SUBSOIL THICKNESS EFFECTS ON CROP YIELD AND SOIL WATER WHEN RECLAIMING SODIC MINESPOIL[1]

by

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Abstract. Minespoil sodicity has the potential to impede reclamation success on surface mined-land. A joint government/coal industry experiment was established near Highvale, Alberta to determine suitable subsoil thicknesses (0, 55, 95, 135, 185 and 345 cm underlying 15 cm topsoil) for reclaiming sodic minespoil and maximizing production of an annual barley (Hordeum vulgare L.) cereal crop or a perennial alfalfa-smooth bromegrass (Medicago sativa L., Bromus inermis Leyss.) forage mixture. Barley and forage yields were lower on the 0 cm subsoil treatment than all other treatments. Yields for both crops increased as subsoil thickness increased to 55 cm. There was a consistent trend toward optimum yields on the 95 cm subsoil treatment, but the difference between 55 and 95 cm was not significant. The replacement of 55 to 95 cm subsoil plus 15 cm topsoil appeared sufficient to restore post-mine productivity to the potential achieved on surrounding agricultural land. Root depth under the forage mixture increased as total soil thickness increased, while increases under the cereal were not generally significant. The average effective root zone extended to about 85 cm under barley and 185 cm under alfalfa-smooth bromegrass. Average seasonal soil water within the effective subsoil root zone generally increased under barley and decreased under alfalfa-smooth bromegrass over time. Accumulations of soil water above the subsoil/minespoil interface under barley were attributed to lower consumptive use of available soil water and a shallower effective root zone compared to forage. Perennial forages appeared to be more effective in reducing soil water accumulations above the interface and promoting reclamation success of sodic minespoil.

Introduction

More than half of the coal recoverable by strip-mining in North America underlies the Northern Great Plains of Canada and the United States (Currie 1981). Research in the Plains region has shown that water infiltration/retention and sodicity/soluble salt levels are two important soil properties that can be modified during reclamation (Doll et al. 1984). When minespoil has properties that restrict plant growth and impede reclamation success, sufficient topsoil and/or subsoil should be salvaged and replaced to restore post-mine productivity (Hargis and Redente 1984). Chemical reclamation has proven effective, but does not have the physical benefits of soil replacement (Doering and Willis 1975).

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Minespoil sodicity causes clay particles to become dispersed, reducing pore size and restricting movement of air and water (Smith et al. 1985; Uresk and Yamamoto 1986). Upward migration of sodium can deteriorate the quality of overlying topsoil or subsoil and contribute to declining productivity (Merrill et al. 1980). Accumulations of sodium have been observed immediately above the minespoil contact (Merrill et al. 1983b; Scholl 1987). Reduced permeability at the minespoil contact can also contribute to accumulations of soil water. Higher water content increases the efficiency of upward sodium movement, such as by chemical diffusion or convection (Merrill et al. 1983a). It also has the potential to reduce surface access by farm machinery if accumulations of soil water persist.

The benefits of topsoil replacement over sodic minespoil have been shown to increase crop yields and improve water use efficiency with the soil profile (Halvorson et al. 1987; Redente et al. 1982; Sieg et al. 1983). Merrill et al (1983a) showed that an application of 30 cm of topsoil over moderately and highly sodic minespoil increased forage yields by 25% and 84%, respectively, compared to only an 8% increase over non-sodic minespoil. Subsoil underlying topsoil has also proven beneficial in reclaiming sodic minespoil and restoring productivity (Pedology Consultants Ltd. 1987; Power et al. 1979). Barth and Martin (1984) showed that about 70 cm total soil thickness over sodic minespoil provided maximum perennial grass yields. Power et al. (1981) reported an increase in yield and root depth for several crops as subsoil thickness increased. Results showed that when sodic minespoil was within 90 and 150 cm of the surface, water extraction under alfalfa was to 135 and 175 cm, respectively; under crested wheatgrass (<u>Agropyron</u> <u>desertorum</u>) it was to 120 and 150 cm, respectively; water extraction under native grasses was to 80 and 120 cm, respectively; and water extraction under spring wheat (<u>Triticum aestivum</u> L.) was to 75 and 95 cm, respectively. Merrill et al. (1985) and Power et al. (1985) reported maximum perennial grass yields on 20 cm topsoil plus 80 cm subsoil over sodic minespoil. They indicated that both root depth and water use efficiency increased as subsoil thickness increased. It was suggested that low hydraulic conductivity in the minespoil had an inhibitory effect on plant growth by limiting water use.

Coal mines in central Alberta frequently disturb sodic material which cannot be reclaimed to acceptable standards without replacement of salvaged topsoil and subsoil. A series of experimental plots were set up to identify suitable thicknesses of subsoil replacement for reclamation that would provide equivalent productive potential to pre-mine conditions. The determination of an optimum thickness for soil replacement over sodic minespoil was also considered important due to the substantial reclamation cost. This paper reviews the effect of subsoil thickness over sodic minespoil on the productivity of selected crops, root zone activity and soil water content (Graveland et al. 1988).

Methods and Materials

The study area was in central Alberta, approximately 65 km west of Edmonton (114° 34' Lat., 53° 29' Long.). Sodic minespoil in the Highvale Mine region originated from Dark Gray Solodized Solonetz and Solonetzic Dark Gray Luvisols that were developed on weathered residual bedrock and glacial till (Canada Soil Survey Committee 1978). The area has a sub-humid to humid climate, averaging 504 mm of precipitation annually (Environment Canada 1982). Growing season (April-October) precipitation was 326 mm in 1983, 428 mm in 1984, 411 mm in 1985, 506 mm in 1986 and 382 mm in 1987. Rainfall across the growing season generally followed a normal distribution, peaking in July. The growing season consists of about 104 frost-free days. The mean daily temperature during the growing season was 11.4°C in 1983, 10.7°C in 1984, 10.6°C in 1985, 11.2°C in 1986 and 12.3°C in 1987.

A series of plots were established on levelled minespoil at the Highvale mine in 1982. The experimental design had six subsoil thicknesses randomized in main-plots, two crops randomized in split-plots and three replications of each treatment. Main-plots included subsoil thicknesses of 0, 55, 95, 135, 185 and 345 cm underlying 15 cm of topsoil. Split-plots were seeded to an annual six-row barley (Hordeum vulgare L. cv. 'Klondike') crop or a perennial alfalfa-smooth bromegrass (Medicago sativa L. 'Rambler', Bromus inermis Leyss. 'Carlton') forage mixture.

Each main-plot measured 16 m wide X 20 m long. Plots were excavated into the minespoil to the required depth and the exposed sides lined with plastic to restrict lateral movement of water and sodium. Subsoil (mixed B and C horizons) was added and packed by a small front-end loader until level with the surface, then topsoil (A horizon) was applied. The experimental area was graded to allow drainage away from each plot. Non-sodic topsoil and subsoil material (Dark Gray Luvisol) was salvaged from an unmined field adjacent to the mine area. The chemical and physical characteristics of the topsoil, subsoil and minespoil materials are shown in Table 1. Samples were air dried and pH, EC, SAR, and soluble Na, K, Ca, Mg, Cl and SO_4 were determined by saturated paste extract (McKeague 1978). A 3-point determination of texture was made by hydrometer.

Two neutron probe access tubes were installed in each split-plot to a depth 50 cm below the subsoil/minespoil interface (Howse 1981). Soil water (% by volume) was measured with a Campbell Pacific Model 501 Nuclear Depth Probe. Soil water measurements were conducted at 15 cm intervals once a month during the 1983 to 1987 growing seasons (April to October).

Barley was drilled-seeded in May of each year at a rate of 108 kg/ha. Fertilizer was applied annually at rates of 17 to 75 kg N/ha and 0 to 17 kg P/ha. Alfalfa and smooth bromegrass were seeded with a Model SST 1201 Brillion seeder in June, 1983 at rates of 8 and 20 kg/ha, respectively. Fertilizer was applied annually at rates of 28 to 56 kg/ha, 11 to 17 kg P/ha and 0 to 9 kg S/ha. All fertilizer applications were made on the basis of spring soil fertility tests. Annual weed growth was controlled as required by hand weeding and herbicide application.

Crop yields were determined by clipping two randomly selected 1-m2 areas from the central portion of each split-plot at 5 cm above ground level. Annual forage samples were clipped from the same areas in late June to early July and again in mid September. Forage material was oven dried at 30°C for 48 hours and weighed. Forage establishment in 1983 and a dry fall in 1984 allowed only one harvest during these years. Grain samples were clipped in early September, air dried, threshed and weighed. In 1984, grain yields on the 0 cm subsoil treatment were reduced somewhat by geese depredation. After the fall harvest, the topsoil, subsoil and minespoil was sampled at 15- to 30-cm increments for chemical and physical analyses. Samples were air dried and analyzed in the same manner as the soil samples collected for plot construction (Alberta Soils Advisory Committee 1987). Root depth was noted from soil cores extracted during the 1985, 1986 and 1987 soil sampling program. The maximum depth of root penetration was measured along with the actual depth of topsoil and subsoil.

Yield, soil water and root data were analyzed statistically using a split-plot analysis of variance procedure for the years 1983 to 1987 (Steel and Torrie 1980). A Duncan's multiple range test was used to compare differences among treatments and years.

Results and Discussion

Crop Yields

The 5-yr mean barley (grain) and alfalfa/smooth bromegrass yields on the 0 cm subsoil treatment were lower than other subsoil treatments (Table 2). Generally, annual yields increased as subsoil thickness increased to 55 cm. There was a consistent trend toward optimum yields of barley and alfalfa/smooth bromegrass on the 95 cm subsoil treatment, but the difference between 55 and 95 cm was not significant. The 5-yr mean yields for barley (318 g/m2) and alfalfa-smooth bromegrass (478 g/m2) on the 95 cm subsoil treatment compare favorably with average 10-yr (1978-1987) barley (230 g/m2) and hay (470 g/m2) yields reported for the surrounding agricultural area (personal communication, March 7, 1988, Keir Packer, Crop Statistician, Alberta Agriculture). The results suggest that post-mine productivity can be restored by replacing 55 to 95 cm of subsoil plus 15 cm topsoil over sodic minespoil. Similar results were obtained by Barth and Martin (1984), with maximum production of a perennial grass obtained on 71 cm of replacement material. Power et al. (1981) recommended 70 cm subsoil plus 20 cm topsoil to maximize yields of several perennial and annual crops. Doll et al. (1984) suggested 60 to 90 cm subsoil plus 15 cm topsoil to maximize productivity on moderately sodic (SAR=10 to 20) minespoil.

Root Depths

Mean 3-yr root depths under barley were not significantly different among subsoil treatments, but a trend toward increasing root depth was observed when total soil thickness increased from 0 to 110 cm (Table 3). Root depths under alfalfa-smooth bromegrass, however, significantly increased as total soil sickness increased from 0 to 200 cm. Based on root depth observations and soil water measurements, the average effective root zone for barley was estimated at about 85 cm. The average effective root zone for alfalfa-smooth brome was estimated at about 165 cm in 1985, 175 cm in 1986 and 185 cm in 1987. Hausenbuiller (1985) reported a similar effective root zone for small grains (90 cm) and alfalfa (180 cm).

Penetration of barley roots from subsoil into underlying sodic minespoil was not generally observed, except in the 0 cm subsoil treatment (average penetration of 24 cm). Penetration of alfalfa-smooth bromegrass roots into sodic minespoil was observed in the 0, 55, 95 and 135 cm subsoil treatments in 1987 (average penetration of 45, 17, 26 and 6 cm, respectively). Root penetration into sodic minespoil was generally greater than the 10 cm reported by Barth and Martin (1984), but less than the 30 to 90 cm reported by Power et al. (1981). Root penetration into minespoil will likely contribute to improved infiltration of soil water and reduce bulk density over time.

Soil Water

Average seasonal soil water content within the effective subsoil root zone tended to increase over time under some subsoil treatments seeded to barley and decrease over time under some subsoil treatments seeded to alfalfa-smooth bromegrass (Table 4). The results suggest greater consumptive use of available soil water by perennial forages than annual cereals. Stoskopf (1981) reported consumptive use of soil water to be about 30% higher in alfalfa than barley. By 1987, soil water content under barley was greater than under alfalfa-smooth brome in the topsoil (26 vs. 20%), subsoil (35 vs. 28%) and minespoil (35 vs. 32%) materials across all treatments. There was a tendency towards lower soil water under forage than barley from topsoil to minespoil throughout the growing season.

Accumulations of soil water immediately above the subsoil/minespoil interface occurred less frequently in subsoil treatments under forage than under barley (Table 5). Soil water content under forage was consistently lower above the interface of the 55, 95 and 135 cm subsoil treatments in 1984, 1985 and 1986, as well as the 185 cm treatment in 1987. There was no change in soil water content above the interface for any subsoil treatment under barley. These results reflect the deeper effective root zone under alfalfa-smooth bromegrass and its higher consumptive use of soil water. Merrill et al. (1985) determined that the reduced capacity of minespoil to accept water infiltration leads to soil water accumulations above the subsoil/minespoil interface.

Occasionally, soil water accumulations above the interface under barley resulted in saturated conditions. Persistent accumulations of soil water could make access by farm equipment difficult when the minespoil interface occurs near the surface. In addition, accumulations of soil water above the interface could increase the opportunity for upward movement of soluble sodium from sodic minespoil into overlying material.

Summary and Conclusions

The application of between 55 and 95 cm of subsoil appears sufficient to restore post-mine productivity and promote optimum yields, provided appropriate crops are grown. The use of a perennial alfalfa-smooth bromegrass forage crop, rather than an annual barley crop, reduced the accumulation of soil water above the less permeable subsoil/minespoil interface, thereby reducing the potential for upward migration of sodium and improving surface access. In addition, forage root activity in the minespoil will likely encourage infiltration of soil water, reduce soil bulk density and generally improve reclamation success.

The accumulation of soil water under barley predisposes the subsoil to this possibility. It was not known if the subsoil would deteriorate and become less productive over longer periods of time due to upward migration of sodium from underlying sodic minespoil if barley rather than alfalfa-smooth bromegrass was grown.

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Table 1. Properties of topsoil, subsoil and minespoil materials used for plot construction in 1982.

Soil Property	Topsoil	Subsoil	Minespoil
Texture+	CL	SiC	SCL
pH	7.2	7.7	8.5
Saturation (%)	57	57	95
EC (dS/m)	0.64	0.51	1.89
Soluble Na (mmol/kg)	0.34	0.51	13.70
Soluble K (mmol/kg)	0.50	0.17	0.30
Soluble Ca (mmol/kg)	5.23	3.81	2.09
Soluble Mg (mmol/kg)	1.27	1.05	0.51
Soluble Cl (mmol/kg)	0.30	0.18	0.18
Soluble SO_4 (mmol/kg)	0.90	0.86	20.33
SAR	0.38	0.65	20.14

+ CL=Clay Loam SiC=Silty Clay SCL=Sandy Clay Loam

Table 2. Dry weight (g/m^2) of barley (grain) and forage (alfalfa/smooth brome) as affected by subsoil thickness.

Subsoil Thickness	1983		1984		1985		1986		1987		5-yr Mean	
(cm)	Barley											
0	112	b*	7	b	154	b	197	b	205	c	135	b
55	284	a	149	a	401	a	305	a	250	bc	278	a
95	293	a	176	a	462	a	336	a	323	a	318	a
135	344	a	188	a	455	a	276	a	313	ab	315	a
185	327	a	176	a	453	a	342	a	291	ab	318	a
345	318	a	171	a	381	a	331	a	291	ab	298	a
SE	37		42		54		47		33		23	
	Forage											
0	68	c	384	a	423	a	467	a	264	b	321	b
55	146	b	483	a	524	a	473	a	486	a	422	a
95	186	a	640	a	516	a	533	a	513	a	478	a
135	125	b	597	a	553	a	530	a	529	a	467	a
185	136	b	597	a	552	a	556	a	509	a	470	a
345	136	b	572	a	501	a	531	a	494	a	447	a
SE	22		98		68		70		75		42	

* Means down the same column (within subtables) followed by the same letter are not significantly different at the 10% level.

Table 3. Root depth (cm) of barley and forage (alfalfa/smooth brome) as affected by soil thickness.

Total Soil Thickness	Average Interface Depth	1985		1986		1987		3-yr Mean	
(cm)	(cm)	Barley							
15	15	40	a*	37	a	40	b	39	a
70	68	45	a	47	a	55	ab	49	a
110	99	58	a	58	a	66	a	61	a
150	145	60	a	58	a	61	ab	60	a
200	205	67	a	65	a	78	a	70	a
360	367	63	a	58	a	69	a	63	a
SE		12		12		12		10	
		Forage							
15	15	50	c	60	e	60	d	57	e
70	76	63	c	82	de	93	c	79	d
110	107	95	b	102	cd	133	b	110	c
150	140	154	a	129	bc	146	b	143	b
200	208	163	a	170	a	146	b	159	a
360	371	158	a	159	ab	179	a	166	a
SE		12		17		13		8	

*Means down the same column (within subtables) followed by the same letter are not significantly different at the 10% level.

Table 4. Changes in seasonal (April-October) soil water content (%) over time within the effective subsoil root zone under barley and forage (alfalfa/smooth brome).

Year	Effective Subsoil Root Zone	Subsoil Thickness				
		55cm	95cm	135cm	185cm	345cm
	(cm)	Barley				
1983	15-70	30.7 b*	31.2 a	30.3 a	30.9 a	31.0 b
1984	15-85	29.4 c	28.5 a	27.3 a	29.2 a	28.7 c
1985	15-85	32.8 a	32.5 a	31.7 a	33.1 a	33.8 a
1986	15-85	33.2 a	33.5 a	32.2 a	33.2 a	34.0 a
1987	15-85	33.0 a	33.8 a	32.9 a	33.9 a	34.2 a
SE		0.52	0.51	0.32	0.39	0.40
		Forage				
1983	15-115	31.6 a	31.8 a	31.2 a	31.8 a	32.0 a
1984	15-155	26.4 a	25.4 b	25.4 b	27.0 a	27.5 a
1985	15-165	25.9 a	25.0 b	24.7 bc	27.2 a	29.4 a
1986	15-175	27.3 a	26.1 b	24.0 cd	26.4 a	28.3 a
1987	15-185	26.0 a	25.1 b	22.9 d	25.5 a	27.5 a
SE		0.52	0.76	0.71	0.36	0.44

*Means down the same column (within subtables) followed by the same letter are not significantly different at the 10% level.

Table 5. Comparison of seasonal (April-October) soil water content (%) immediately above the subsoil/minespoil interface among subsoil treatments under barley and forage.

Total Soil Thickness	Sample Depth	1983	1984	1985	1986	1987
(cm)	(cm)	Barley				
70	55-70	31.6 a*	29.7 a	33.2 c	33.7 a	34.1 a
110	95-110	32.4 a	30.3 a	34.5 bc	34.1 a	36.4 a
150	135-150	32.6 a	31.5 a	35.7 b	35.5 a	38.3 a
200	185-200	29.6 b	30.3 a	33.1 c	32.3 a	35.1 a
360	345-360	33.3 a	32.2 a	38.0 a	35.9 a	37.7 a
SE		0.89	1.27	1.15	1.29	1.57
		Forage				
70	55-70	32.2 a	26.7 b	26.3 b	27.3 b	26.4 c
110	95-110	32.3 a	27.4 b	27.6 b	26.4 b	26.6 c
150	135-150	34.4 a	26.7 b	25.2 b	24.9 b	24.6 c
200	185-200	33.5 a	32.5 a	36.2 a	32.7 a	30.9 b
360	345-360	31.8 a	32.0 a	37.7 a	35.2 a	36.5 a
SE		0.77	1.31	1.57	1.93	1.90

*Means down the same column (within subtables) followed by the same letter are not significantly different at the 10% level.