridisols and Mollisols developed in glacial till under mixed prairie vegetation. The surface mantle is thin and the underlying Cretaceous Bearpaw Shale is often near the surface (Alden, 1932). Bearpaw Shale, of the Montana Group of soft grey-black shales, was deposited by marine regression over the Judith River Formation sandstones of the Claggett Sea regression. It is characteristically a steel or lead grey to black, fissile, clayey shale with numerous limestone and ferruginous concretions and bentonite seams. A few thin fine-grained sandstones may be found in the upper part. Bearpaw Shale is nonresistant forming a subdued topography on the landscape (Veseth and Montagne, 1980). Both the glacial till parent material and the shale are somewhat saline (Lemke et al., 1965).

Localized areas of naturally occurring salt-affected soils are common throughout the region. They have distinctive argillic or natric horizons which are low in soluble salts but contain significant exchangeable sodium. The lower horizons usually contain both appreciable soluble salts and exchangeable sodium and magnesium.

Within a typical salt-affected landscape, the degree of salinization and/or alkalinization of individual pedons varies significantly. The most severely affected soils are panspots, or soils from which the A horizon has been eroded, exposing the columns of the B horizon. They are very sparsely vegetated by halophytes due to unfavorable physical conditions and extremely low water infiltration rates caused by the high exchangeable sodium levels.

Panspot soils occur in complex patterns on the landscape with less severely sodium affected and partially leached soils. The presence of an A horizon on these associated soils sufficiently ameliorates unfavorable conditions so that mesophytic species can survive. The proportion of mesophytic plants and total vegetative productivity tend to increase as depth to the impermeable B horizon increases. The partially leached soils, in which the columnar structure has to some extent degraded, do not as severely restrict infiltration or root and water penetration. They are the most productive soils on the landscape.

Present views on the genesis of salt-affected or "solonetzic" soils (natric great groups of Alfisols, Mollisols or Aridisols in Soil Taxonomy, 1975) are mainly based on the concepts of "colloidal-chemical exchange" originally outlined by two early Russian workers, Gedroits and Vil'yams (Tyurin, 1960). Briefly, they postulated that the evolution of a solonetzic soil involves cation exchange in which sodium eventually dominates the colloidal system. The soil colloids become highly dispersed and mobile under such conditions, and are carried downward with percolating water or upward from moist subsoil during a dry season. Upon drying, they form a dense, compact and intractable illuvial horizon, in which, after many wetting and drying cycles, columnar structures develop (Tyurin, 1960; Arshad and Pawluk, 1966; Birkeland, 1974).

Conditions necessary for the development of solonetzic soil include: 1) periods of temporary excessive moisture (Westin, 1953), or 2) "an arid or semiarid climate, 3) an impervious subsoil or hardpan layer, and 4) a temporary abundance of humidity interspersed with dry periods" (de Sigmond, 1938). In the Northern Great Plains, solonetzic complexes are associated with thin glacial till parent material which is somewhat less calcareous than parent material of associated "unaffected" soils, and which is underlain by Cretaceous marine shales which are devoid of lime and which frequently contain appreciable amounts of salts (Kellogg, 1934; MacGregor and Wyatt, 1945; Bentley and Rost, 1947; Westin, 1953; Bowser et al., 1962; Arshad and Pawluk, 1966). The presence of relatively impermeable strata fairly close to the surface would likely have caused the formation of a perched water table, particularly in immediate post-glacial times, which provided appropriate conditions for the temporary infusion of salts by capillary moisture towards the surface during periods of low precipitation. The process would have been intensified by the significantly warmer climate that characterized the period of thermal maximum (Arshad and Pawluk, 1966).

There is general agreement in the literature that solonetz will only develop in situations where sodium ions moved upward in greater concentration than either magnesium or calcium ions. The sodium ions then competed favorably for positions on the exchange sites. Since salts of calcium and magnesium are generally of lower solubility, they tended to precipitate in the lower solum when the soil dries. Thus, the selective removal of salts resulting from water table influence maintained the exchangeable sodium status in the upper solum. Variation in the occurrence and fluctuation of temporary and permanent water tables, and variability in the differential removal of sodium ions, produced soils with B horizons varying both chemically and morphologically (Kellogg, 1934; MacGregor and Wyatt, 1945; Bentley and Rost, 1947; Westin, 1953; Bowser et al., 1962; Arshad and Pawluk, 1966; Rasmussen et al., 1972). Canadian researchers have reported studies on morphological solonetz in which magnesium is the dominant cation on the B horizon exchange complex (Ellis and Caldwell, 1935; Bentley and Rost, 1947; Bowser et al., 1962).

Vegetation and Land Use

Vegetation in northern Blaine County is typical of the *Stipa-Bouteloua* faciation of the mixed prairie association (Coupland, 1961). Dominant species of potential climax communities would include needle-and-thread grass, blue grama grass, green needlegrass (*Stipa viridula*), western wheatgrass, blackroot sedge (*Carex eleocharis*), sandberg bluegrass (*Poa secunda*), clubmoss, and prickly pear cactus. Introduced species, notably crested wheatgrass (*Agropyron cristatum*), have become common members of the association.

Needle-and-thread grass and western wheatgrass tend to dominate ungrazed sites. As grazing intensity increases, blue grama grass, fringed sagewort, and clubmoss increase considerably (Dormaar et al., 1977).

Land use is primarily livestock grazing. Some of the rangeland has been improved by reseeding, fertilizer or mechanical treatments. Where soil conditions are compatible, cereal grains are produced in a dryland crop-fallow rotation.

Attempts to homestead in northern Montana were often unsuccessful as many of the early settlers failed in their attempt to dryland farm wheat. Frequently their farmland was abandoned and allowed to revegetate naturally. The restoration of many such disturbed sites was monitored by ecologists who observed that secondary succession proceeded in distinct stages, reculminating in native grassland (Costello, 1944; Hironaka and Tisdale, 1963; Looman, 1963). Their studies indicated that three successional plant communities preceded the re-establishment of a climax community.

The initial stage was characterized by annual forbs, most notably Russian thistle (Salsola kali). Within 3 to 5 years, perennial forbs began to replace Russian thistle and western wheatgrass and blue grama grass were occasionally observed. Gradually, perennial "weeds" were replaced by a short-lived community of perennial grass, as foxtail barley, western wheatgrass and blue grama grass became dominant. Prickly pear cactus and clubmoss were usually established by the end of this stage. The subsequent transition to native mixed prairie was usually complete within 25 years, characterized by an increasing dominance of blue grama, buffalo, needle-and-thread, and western wheatgrass. Forb population was extremely variable by this stage (Costello, 1944; Hironaka and Tisdale, 1963; Looman, 1963).

Transition between stages was generally progressive, unless retarded by severe climatic stress or overgrazing. The frequency of mid-grasses varied with precipitation, being inconspicuous in dry years (Hironaka and Tisdale, 1963). Costello (1944) noted that excessive grazing may maintain the forb stage indefinitely and, further, that overgrazing of the climax community may re-establish the forb community.

Overgrazing has been a serious problem on rangelands throughout the Northern Great Plains. Excessive grazing pressure upon natural plant communities is marked by a significant loss of forage species, however, it is the degree of overall environmental deterioration which must be used to measure grazing impact (Daubenmire and Colwell, 1942). In northern Montana, many plant communities are associated with morphologically and/or chemically unpropitious soils and are frequently subjected to climatic stress. Their survival is ensured only by the maintenance of a fragile balance. Edaphic changes and reduced vegetative cover due to overgrazing at such sites may result in serious erosion and compaction problems that complicate maintenance or restoration of mixed prairie vegetation, thus perpetuating the retrogradational trend (Daubenmire and Colwell, 1942; Smoliak et al., 1972; USDA, 1975; Dormaar et al., 1980).

MATERIALS AND METHODS

Sites were located 57 km north of Chinook in Blaine County, Montana on land administered by the Bureau of Land Management and on the Russell Unruh ranch (Figure 1). The area is located on gently undulating glacial topography with typical northern mixed prairie vegetation (Coupland, 1961). Parent material is glacial till which varies in thickness from a veneer to greater than 1 m over a Cretaceous saline, marine shale. Elevation ranges from 807 to 825 m. Mean annual precipitation is about 30 cm with half falling during May, June, and July.

Four major soils, representing extensive acreages of rangelands in the state were selected for study. They were identified with the help of Dan Tippy, BLM soil scientist in the Havre Resource Area. Three of the soils were Borollic Natrargids: Tealette, Elloam and Thoeny. The fourth soil was Phillips, a Borollic Paleargid. All four soils are in fine-textured families. They were identified in the field on the basis of depth to the tops of the columnar structure characteristic of Natrargids with caps of Tealette being 0-3 cm, Elloam being 3-13 cm, and Thoeny being 13-23 cm below the surface. Phillips does not exhibit columnar structure. The photograph (Figure 2) of the Thoeny and Phillips soils shows the variation in depth to caps and the abrupt breakdown of columnar structure between Thoeny and Phillips.

Field work was undertaken in July 1979 and June 1980. During July 10-13, 1979, three pedons were sampled for each soil representing