BATTLE RIVER SOIL RECONSTRUCTION PROJECT: FIVE YEAR RESULTS OF THE TORLEA SOIL EXPERIMENT*

by

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Abstract. The Battle River Soil Reconstruction Project (BRSRP), featuring four experiments, was intensively monitored for five years, 1982-86. Goals were to determine the most effective methods of reclaiming mined lands using different depths and qualities of soil materials. This paper focuses on the Torlea Soil Experiment which was designed to asses the following methods of ameliorating sodicity: (1) removal of the sodic B horizon; (2) mixing the sodic B with calcium enriched C horizon; (3) applying gypsum; and (4) applying calcium rich bottom ash. With respect to crop yields there was no growth without topsoil or subsoil over spoil; poor growth with topsoil over spoil; and good growth with topsoil over subsoil over spoil. Subsoil horizon mixes and variations in depths did not result in statistically significant yield differences; however, deeper subsoils tended to yield better. Amendments proved to be very beneficial: ash outyielded gypsum and control plots. Gypsum treated plots were almost significantly higher yielding than control plots. Yields declined over time likely due to aging forage stands and to differences in rainfall. Soil quality expressed by salinity and sodicity more or less parallels yields in that better yields match better soil quality. Spoil alone is unsuitable for crop growth. Topsoil over spoil is better but salinity and sodicity levels in the topsoil remain moderate and high, respectively. Topsoils and upper subsoils have improved since construction and lower subsoils have degraded indicating leaching. in the upper profile and salt accumulation at depth. These changes were more pronounced during the first couple years than later, indicating that conditions may be stabilizing, at least during current drier than normal weather. Addition of bottom ash to topsoil has been very beneficial in improving soil quality.

Additional Key Words: land reclamation; solonetzic soils; saline-sodic mine soils; amendments; reclaimed land yields.

Introduction

The Battle River Soil Reconstruction Project (BRSRP) involved establishment, soil and crop management, and research monitoring of four experiments designed to assess methods of reconstructing soil profiles following surface mining of coal in order to ameliorate the problems caused by the saline and sodic nature of the subsoils and bedrock.

The four experiments assess soil reconstruction methods in terms of soil materials, amendments and crops, as follows:

1. Subsoil Depth
   - varying subsoil depths, (ranging from 25 to 350 cm);
   - productivity of forage and cereal.
2. Torlea Soil
   - separating and mixing subsoil horizons, including different thicknesses;
   - use of gypsum and bottom ash as a surface amendment;
   - use of bottom ash as a capillary barrier;
   - productivity of forage crops.
3. Bottom Ash
   - the use of bottom ash and gypsum as a barrier to salt movement;
   - productivity of forage and cereal.

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4. Slope Drainage - manipulating the slope and aspect of reclaimed land;
   - upper, middle and lower slope positions;
   - productivity of forage.

This article presents the main findings of the Torlea Soil Experiment.

Background

Sodic mine spoil presents major technical problems in reclamation of surface mined lands in east-central Alberta. Adverse chemical and physical properties, and limited depths of reclamation materials are further complicated by climatic and hydrogeologic conditions that result in water movement and salt migration. Restoring and sustaining land capability and productivity to pre-mined levels in this dynamic environment is complex and challenging.

The most popular method for ameliorating problems caused by sodic mine spoils involves the placement of good quality topsoil, subsoil, or both, above the mine spoil to provide a root zone with favorable chemical and physical properties. Benefits of topsoil placement over spoil were well documented prior to the establishment of the BRSRP (U.S.D.A. 1977; Dollhopf et al. 1977; Grandt 1978; Nielsen and Miller 1980; Sandoval et al. 1973).

Soil depth required for adequate reclamation depends on environmental factors, intended land use and the nature of the spoil and soil materials. Soil thickness requirements for saline and sodic spoils may need to be greater than for other spoils to allow for upward salt migration, settling and subsidence, surface erosion, uneven spreading of soil material and internal drainage restrictions (Power et al. 1978). Numerous studies in the United States conducted under conditions that are considered to be similar to those at the BRSRP site revealed that optimum crop yields were obtained at total soil depths (topsoil and subsoil) ranging from about 60 cm to 120 cm (Barth and Marten 1984; Doll et al. 1984; Hargis and Redente 1984; Merrill et al. 1985; Power et al. 1981; Schuman and Power 1981).

Solonetzic soils are common in the coal fields of the Alberta plains where the bedrock of the coal bearing formations occurs close to the surface. Reclamation of lands with extensive areas of Solonetzic soils is difficult, because these soils often have very thin A horizons making salvage of suitable quantities of topsoil a problem. Furthermore, the subsoils are often shallow and have undesirable characteristics resulting from the accumulation of clay and sodium in the Bnt horizon. Additional management must be employed to improve subsoil quality. During stripping of soil materials prior to mining, the sodium enriched B horizon can be mixed with the calcium enriched upper C horizon for replacement over the spoil during reclamation.

Various chemical amendments containing calcium can be applied to remove the sodium from the soil colloids and improve the soil's physical characteristics. Gypsum has been applied with varying degrees of success to sodic strip-mined spoils. Dollhopf and DePuit (1981) found no significant effects of incorporated gypsum after 3 years of monitoring reclaimed mine spoil in Montana. Merrill et al. (1983), reported that, at four locations studied in North Dakota, gypsum incorporation increased average yields by 19% on topsoiled, highly sodic spoil. Furthermore soil water depletions and recharges were significantly higher, and the sodicity of highly sodic topsoiled spoils was decreased by up to 25%. In Alberta, gypsum was applied as an amendment to trial plots of the Camrose Ryley Project (Transalta Utilities Corp. and Fording Coal Ltd. 1987). After 10 years, topsoil salinity had increased, sodicity decreased, and average crop yields were not affected.

Ash from the coal burning thermal power stations in Alberta was considered to have potential for use as a soil amendment on sodic soils (Lutwick et al. 1981). Shaneman and Logan (1978) determined that a 15 cm layer of bottom ash contains an exchangeable calcium content roughly equivalent to 20 t/ha. The application of bottom ash over the surface of reclaimed lands increases the water holding capacity and can result in a better medium for crop growth than sodic spoil. On Bottom Ash Trial Plots, set up adjacent to the BRSRP site, ash was applied at thicknesses of 10, 20 and 30 cm and was incorporated using a disc, chisel plow or Kellough Subsoiler, or left as a blanket on the surface of the spoil (Fullerton 1987). The 30 cm rate was the most effective in promoting growth. Forage yields were higher than those reported for local farms. Eventhough ash appeared to stabilize over time, trafficability remained a problem on the 30 cm plots.

Buried bottom ash between spoil and subsoil was considered to be a useful barrier to sodium movement in that the coarse, sand-like ash would act as a capillary barrier. Its high calcium content could provide a potential buffer against sodium movement

(Parker 1981). Redente et al. (1982) working in northwestern Colorado, tested the use of gravel and cobble as a capillary barrier between a good quality topsoil and retorted oil shale having EC of 7 mS/cm and SAR of 14. The capillary barrier enabled topsoil depths to be reduced from 90 to 60 cm without a reduction of forage growth. However, the filling of capillary pores with topsoil particles was observed after 3 years and could effectively reduce the long term benefits of the capillary barrier.

Leaching of surface materials by both saturated and unsaturated percolation into and through a soil can occur. Where rainfall is sufficient, saturated flow through the soil will occur, with the wetting front proceeding at a uniform rate through the soil, provided materials are uniform. Where surface fissures and cracks are common, unsaturated flow down them can occur. Halvorson (1985) sampled seventy sites in North Dakota, reclaimed for more than 10 years, and found increases in sodium to an average depth of 38 cm below the soil-spoil interface indicating that Na had been leached out of the upper part of the profile. Richardson and Farmer (1982) found that SAR values had decreased, from 12 to below 3, in surface materials of sites in southeastern Montana reclaimed for 5 to 7 years.

The migration of salts from the sodic mine spoil into the soil materials was a major concern of reclamation in the Great Plains Region at the time the BRSRP was established. Several mechanisms are likely responsible for this phenomenon including capillarity, diffusion and convection. In central Alberta, Moran et al. (1987) found that within reconstructed soils where the water table occurred within 1.0 m of the soil surface, soils could be expected to become saline and sodic through capillary rise of water and salts: where water tables were deeper, downward leaching of salts predominated. Diffusion and convection as mechanisms of upward salt movement in reclaimed soils were studied by Merrill et al. (1983) in laboratory column studies and results were then applied to field situations. It was concluded that significant sodium accumulations did occur by diffusion when a sufficiently large chemical gradient between soil materials and spoil existed. A very low hydraulic conductivity of materials was also necessary to prevent removal of accumulated salt by leaching. It was considered unlikely, however, that Na could be carried higher than 10 to 15 cm upward into non-sodic materials. Upward salt migration to similar heights has been reported in a number of studies on the Northern Great Plains (Barth 1983, Barth and Martin 1984, Merrill et al. 1980).

Materials and Methods

The study area is in east central Alberta, about 20 km north of Halkirk. It lies within the Castor Plain Physiographic District, an area of morainal veneer and blanket overlying undulating bedrock of the lower Horseshoe Canyon Formation (Pettapiece 1986). This bedrock which occurs above coal seams is saline, sodic and high in clay, and is rated "Unsuitable" for reclamation. Where residual materials are found at or near the surface, soils of the Torlea Series (Dark Brown Solodized Solonetz) occur. The Torlea experimental plots were constructed from Torlea soil materials. A soil profile description of a native Torlea Soil follows (from Wells and Nikiforuk 1988).

Horizon	Depth cm	
Ap	0 to 11	Dark brown (10YR 4/3 m); silt loam; weak, coarse cloddy and weak to moderate, fine granular; friable; abundant roots.
Bnt	11 to 28	Very dark brown (10YR 3/2 m); clay loam; weak to moderate, very coarse columnar breaking to moderate to strong; medium, angular blocky; very firm; plentiful roots.
Csa	28 to 48	Very dark gray (10 YR 3/1 m) and dark grayish brown (10YR 4/2 m); clay loam; moderate very fine to fine, angular blocky; firm; few roots.
IICsaca	48 to 55	Dark grayish brown (10YR 4/2 m); sandy clay loam; weak fine to medium pseudo platy; firm; very few roots.
IICs	55 +	Pale olive (5Y 6/3 d); common, medium, distinct (5Y 6/6 d) mottles; loam to clay loam; weak, fine to medium pseudo platy; firm; no roots.

The project area experiences a continental climate characterized by warm summers and cold winters. January is the coldest month with a mean temperature of -16 degrees C and July is the warmest month with a mean temperature of 17 degrees C. The agroclimatic class is 2AH indicating slight moisture and heat limitations (A.S.A.C. 1987). There is adequate precipitation (400 to 450 mm annually) and a long enough frost free period (averaging over 90 days) to permit the growing of all dryland crops that are typical to the prairie region of western Canada. Growing season precipitation data presented in Table 1 indicate a micro-climatic effect such that conditions at the project compound were drier than at the nearby Forestburg Plant Site during the monitoring period.

Table 1. Precipitation (mm) Forestburg Plant Site and BRSRP Compound.

	May	Jun	Jul	Aug	Sep	Sum
	mm					
20-yr Average FPS*						
1967 to 1986	45	77	72	53	42	289
5-Yr Average FPS						
1982 to 1986	44	72	88	55	55	314
4-Yr Average FPS						
1983 to 1986	42	78	76	45	69	310
4-Yr Average BRSRP*						
1983 to 1986	32	66	58	42	48	246
1983	44	133	60	19	20	276
1984	15	67	26	38	104	250
1985	57	36	50	98	17	258
1986	12	28	93	15	52	200

* FPS – Forestburg Plant Site (monitored by Environment Canada)

** BRSRP – BRSRP Compound (monitored by Alberta Research Council since 1983).

Arable soils in the region are used for dryland crop production, mainly wheat, barley and canola: non-arable lands are utilized for pasture and forage production. Forage yields specific to the BRSRP location are scarce, since most available data are reported on a Crop District, or Agro-ecologic Unit basis. A number of sites on Solonetzic soils in Flagstaff and Paintearth Counties were studied to evaluate deep plowing, ripping, and liming feasibility, from 1982 to 1986 by the Soils Branch, Alberta Agriculture. Crop yields from a number of these trials, near the BRSRP study site, and from regional records are compiled in Table 2, based on file information provided by Alberta Agriculture.

Plots were constructed and materials were initially sampled in 1980 to establish baseline chemical characteristics. Construction simulated the "take and put" technique of mine reclamation as described by Grandt (1978). First, the area of mine spoil was levelled, then plots were constructed using Manalta Coal Ltd. – Vesta Mine machinery (dozers and scrapers).

Table 2. Forage yields (kg/ha) from agricultural lands and plot studies for comparison with BRSRP yields, 1983 to 1986.

Source*	Mean	1983	1984	1985	1986
A1	1550	1682(1)**	1457(1)	1525(2)	1535(3)
A2	2477	2959(1)	1726(1)	2915(1)	2309(2)
B	3141	3254	2940	2625	3747
C	1373	1117	676	2242	1456

* A – Yields from Solonetzic Soils Studies: (A1) control plots, (A2) 3 layer plow plots, Flagstaff and Paintearth Counties, Alberta Agriculture. Yields are from strips on farm fields.

B – Agricultural Reporting Area 4 data, Alberta Agriculture. (Farmers reported yields).

C – Paintearth Mine Torlea Soil Reclamation Trials. Reference yields (reseeded natural Torlea soil).

** Number of reporting trials.

A series of plots were established consisting of seven treatments as follows:

Treatment	Thickness of Layers
1	spoil
2	20 cm topsoil/spoil
3	20 cm topsoil/20-30 cm B+C/spoil
4	20 cm topsoil/45-55 cm B+C/spoil
5	20 cm topsoil/75-90 cm C/spoil
6	20 cm topsoil/100-115 cm C/spoil
7	20 cm topsoil/45-60 cm C/20-35 cm ash/spoil

Within each treatment surface amendments of 15 cm bottom ash and 20 t/ha gypsum were each spread on each of two subplots and incorporated during cultivation, while the third subplot was a control. Plot dimensions are 4 m x 24 m and each subplot is 4 m x 8 m. Note that actual depths of soil layers varied from original design specifications hence the ranges in thicknesses of subsoils. Selected properties of materials determined from grab samples collected during construction are given in Table 3 and original soil quality is rated according to recent guidelines (Alberta Agriculture 1987). Samples were air dried and pH, EC (electrical conductivity), SAR (sodium adsorption ratio), and soluble Na, K, Ca, Mg, Cl, and SO_4 were determined by saturated paste extract (McKeague 1978). The same methods were used subsequently in the annual monitoring of soils.

Table 3. Selected properties of materials from grab samples taken during construction.

Material	n	EC(mS/cm) Mean	SD*	SAR Mean	SD	SUITABILITY RATING**
Topsoil	90	2.4	1.0	13.5	1.2	U(SAR)
Subsoil	252	5.7	1.3	14.2	1.6	U(SAR)
Spoil	21	2.7	0.7	20.2	4.6	U(SAR)
Ash		1.2	0.2	24.5	3.7	-

Source: Techman Engineering Ltd. 1982, n = number of samples per reported mean.
* SD = Standard Deviation
** Alberta Soil Quality Criteria (Alberta Agriculture, 1987).

Ratings	Constraints
U - Unsuitable	SAR - High sodium adsorption ratio (sodicity)

One of the major aspects of reclamation of surface mined lands involves the use of readily available materials for soil reconstruction. Materials assessed for reclamation in this research include the following:

Topsoil: loam to clay loam textured Ah or Ap horizon material removed from the native soils before mining. It had an "Unsuitable" rating because of its excessive sodicity, based on Alberta soil quality criteria (Alberta Agriculture 1987).

Subsoil: clay loam B and C horizons plus underlying material that has chemical and physical properties suitable for sustaining vegetative growth. Subsoil materials consist of shallow till and weathered bedrock and are rated Unsuitable because of high sodicity.

Spoil: consists of clayey sodic bedrock materials of the Horseshoe Canyon Formation. It is "Unsuitable" reclamation material because it has SAR values above 20. The relatively low EC values in comparison with the SAR values is characteristic of spoil materials of the Northern Great Plains (Power et al. 1978).

Bottom Ash: the waste product of coal burned at the Battle River Thermal Power Station. It is a sandy textured, pumice-like material characterized by relatively high calcium content and potentially toxic concentrations of boron (McCoy et al. 1981).

Gypsum: was applied at 20 t/ha as a surface amendment and as a 20 to 35 cm layer below the subsoil in Treatment 7.

One neutron probe aluminum access tube was installed at the centre of each subplot to a depth 50 cm below the subsoil/spoil interface. Soil water was measured monthly, May through September, at specified depth increments with a Campbell Scientific Hydroprobe Subsurface Moisture Gauge, Model 503. Soil bulk density was measured annually with a Campbell Pacific Model 501 Nuclear Depth Probe. Both probes were calibrated annually by regression analysis of apparent readings and gravimetric measurements.

The soils within each subplot were sampled at a different point on a 1 m x 1 m grid each autumn with a 7.5 cm coring tube, at 15 cm intervals, continuing into the underlying spoil. Depths to material interfaces were noted and samples were taken above and below interfaces to preclude mixing of materials. Roots were described in the soil cores by noting depth, abundance and size in accordance with standard definitions (Agriculture Canada 1975).

An attempt to establish a forage mixture in 1981 failed so in 1982, Neepawa wheat was drill seeded as a nurse crop at a rate of 55 kg/ha and underseeded with Carlton bromegrass (Bromus inermis) drilled at 8 kg/ha and Rambler alfalfa (Medicago sativa) broadcast at 15 kg/ha. Fertilizer was broadcast each spring at recommended rates of approximately 45 kg N/ha, 45 kg P/ha, and 22 kgK/ha.

Forage yields were determined by mowing with a lawn mower and bagger 2 m x 6 m central portions of each subplot in mid to late July, 1983 to 1986. Yields were determined on a dry weight basis calculated from entire plot fresh weights measured in the field and subsamples oven dried at 30 degrees C for 48 hours.

Yield, saturation %, EC and SAR were analyzed statistically using a split-split-plot design with treatments as the main plot factor, amendment as the subplot factor and year as the sub-subplot factor. The amendment main effect was analyzed as three planned contrasts. Year main effects were decomposed into planned linear and quadratic contrasts using standard coefficients (Snedecor and Cochran 1980). Additional post hoc comparisons, including comparisons of treatment means, were conducted using Tukey's HSD at $p=0.05$. Data on soil moisture, density and rooting were summarized and used as an aid in interpreting soil forming processes.

Results and Discussion

Forage Yields

Forage yields were measured on first cuts taken each July, 1983 to 1986. Results are not presented for Treatment 1 which had little growth on ash amended plots and no growth on the others. Yields for Treatments 2 to 7 are given in Table 4: they were lowest for Treatment 2, highest for Treatments 3 to 6, and intermediate for Treatment 7. A pattern of gradually increasing yields corresponding to increasing subsoil thickness from 20 to 115 cm is evident, but not statistically significant. Treatment 7 with a buried ash layer between the spoil and subsoil produced inferior yields compared to subsoil alone, regardless of subsoil thickness.

Table 4. Forage yields 1983 to 1986.

Treatment	2	3	4	5	6	7
kg/ha	1872a*	3514b	3700b	3761b	3813b	3168ab

**n = 36, s.e. = 325, c.v. = 1595.

Amendment	1 (Ash)	2 (Gypsum)	3 (Control)
kg/ha	3624b	3292a	2986a

n = 72, s.e. = 113, c.v. = 330.

Year - linear and quadratic contrasts indicate a decline with time and a peak in 1984.

Year	1983	1984	1985	1986
kg/ha	3397b	3998c	3033ab	2783a

n = 54, s.e. = 138, c.v. = 520.

Year x Amendment

Year	1983	1984	1985	1986
Ash	4319cd	4174cd	2749ab	3256abc
Gypsum	3186abc	3942cd	3355abc	2685a
Control	2642a	3878bc	2994abc	2408a

n = 18, s.e. = 240, c.v. = 1166 (not within year).

* Values followed by same letter are not statistically different.

** n = number of observations per mean; s.e. = standard error; c.v. = critical value.

Surface amendments had important effects on crop growth. The control plots yielded lowest, gypsum treated plots were intermediate and almost statistically higher than controls, and ash amended plots yielded highest.

Time also had a significant effect in that yields peaked in 1984 and declined subsequently, the latter likely due to aging stands and to intensifying spring drought. Time amendment interactions were important in that yields on ash > gypsum > control in all years except 1985. Poor yields on ash amended plots in 1985 were likely a result of serious gopher damage which occurred only on ash amended plots.

In comparing these plot yields with those of other studies and farmers reported yields in the region (Table 2) it is clear that reclamation was very successful as evidenced by much higher crop productivity on the Torlea Treatments 3 to 7.

Soil Salinity

This section addresses saturation %, EC and SAR in topsoils, upper subsoils and lower subsoils, and spoils. Statistically significant findings are given in Tables 5 and 6. Significant interactions usually between year and amendment or year and treatment also occurred and are discussed.

Topsoils: There were expected marked differences in saturation %, in that both ash and gypsum amendments reduced saturation % relative to the control. There was also a decrease with time, most pronounced in the early years. EC and SAR levels were different in response to treatment, amendment, year, and interactions of these. In summary, the following are the most important results regarding topsoil quality after five years:

Treatment: Treatment 1 (no topsoil) was unsatisfactory throughout. Treatment 2 (topsoil over spoil) was better than Treatment 1 but inferior to Treatments 3 to 7 with subsoil. As of 1986, topsoils in Treatment 2 had highest EC and SAR levels, due to upward movement of sodium from the spoil or limited leaching, or both. Treatment 6 topsoil ranked next and was higher in EC and SAR than others.

Amendment: While ash caused trafficability problems, it clearly helped to improve topsoil chemical and physical properties. In ranking amendments, ash was usually superior, such that: EC - ash < control < gypsum; and SAR - gypsum < ash < control. Gypsum was effective in reducing SAR whereas ash "diluted" the soil and effectively enhanced infiltration, leaching and thereby reduced EC.

Time: EC and SAR decreased over the five-year period, with the major declines occurring in the last couple years.

Subsoil: Upper subsoils also differed in saturation percentage, EC and SAR.

Treatment: Saturation percentage of C materials was higher than of B+C mixes.

Table 5. Topsoil salinity, 1982 to 1986.

Treatment	2	3	4	5	6	7
Sat%	81b	61a	62a	62a	70ab	65a

n = 45, s.e. = 2.92, c.v. 14.3.

Amendment - ash (63) and gypsum (65) < control (72).

Year - linear and quadratic contrasts are significant, and there are differences between years.

Year	1982	1983	1984	1985	1986
Sat %	87c	69b	62a	58a	57a

n = 54, s.e. = 1.6, c.v. = 6.2.

Treatment	2	3	4	5	6	7
EC	4.1b	2.2a	2.2a	2.5a	3.3a	2.6a

n = 45, s.e. = 0.23, c.v. = 1.2.

Amendment	Ash	Gypsum	Control
EC	1.7a	4.1c	2.7b

n = 90, s.e. = 0.12, c.v. = 0.4.

Year - the linear decrease with time is significant.

Year	1982	1983	1984	1985	1986
EC	3.4	3.5	3.0	2.3	2.0

n = 54.

Treatment	2	3	4	5	6	7
SAR	18b	6.2a	8.7a	8.4a	10a	9.3a

n = 45, s.e. = 0.94, c.v. = 4.6.

Amendment	Ash	Gypsum	Control
SAR	9.5b	7.8a	13c

n = 90, s.e. = 0.40, c.v. = 1.4.

Year - The linear and quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
SAR	13	11	13	8.9	4.4

n = 54.

Amendment: Amendments are ranked the same as in topsoils for levels of EC indicating enhanced leaching in upper subsoils likely due to superior physical properties in the topsoil. But SAR levels in upper subsoils did not differ among amendments. Time: Linear and quadratic contrasts are significant for saturation %, EC and SAR. Saturation % decreased with time and levelled off in the last two years; EC increased with time then appeared to be levelling off; SAR increased, peaked in 1984, and then decreased but in 1986 was still above initial levels.

Table 6. Upper subsoil salinity, 1982 to 1986.

Treatment	3	4	5	6	7
Sat %	70a	72ab	94bc	96c	101c

n = 45, s.e. = 4.8, c.v. = 23.

Year - the linear decline and quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
Sat %	110c	92b	84a	77a	79a

n = 45, s.e. = 1.8, c.v. = 7.1.

Amendment	Ash	Gypsum	Control
EC	6.0a	7.7c	6.8b

n = 75, s.e. = 0.19, c.v. = 0.7.

Year - linear and quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
EC	5.0	6.6	7.3	7.6	7.8

n = 45.

Year - the quadratic contrast is significant.

Year	1982	1983	1984	1985	1986
SAR	16	19	21	18	17

n = 45.

Caution is advised in interpreting the technical significance of these results due to effects of declining saturation % over time. When saturation % is adjusted downward to be constant, EC levels in the early years become relatively higher. The overall trend becomes gradual improvement in upper subsoil quality over five years rather than initial degradation followed by improvement as signified by results given. This occurs in spite of salts being leached from topsoils and added to the upper subsoils.

Lower subsoils changed with time such that saturation % decreased mostly in the second year; EC increased considerably from 1982 to 1984 (6 to 9) then appeared to level off; SAR increased from 17 in 1982 to 24 in 1984 and declined to 19 in 1986. Without or with adjustments to standardize saturation %, final EC and SAR values are higher than 1982 values, indicating increasing salinization of the lower subsoil. Spoils in the layer below the interface did not change significantly over time. In

1983, EC was 5.9 and SAR was 32: in 1986, EC was 6.3 and SAR was 30. Note that EC levels in 1983 exceeded values from grab samples taken during construction (Table 3). Since fewer samples were taken during construction, it cannot be ascertained whether the apparent increase is due to spatial or temporal variation.

Soil Moisture

Major factors considered in gathering and interpreting moisture data included: moisture availability to plants and depth of rooting; occurrence of saturated conditions, or perched water table; and effects of moisture on soil development. Lab analyses of disturbed samples were conducted to determine wilting point (WP) and field capacity (FC). Values for topsoil are 22% and 40%, respectively, and for subsoil they are 29% and 47%, respectively, or a volume basis. Meaningful values for spoil could not be determined due to high sodicity; however, for reference purposes the subsoil limits are used. To summarize the five year data soil moisture classes were developed indicating droughty (wilting point plus 5% moisture) and readily available (remaining available moisture) soil moisture levels for crop growth (Can-Ag Enterprises 1989).

Maximum moisture levels seldom exceeded field capacity and never approached saturation %. This indicates an absence of water tables within the monitoring depths. Driest moisture levels measured by neutron probe on Torlea topsoils and subsoils were about 10% less than the mean wilting points determined by lab measurements. The wilting point moisture content used for spoil matched the lowest readings observed. Generally, the topsoils had moisture contents within the readily available range about one-third of the time in gypsum and control subplots and two-thirds of the time in ash subplots. The ash amended topsoils appear to store more moisture, perhaps reflecting higher infiltration rates and less runoff. This could be very important in "trapping" rainfall from short, intensive summer storms. Subsoils were generally always very dry in ash subplots; moist in the upper subsoil some 10 to 15% of the time in gypsum subplots; and moist about 20% of the time in control plots. This overview of subsoil moisture reflects trends opposite to those of yields suggesting that higher moisture extraction contributes to higher yields and reduces soil moisture contents.

Bulk Density

Measurements of apparent soil density in 1983 indicated the following mean values for control subplots, in g/cm3; topsoil 1.10; upper subsoil 1.48; lower subsoil 1.45; and spoil 1.45. Soil densities on a dry weight basis were calculated by subtracting moisture content as measured by moisture probe from soil density at field moisture levels as measured by density probe. The readings must be considered as approximate in this context as they are dependent on calibrations and operating errors of two instruments. Nevertheless, the soil density values obtained are considered to be within the range for natural soils but the subsoil densities are considerably lower than those found on the other three adjacent experiments where subsoil densities averaged around 1.80 g/cm3 (Can-Ag Enterprises 1989).

Root Distribution

All topsoils in Treatments 2 to 7 contained abundant fine and very fine roots. Subsoils had plentiful roots to 35 to 60 cm below ground surface and few roots beyond to a maximum of about 130 cm. Root penetration into spoil was limited to some 15 cm. Amendment effects were clear in Treatment 1 (spoil); in that the ash amended plots had much more forage growth and more roots than gypsum and control plots. In other treatments, effects of amendments were not well defined; however, it appeared that gypsum promoted deeper rooting in Treatment 6.

Synthesis

Treatment Effects

Treatment 1, no topsoil over spoil, was totally unsatisfactory as there were complete crop failures except on the ash amended subplots which yielded very poorly. Soil properties (EC, SAR) and soil quality remained Unsuitable throughout the monitoring period. Treatment 2, 20 cm topsoil over spoil, yielded poorly compared to treatments with subsoils. Topsoil quality remained Poor due to excessive SAR. It appears that leaching of salts was either restricted or countered by upward migration of sodium salts from spoil, or both. The rooting zone was severely restricted by shallow spoil so that available water storage capacity was essentially limited to that of the topsoil. Treatments 3 to 6, topsoil over increasingly thicker subsoils (correspondingly about 25, 50, 80 and 110 cm) produced good yields, almost doubling those obtained on similar natural soils in the region. There were increasing yields with increasing subsoil thickness, however this was not statistically significant. Topsoils in Treatments 3 to 6 improved from Poor to Fair at the start to Good by 1986, resulting from downward leaching of soluble salts. All upper subsoils remained Unsuitable but those in Treatments 4 and 6 were improving in the latter years while those in Treatments 3 and 5 were degrading as measured by EC changes of about 1 unit. Treatment 3, was degrading, possibly due to shallow depth to spoil (40 to 50 cm). More time is needed to determine whether these trends will become more pronounced and statistically significant.

Treatment 7, topsoil over 50 cm subsoil over 25 cm ash over spoil, had lower yields than Treatments 3 to 6; therefore buried ash was detrimental. There was no apparent beneficial or detrimental effect on subsoil quality compared to other treatments. Lower subsoil, that is, the layer above spoil, degraded an average of about 1 unit in EC in Treatments 4 to 7. This may be due to accumulation of salts leached from above, to upward migration from spoil, or both.

Amendment Effects

Forage yields across Treatments 2 to 7 were best on ash (3620 kg/ha) amended plots, followed by gypsum (3290 kg/ha) then control (2990 kg/ha). This is about a 10% difference between each. Treatment x amendment interactions were not significant, but the relative increases in yields imply the ash or gypsum surface amendments are much more effective than 30 cm increments of subsoil beyond a 50 cm thickness. The benefits of ash, however, are partly negated by poor trafficability and the duration of benefits or problems under repeated cultivation is not known.

Amendment effects were also important as EC and SAR levels in topsoils and upper subsoils clearly show that the ash amendment is superior. Gypsum is ranked intermediate: EC was highest in topsoils and upper subsoils, but SAR was lowest in the topsoils. Control plots had intermediate EC levels but highest SAR in topsoils and intermediate EC levels in upper subsoils. Over time, as topsoils improved, differences in chemistry between amendments and the control were decreasing.

In upper subsoils, there were very minor differences initially, grading to most pronounced differences and increasing levels in 1984, then improvement and declining differences in the last couple years. Therefore, it appears that Ash followed by Gypsum helped to hasten soil improvement in the upper profile. More time is needed to establish the longer term equilibrium.

Concerns

The results of this experiment are similar to those reported in the literature considering response to soil depth and amendments. However, the high yields compared to farmers yields and to those on the other three experiments at the BRSRP compound are puzzling. While initial construction design specified 10 cm of topsoil to match native soils, the final depths were about 20 cm. Also, bulk densities of subsoils in this experiment are in the order of 0.20 to 0.30 g/cm3 less than in the other BRSRP experiments. Lower densities should increase water availability in the root zone. The combination of thicker topsoils and lower soil densities no doubt contributed to the excellent yields and may have masked the importance of other characteristics including subsoil depth and horizon mixes.

At this time a salt accumulation layer is developing in the lower subsoil regardless of depth to spoil. If salt concentrations in this layer continue to increase, the salt levels could restrict the rooting zone making it somewhat shallower. Periodic monitoring in the future should establish whether this occurs.

Summary and Conclusions

Reconstructed soils consisting of 20 cm of topsoil over increasing thicknesses, from about 50 to 110 cm, of saline-sodic subsoil over sodic spoil were found to out-yield natural soils comparable to those from which the construction materials originated. However, caution is advised in extrapolating the results in that the reclaimed soils had thicker topsoils (20 cm) than the native soils (10 cm).

Topsoil quality improved significantly over time as salts were leached downward. Upper subsoils seemed to be improving in some treatments and degrading in others but more time is needed to determine whether current trends become statistically significant. Lower subsoils degraded over the five year period, regardless of treatment, indicating accumulation of salts leached from the upper profile.

Additions of ash and gypsum as surface amendments enhanced yields and improvement of quality of upper soil layers. The better yields are likely attributable to increased moisture availability resulting from the effects of the amendments.

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