CLAYPAN SOIL FACTORS FAVORING SHORTGRASS DOMINATION IN WESTERN SOUTH DAKOTA

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ABSTRACT

Forage on claypan (CP) range soils in some old landscape positions in western South Dakota could be increased if western wheatgrass (*Agropyron smithii* Rydb.) would invade the bluegrama (*Bouteloua gracilis* H.B.K. Lag.) and buffalograss (*Buchloe dactyloides* Englem.) shortgrasses on these areas. Factors limiting the growth of western wheatgrass (WW) on CP soils were studied near the boundary with the surrounding WW-dominated claypan-clayey intergrade (CL) range. WW growth on unfertilized CP soil in the greenhouse was poor, slightly better with N fertilization, and significantly better with NPK. In the field, NPK-fertilized Japanese brome (*Bromus japonicus* Thunb.) crowded out the shortgrasses but not WW on the WW-shortgrass boundary. The boundary did not change during four years following fertilization. The CP- and CL-phosphorus-sorption mechanisms as evaluated by Langmuir isotherms are similar, but total P, N, and organic matter are slightly larger for the CL soil. Because root growth into the claypan is reduced, readily available Bray-P in the claypan apparently has not been used by the plants. Low N and P supplies in the CP surface soil reduce root growth into the claypan which in turn reduces water infiltration and storage for WW. Subsoil applied fertilizer and/or ripping may be needed for the growth of WW on the CP areas with shortgrasses.

INTRODUCTION

Some claypan (CP) soils (fine, montmorillonitic mesic Ustollic Natrargids) in old landscapes in western South Dakota (White, 1982) support blue grama and buffalograss but not western wheatgrass.

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Contiguous claypan-clayey intergrade (CL) and clayey range soils have dominantly western wheatgrass (WW). The two vegetation types are separated by a well-defined boundary even where the area has not been grazed for many years and precipitation has been above average.

The shortgrasses on CP are chlorotic and lack vigor, while WW vigorously dominates the shortgrasses in the adjacent clayey soil. WW grows on well-developed clay soils (White, 1971) and even on clay soils with poorly developed surface layer structure where shortgrasses do not grow (White and Lewis, 1969). Reasons for the lack of WW on these claypan soils has not been studied previously. Blue grama grown on CP surface soil in the greenhouse responded mainly to NPK fertilization and secondarily to minor element additions in Hoagland-type formulations (White, Gartner, and Butterfield, 1983). The most limiting minor element probably is Zn (White and Gartner, 1986). Hoagland-type solutions contain soluble Zn and P that can move directly into roots, while these elements could react with each other and the soil and become unavailable if added in fertilizers in the field. The present study was initiated to determine if:

1. WW could grow in CP surface soil in the greenhouse when fertilized with Hoagland solutions,
2. the phosphorus chemical systems of claypan and clayey soils are different because phosphorus can interact with Zn (Tisdale et al., 1985, p 386), and
3. fertilizers applied in the field would increase the shortgrass-herbage yield and stimulate WW to invade from the clayey soils into the claypan soils.

DESCRIPTION OF THE SOIL AREA

The study area is in the SE corner of the Cottonwood Range Field Station which has an average 360 mm precipitation annually. The claypan is at a depth of 0.1 to 0.2 m. The A horizon is water saturated after large rainfall events and remains water saturated for several weeks if evapotranspiration is low. Water movement into the claypan is negligible. A week or so after a large rain, a hole dug into the A horizon will fill with water from the surrounding soil but only the upper two or three cm of the claypan will be water saturated. The A-horizon moisture regime fluctuates from saturated to near the wilting point at least once each season. Because of the moisture distribution, roots are found mainly in the A horizon. The soil surface lacks the gilgai microrelief (White and Bonestell, 1960; White, 1961) which occurs on many lower lying, younger slopes on the station. Gilgai normally occurs on older semiarid landscapes with clay subsoils (White, 1964) that are moistened and dried every few years. Microrelief absence on this old landscape position is evidence the subsoil is not moistened and dried. Based on the 77-yr-weather record, soil-water-holding capacity, and Thornthwaite evapotranspiration relationships, a very fine-textured clay soil at Cottonwood would not be moistened below 0.8 m depth and moistened only in four-yr 100-yr^{-1} below the 0.6 m depth and in 21-yr 100-yr^{-1} below the 0.4 m depth (White, 1990).

METHODS

Experiment 1

Dormant WW sod from the CL area was placed in the greenhouse and watered with a solution containing a small amount of NH_4NO_3 until culms grew and were well developed. The culms with roots and rhizomes were washed free of clayey soil and transplanted into 1.5 kg of claypan surface soil in 0.13 m diameter by 0.1 m deep plastic pots. These pots were watered until additional culms were established. The culm numbers per pot were counted, and six replications of four treatments were established so that each treatment in each replication contained nearly the same number of culms per pot. Solutions applied in the four treatments contained water with: 1. nothing else, 2. N, 3. NPK, or 4. NPKME (ME means all essential minor elements) in Hoagland formulation (Hoagland and Arnon, 1938; Jacobsen, 1950). Culms were counted, harvested three times, and the oven-dry herbage weighed for each harvest. The LSD's for means were calculated (Steel and Torrie, 1960).

Experiment 2

A soil profile was sampled to a depth of 1.25 m at one location in the CP area and at one location in the CL areas. The CL profile was located on a 6% slope where erosion has been more active than on the adjacent CP area. The CP profile was 20 m upslope from the CL profile on a two to three percent slope. Soil samples were analyzed for total and Bray phosphorus (Jackson, 1958) by the ascorbic acid procedure (Watanabe and Olsen, 1965). The Langmuir-phosphorus-adsorption constants, k and s, were calculated (Udo and Uzu, 1972) from regression (Steel and Torrie, 1960) of the adsorption data. The constant k is related to the bonding energy for phosphate and s is the maximum amount adsorbed. To aid in the interpretation of the phosphorus data, particle size (Day, 1965), total N and organic matter (Jackson, 1958), and saturated-soil pH and electrical conductivities, EC, (Richards, 1954) were determined.

Experiment 3

CP range was unfertilized or fertilized with NPK, NPK+Zn, NPK+Mn+Fe, or NPK+B+S in plots (2 x 2 m) with four replications. Rates were equivalent to 10 Hoagland solution applications in the greenhouse pots, or 34, 8, and 12 kg ha^{-1} of N, P, and K respectively.

The first application was in the spring of 1980, and other applications were that fall, spring and fall 1981, spring and fall 1982, and spring 1983 and 1984 for a total of 272, 64, and 96 kg ha^{-1} of N, P, and K. Meter square areas were harvested October 1986. The 1986 herbage was separated into annual grasses and the weathered top growth accumulated from previous years. Perennial plant herbage also was collected on plots where it occurred. After weighing, the dried herbage was ground and analyzed for total P content.

Soils were sampled at the center and midway from the center to each of the four corners of each plot with a 2-cm-dia probe to a depth of 0.1 m after the herbage was harvested. The five subsamples were composited and analyzed for total N and organic matter, Bray-Kurtz phosphorus (Jackson, 1958, p 159) and DTPA-extractable Zn and Fe (Lindsay and Norvell, 1978).

Two replications of 2 m by 4 m plots were located across the CL-CP boundary and were unfertilized or fertilized with commercial fertilizer (34-0-0, 29-14-0, or 35-7-7) at rates of 112 kg N ha^{-1} to observe if fertilizers would cause WW to invade the CP area. Stakes were placed along the boundary between the two vegetation areas so that the possible spread of WW into the CP area could be observed.

RESULTS

Experiment 1

The initial number of culms or weight of culms of WW per pot was not significantly different for the different treatments (Table 1). At the third harvest, culm numbers and culm weight per pot were smaller for the water only and N-treated plots than for the NPK- or NPKME-treated pots. Lower leaves of many WW plants that received NPK or NPKME had a reddish color before the first and second harvests, but the red did not develop in the leaves before the third harvest.

Experiment 2

The upper three layers of the CL soil in comparison to the CP soil had similar textures, electrical conductivities, and Bray P contents but higher N and organic-matter contents and lower pH's (Table 2). The subsoil clay and total-P contents were highest in the CL soil, but the subsoil Bray-P contents were lower than in the CP soil. The Langmuir constants for P adsorption are similar for the two profiles.

Experiment 3

Vegetation on the small CP plots was darker green and more vigorous than on the unfertilized plots a few weeks after NPK was first applied. Initially, all plant species responded, but by the end of the second growing season nearly all bluegrama and buffalograss had been replaced by annual grasses, mainly Japanese brome (*Bromus japonicus* Thunb.). The taller annual grass vegetation in the fertilized plots sheltered small rodent burrows in the winter, but burrows were not observed in the surrounding unfertilized area. Subsoil excavated from burrows supported diverse weedy species.

The mean P content of the 1986 current herbage from the fertilized and unfertilized plots was not significantly different (Table 3). However, annual grasses made up only 32 percent of the total vegetation on the unfertilized plots and nearly 100 percent in the fertilized ones. Although the pre-1986 annual grass herbage residue was not separated and weighed for all treatments, it was for the unfertilized plots and for the plots receiving NPK+Mn+Fe. These two treatments, respectively, had mean pre-1986 annual herbage residue weights of 44 and 274 g m^{-2}.

The fertilized-plot soils had larger Bray-P contents than the unfertilized ones (Table 4). Soil-organic-matter and total N contents were not significantly different for the different plots. The DTPA-extracted Zn or Fe contents were not significantly different for the different plots.

Fertilizer applied across the CL-CP boundary stimulated Japanese brome growth, decreased bluegrama and buffalograss growth and plant numbers, and did not cause WW to grow into the claypan area in a four year period. Japanese brome did not shade WW as much as it did the shortgrasses.

Table 1. Mean numbers and weight of western wheatgrass culms at first and third harvest under four nutrient regimes.

	Nutrient Treatment				LSD
Harvest	Control	N	NPK	NPK+ME	P=0.05
Culms (No. pot^{-1})					
First	18.3	18.7	18.7	18.7	1.5
Third	7.7	25.3	60.7	64.3	9.3
Culm weight (g pot^{-1})					
First	2.0	1.7	2.2	1.9	0.5
Third	1.6	7.8	15.5	20.0	1.3

N = nitrogen, P = phosphorus, K = potassium, ME = minor elements

Table 2. Particle-sizes, total N and organic matter (OM) contents, pH, electrical conductivities (EC), and phosphorus measurements of the clayey and claypan soil profiles.

Depth cm	Particle-size percent <2µ	2-20µ	>50µ	Total N percent	Total OM percent	pH	EC dS m^{-1}	Phosphorus Total mg kg^{-1}	Bray mg kg^{-1}	Langmuir constants k	
Clayey soil											
0-4	19	21	35	0.20	3.4	5.4	0.14	456	14.3	0.61	133
4-8	23	19	38	0.12	2.0	5.3	0.14	366	5.9	0.56	161
8-12	39	17	31	0.12	1.9	5.9	0.27	406	6.6	0.72	212
12-30	59	15	22	0.11	1.5	6.7	0.58	446	5.8	1.60	312
30-40	55	18	22	0.08	1.1	7.6	0.66	466	4.8	1.04	320
40-67	58	22	15	0.07	0.8	7.9	1.30	476	3.0	0.58	263
67-75	62	26	11	0.06	0.5	7.5	2.50	546	7.5	0.20	354
75-90	65	29	6	0.04	0.3	7.7	1.65	586	6.2	0.38	384
90-105	68	32	trace	0.04	0.2	8.0	1.55	506	7.4	0.26	476
105-125	68	32	trace	0.04	0.2	7.6	1.40	610	4.4	0.30	217
Claypan soil											
0-5	17	22	36	0.16	2.9	6.4	0.16	376	13.4	0.18	169
5-14	22	21	38	0.10	1.6	6.2	0.14	306	5.6	0.55	177
14-19	32	19	34	0.10	1.5	6.1	0.19	346	5.4	0.74	226
19-35	58	13	nd	0.10	1.5	6.6	0.75	386	5.2	1.38	486
35-50	50	14	27	0.05	0.7	7.7	1.01	386	7.9	0.88	289
50-60	49	19	29	0.04	0.5	7.5	2.75	446	12.8	0.49	308
60-75	54	24	19	0.04	0.5	7.8	2.60	426	13.3	0.75	260
75-100	56	24	18	0.04	0.5	7.7	2.00	436	12.2	0.66	241
100-125	57	26	15	0.04	0.3	8.0	1.47	506	10.3	0.39	288

Table 3. Dry matter yield and phosphorus content from claypan plots receiving various fertilizer treatments.

	Fertilizer treatment Control	NPK+Zn	NPK+B+S	NPK+Mn+Fe	LSD p=0.05
Dry Matter (g m^{-2})					
Current year	90	219	300	203	90
Total	134	442	531	447	76
Phosphorus content (g kg^{-1})					
Current year	1.2	0.8	0.6	0.9	NS
Total	0.3	0.7	0.6	0.6	0.2

Table 4. Soil N, organic matter, Bray P, and DTPA extractable Zn and Fe for the claypan plots.

Fertilizer treatment None	NPK Zn	NPK B+S	NPK Mn+Fe	LSD p=0.05
Total N -- percent				
0.148	0.157	0.141	0.145	0.016
Organic matter -- percent				
2.65	2.62	2.56	2.73	0.41
Bray P -- mg kg^{-1}				
15	47	36	32	22.0
DTPA - extracted Zn -- mg kg^{-1}				
1.2	1.1	1.1	1.1	0.3
DTPA- extracted Fe -- mg kg^{-1}				
37	37	35	37	3.0

DISCUSSION

The reddish color in the NPK-treated WW plants was similar to the purplish color of P-deficient corn plants (Bingham, 1966). Hoagland solution or the soil may have supplied the deficient element for the third-harvest culms. WW plant growth in CP soil was poor if the plants received only water, slightly better with N, and much better with NPK either with or without ME. Vigorous WW growth in the CP soil apparently could not be sustained by applying N without at least P and/or K, too.

The Langmuir phosphorus-adsorption k and s values are similar for the CP and CL soil profiles. However, Harter and Smith (1981) indicated that comparisons between layers in soils or between soils are difficult to interpret. The largest k values in both soils occur in the upper B horizon where clay degradation may have increased the activity of Al and/or Fe which, in turn, would increase P adsorption.

The total P and Bray-P contents of the CL soil upper layers are slightly larger than in the CP profile. Subsoil layers in the CL profile contain higher clay and total P contents than in the CP profile. However, the subsoil Bray-P content is much higher in the CP profile than in the CL profile. The contents of total N and organic matter are larger in the upper layers of the CL soil than in the CP soil. Possibly, the N and P contents in the soil solution could be maintained at higher levels in the CL soil in the spring when western wheatgrass growth is rapid. In contrast, the CP lower layers have higher Bray-P contents, probably because the layer is infrequently moistened sufficiently so that roots can grow into the layer and adsorb P. The higher EC of the CP subsoil in comparison to the CL subsoil is consistent with a lower leaching rate of the claypan.

The data from the fertilized and unfertilized CP-soil plots (Table 3) need to be evaluated carefully because in the fertilized plots the plant species changed and subsoil was moved to the surface by small rodents. The significantly lower P content of the pre-1986 annual grass residue on the unfertilized plots in comparison to those receiving NPK probably is a real difference that reflects the difference in P availability. The higher P content of the 1986 herbage from the unfertilized plots in comparison to the fertilized ones, although not statistically significant, may also be a real difference. Most of the 1986 herbage in the unfertilized plots was from fine leaves of the warm-season shortgrasses which would contain a higher P content than the annual grass stems from the fertilized plots that made up much of the harvest in October. If the mean pre-1986 annual grass residue weights for the unfertilized and NPK+Mn+Fe plots (44 and 274 g m^{-2}) are multiplied by the P contents (Table 3), the residues contain 0.014 and 0.173 g P m^{-2}, respectively. Thus the mean yield and P contents of the unfertilized-plot residues were both low, which could result from the slow release of P in the spring and the unavailability to roots of the Bray-P in the CP subsoil.

CONCLUSIONS

Blue grama and buffalograss dominate CP areas in some old-landscape positions while WW dominate adjacent CL soils with more permeable profiles. In the study area, Langmuir-P-adsorption constants are similar for the CP and CL soils but the Bray-P content is higher in the CP subsoil. Bray-P may accumulate in the CP subsoil because roots cannot grow into the claypan and adsorb the P. Root growth may be reduced because the nearly impermeable claypan does not accumulate plant available water or because some minor element is deficient. Fertilization with acidic phosphate decreases soil pH and increases minor-element availability (Shuman, 1988). Thus, increased WW growth from NPK compared to N fertilization in the greenhouse could be from a minor element as well as from P and/or K. In the field, fertilization increased Japanese brome vegetation which shaded and killed blue grama and buffalograss. WW survived but did not invade into the CP area. Shortgrass domination of the claypan areas is caused by low soil fertility which reduces plant and root growth. As root channels become progressively less numerous, water infiltration and storage decreases, which in turn further decreases root growth. Blue grama and buffalograss can survive if roots are restricted to a surface layer but WW cannot survive. With fertilization, western wheatgrass apparently can grow on the claypan soil, but ripping or some mechanical treatment may be needed to increase subsoil-water storage and root penetration (White, et al., 1981).

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