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REVEGETATION OF SALINE LAND CAUSED BY POTASH MINING ACTIVITY

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Potash mining in Saskatchewan produces 20 million tonnes of waste salt (NaCl) each year. The salt is stored in surface piles which are primarily eroded by precipitation. The resulting brine is contained by a system of dykes but seepage through the dykes has salinized adjacent areas at most mines sites. Our study investigated ways of revegetating a severely salinized area at one mine. Two 30 cm deep surface amendments, topsoil and sewage sludge, were applied to the area and salt and water movements were monitored in the amendments for three years. Topsoil became severely salinized during the first summer and all the seeded grasses growing on it were killed. Sewage sludge sustained vegetation for three years. A greenhouse column experiment indicated that surface evaporation was the key factor determining salt movement into the two amendments. Field and greenhouse results were accurately simulated by the Trasee/Tracon computer model (r^2 values > 0.86 for sewage sludge). The model was used to simulate salt movement into different depths of amendments under various microclimatic conditions in order to assess the long-term suitability of the amendments to support vegetation.

La revégétalisation de surfaces salinées par les activités minières de la potasse

par

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En Saskatchewan, l'exploitation minière de la potasse produit approximativement deux tonnes de sel (NaCl) pour chaque tonne de potasse produite. Ce sel est entreposé en surface pour former d'énormes piles gui sont sujettes à une érosion surtout causée par la pluie et la fonte des neiges. La saumure gui en résulte est retenue par une série de digues. Cependant, dans certains cas, un écoulement provenant de ces digues a causé le salinage des secteurs adjacents en y détruisant la végétation, ce gui a suscité beaucoup d'intérêt concernant le confinement du sel à long terme. Notre étude a porté sur les méthodes de revégétalisation des sols ainsi salines gui continuent à recevoir de grandes guantités de sel. Deux revêtements de surface de 30 cm d'épaisseur, l'un composé de sol superficiel et l'autre de boues d'égout, ont été déposés sur une surface dénudée et de salinité très élevée, à la division Cory de PCS Mining. Les mouvements de l'eau et du sel ont été surveillés dans les deux revêtements ainsi gué dans le substrat souterrain. La capacité de ces revêtements, à permettre la croissance des herbes tolérantes au sel, gui y avaient été plantées, a ainsi pu être étudiée. Le revêtement de sol superficiel est devenu salin pendant le premier été et toute sa végétation a été détruite. Le revêtement de boues a cependant pu supporter une végétation sur les trois années de notre travail. L'étude du mouvement de l'eau et du sel s'est poursuivie en serre à l'aide d'expériences sur colonnes. Elle a révélé gué le taux d'evaporation de surface représentait le facteur le plus important, agissant sur la pénétration des deux revêtements par le sel. Finalement, les résultats sur le terrain et en serre ont pu être simulés avec précision (valeurs $r^2 > 0.86$ pour les boues d'égout) à l'aide du logiciel Trasee/Tracon. Ce modèle fut ensuite utilisé pour prédire les effets à long terme de l'utilisation de différentes épaisseurs de revêtements et de différents taux d'evaporation de surface (simulation de paillis de surface) et d'infiltration (simulation de barrières de neige accumulant la neige d'hiver) sur la capacité des revêtements à supporter une végétation.

INTRODUCTION

The potash mining industry in Saskatchewan produces about 10 Mt of potash (KCl), and wastes of about 20 Mt of salt (NaCl) and 10 Mm^3 of concentrated brine each year (Hart 1985a). PCS Mining, Cory Division, located 10 km west of Saskatoon, is typical of the 10 potash mines in the province. Ore (sylvinite) is brought to the surface from deep underground. It is crushed, and the KCl is separated by flotation and refined. Cory Division presently produces about 1 Mt/yr of KCl and generates approximately 2 Mt/yr of tailings. The tailings, comprised of 95% salt (NaCl) and 5% clays, are concentrated as a slurry and pumped to the tailings pile where they are deposited. Brine carrying the slurry percolates through the pile and is collected in brine ponds. The 35 Mt of tailings at Cory Division cover 150 ha and the brine ponds an additional 60 ha to form the core of the waste management area (Hart 1985a, Thorpe 1989).

About 1 m^3 of fresh water is required for each tonne of KCl produced, and each year the waste management area deals with 1 to 1.5 Mm^3 of saturated brine (Hart 1985a) . Approximately 45% of this water comes in the form of fresh water from the South Saskatchewan River and the remainder from precipitation over the waste management area. The latter erodes the salt as it percolates through the potash tailings. About half of the brine is disposed of by deep well injection, 30 - 40% evaporates from the area, and less than 10% remains in the tailings as residual moisture. The waste management area is surrounded by a dyke to contain the brine. Nevertheless, there is significant brine seepage through the dykes, as well as the underlying foundation soils, but much of this is intercepted by surrounding slurry trenches and pumped back to the brine pond. At present a small amount of brine escapes and enters the surficial aquifer. However, the containment of these huge surface salt deposits obviously presents a major waste management challenge in the long-term, particularly when the mines are decommissioned (Hart 1985b).

Much of the 190 ha area between the dykes and the slurry trenches at Cory Division is too saline to allow plant growth (Thorpe 1989). This paper summarizes some of the investigations of Thorpe (1989) on ways of rehabilitating these severely salinized areas. Two amendments, topsoil and sewage sludge, were applied to a denuded seepage area at the mine. The ability of the amendments to support seeded grasses was followed over a three-year period. A greenhouse column experiment was also made so that the movement of salt and water could be accurately predicted in the two amendments. A computer simulation model was then used to predict the performance of different depths of amendments, under various climatic conditions, to assess their suitability to sustain vegetation in the long-term. The results are also relevant to studies of the long-term management of potash mine tailings by encapsulating them with soils (Hart 1985b).

METHODS

Greenhouse column experiment

Fifty columns were constructed, 25 of sewage sludge and 25 of topsoil. Each column was housed in an open plastic pipe 55 cm high and 10 cm internal diameter. The bottom 20 cm of the pipe was packed with base material with a conductivity of 50 dS/m and a bulk density of 1.3 g/cm^3. A 30 cm layer of either topsoil or sewage sludge was loosely packed above this layer. The salinity of the base layer was maintained by standing each column in a 3 cm layer of NaCl solution maintained at a conductivity of 50 dS/m throughout the experiment. Each column was seeded with 10 seeds of E. junceus and watered with 2 cm of distilled water at O, 2, 7, 11, 17, 18, 28, 35, 42, 53, 60, 85, and 99 days and maintained at 22^{0}C with 16 h of daylight. For each treatment, five columns were destructively sampled after 60, 70, 80, 98, and 107 days and the gravimetric water content and ion concentrations in the soils measured at 5 cm depth intervals.

Field amendments

Two amendments, topsoil (a sandy loam) and sewage sludge, were applied on July 1, 1985 to a denuded seepage area. Each amendment was spread over a 6 m * 6 m area to a depth of 30 cm, and seeded with Agropyron elongatum, A. trachycaulum, Elysmus angustus, E. junceus, and Puccinellia nuttalliana in a 5 m * 5 m Latin square design. The amendments were watered on July 5 and 11 (totalling 4.9 cm for sewage sludge and 5.1 cm for topsoil) to stimulate the germination of the grasses. Both amendments were sampled at weekly intervals in 1985 and 1986 but in 1987 only the sewage sludge was sampled at monthly intervals. On each sample date 8 random soil cores (4 to determine soil moisture and 4 for ion analysis) were taken to a depth of 75 cm (i.e. the amendment plus 45 cm of the underlying saline base material). For analysis each core was split into six 7.5 cm sections down to a depth of 45 cm, and into two 15 cm sections between 45 cm and 75 cm.

Determination of soil parameters

Physical and chemical characteristics were measured directly for each soil type (sewage sludge, topsoil, and saline base), and for each depth if necessary. The various methods are described in detail by Thorpe (1989).

Computer simulation of sodium movement

The Trasee/Tracon computer model (Lam et al. 1987) was used. The Trasee model simulates the movement of water according to the physical and chemical properties of the soil (determined directly), the measured water inputs (rainfall or watering), and evaporation. Evaporation was determined by running the model and varying the seasonal evaporation level to achieve a "best fit" to the observed data. The Tracon model simulates the movement of a contaminant according to its diffusion properties and water movement (determined by the Trasee model). We used sodium as the marker contaminant because this is the major cation in the system. Observed and simulated values were compared using reduced major axis regression (Sokal & Rohlf 1981).

RESULTS AND DISCUSSION

Column experiment

The greenhouse column experiment was designed to investigate how salt moved into the topsoil and sewage sludge amendments by following the movement of sodium ions in columns maintained under controlled conditions. The physical properties of the two amendments were very different (Table IA) . Sewage sludge had a higher saturated hydraulic conductivity (K_{sat}), cation exchange capacity (CEC) and organic matter content, and a lower bulk density than topsoil. The volumetric water content was 30-50% higher in the sewage sludge compared to topsoil (Thorpe 1989), although the matric potentials in both amendments indicated that water would not be a limiting factor to plant growth (Russell 1971).

The biomass of Elysmus junceus was significantly higher (approximately 40% higher) on sewage sludge than on topsoil (Thorpe 1989). Two factors probably accounted for this difference in biomass: the higher nutrient level of the sewage sludge, and the higher salt contamination of the topsoil (Fig. 1).

Table 1. (A) Physical properties of amendments. (B) Observed rates of sodium movement from saline base into amendments. (C) Evaporation rates estimated by the Trasee/Tracon model. (D) Comparison of observed and simulated values of sodium at different depths using the coefficient of determination (r^2 value) of regression analysis.

		TOPSOIL	SEWAGE SLUDGE
A. Soil characteristic			
K_{sat} (m/s)		$1.4 * 10^{-5}$	$1.9 * 10^{-5}$
bulk density (g/cm^3)		1.26 ± 0.06	0.72 ± 0.24
organic matter (%)		4.2 ± 0.81	27.6 ± 0.94
CEC (meq/100g soil)		15.4	27.1
B. Rate of sodium movement into amendments (μg Na/cm^2/d)			
Greenhouse experiment		3600 ± 935	1780 ± 256
Field amendments	1985	8170 ± 4734	2042 ± 934
	1986	1430 ± 2274	970 ± 668
	1987	-	3500 ± 1642
C. Estimated evaporation rates (mm/d)			
Greenhouse experiment		3.5	2.5
Field amendments	1985	3.0	2.0
	1986	2.5	1.5
	1987	-	2.0
D. r^2 values of regression of observed versus simulated Na values			
Greenhouse experiment		0.82	0.90
Field amendments	1985	0.93	0.97
	1986	0.63	0.94
	1987	-	0.87

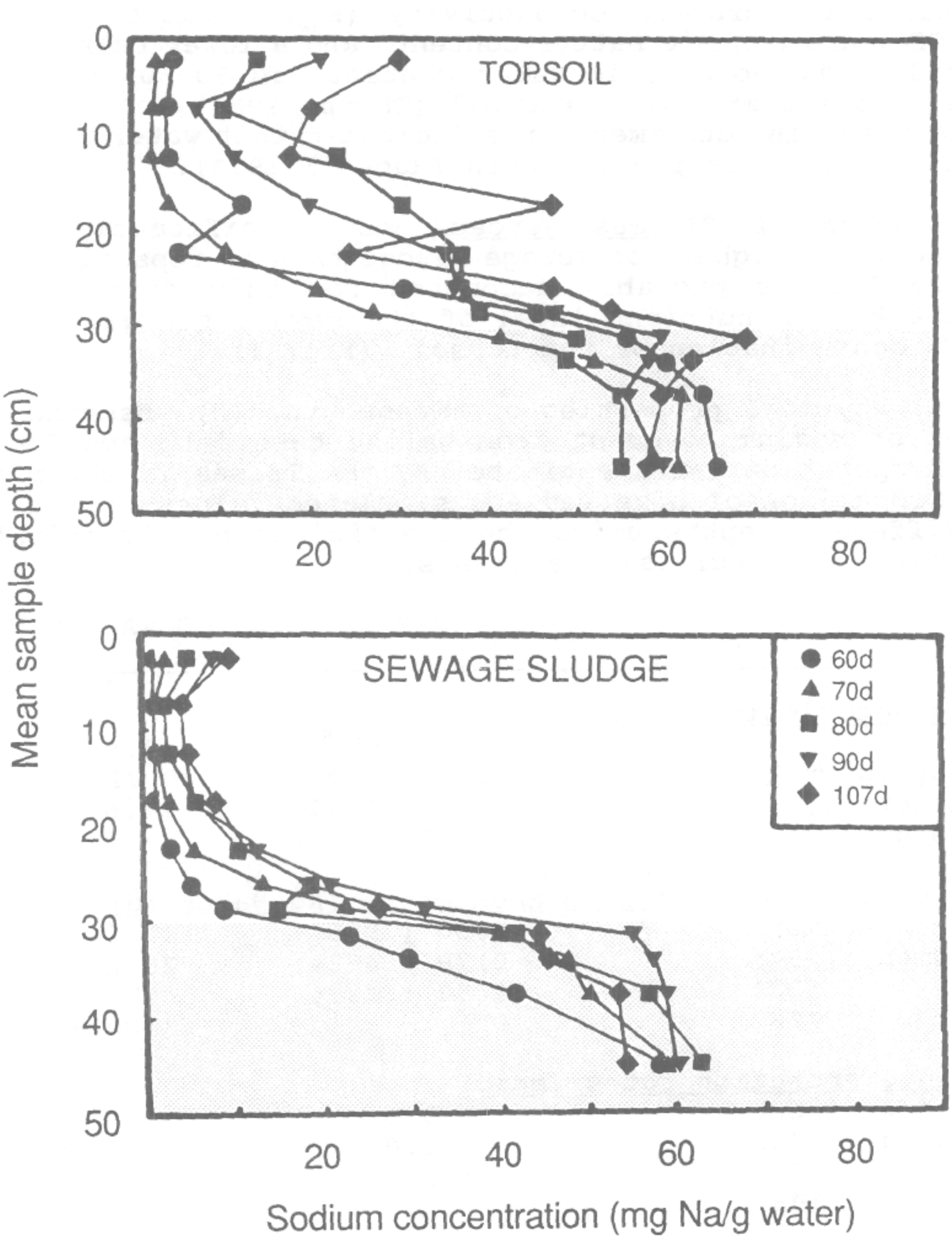

Figure 1. Mean soil water sodium concentration between 60 and 107 days in topsoil and sewage sludge columns overlying saline base layer (stippled).

The topsoil columns salinized more rapidly than the sewage sludge columns (Fig.1) and the upward migration rate of sodium from the saline base into the overlying topsoil was approximately twice that into sewage sludge (Table IB).

Sodium concentrations at the various depths in the amendments and underlying saline base were accurately simulated using the Trasee/Tracon model (Table ID). The simulation for the end of the experiment (day 107), when the greatest discrepancy between observed and simulated results would be expected, *is* illustrated in Fig. 2. The goodness of fit ($r^2 > 0.82$) was similar to, or better than, those reported for other studies (Merrill et al. 1983; van der Molen 1956). However, there was a systematic deviation between the actual and simulated data for the sewage sludge columns (Fig. 2). The actual data consistently showed a more S-shaped distribution with depth compared to the simulated data, with a much steeper concentration gradient at the amendment-saline base interface. We suspect that this is due to a poor seal between the two materials related to the lumpy nature of the sewage sludge, which was not easy to pack uniformly in the 10 cm wide columns.

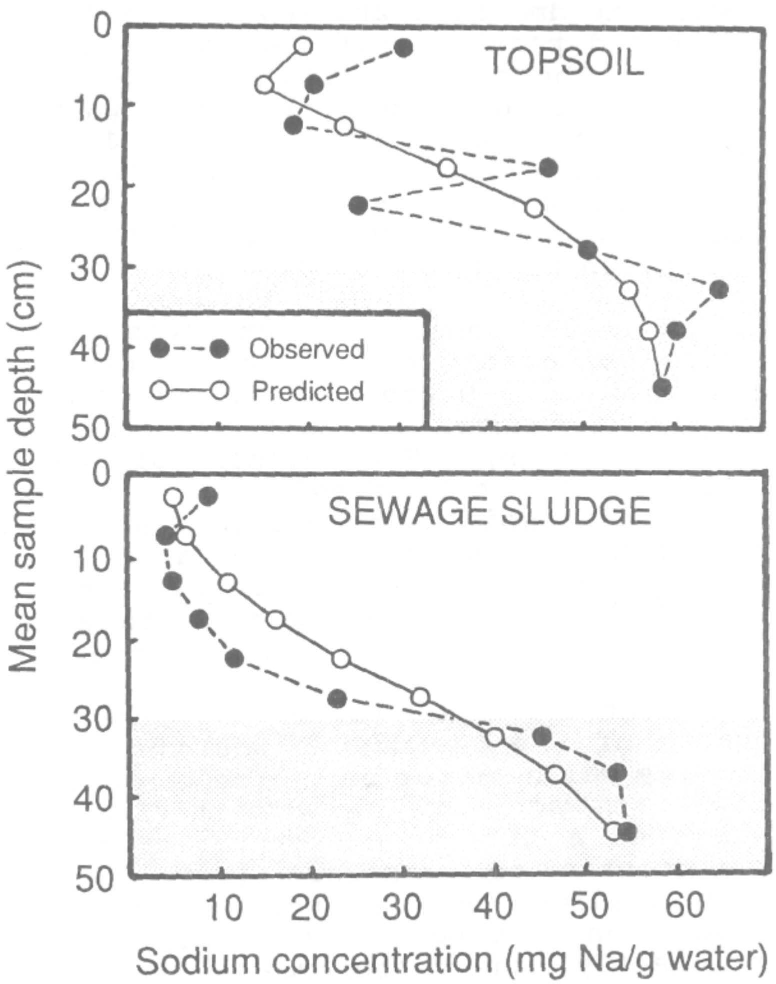

Figure 2. Observed and simulated soil water sodium concentrations for topsoil and sewage sludge columns after 107 days.

Sensitivity analysis of the computer model indicated that surface evaporation was the key factor governing the rate of sodium movement into the two amendments. The model indicated that sewage sludge had a lower evaporation rate than topsoil (Table 1C) , probably because of its ability to dry at the surface like a mulch. The result would be a faster build up of salt in topsoil compared to sewage sludge because of the greater mass flow of contaminated water from the saline base into the amendment to replace the water lost by evaporation. A similar positive correlation was found between surface evaporation and the movement of pollutants into topsoil amendments in a column experiment by Merrill et al. (1983).

Field amendments

Sewage sludge and topsoil amendments were applied to a severely saline site where vegetation had been killed by salt. Salt (NaCl) was continuously being added to the site by seepage through an adjacent dyke.

Initially the two amendments were very dry, but following watering in early July 1985 the volumetric water content and matric potentials in both amendments increased to the point that water would not have limited plant growth during the remainder of the study (Thorpe 1989). The five species of seeded grasses quickly became established on both amendments after watering, with E. junceus showing the best growth. On October 3, 1985, three months after applying the amendments, all the vegetation on the topsoil amendment was dead. In contrast, E. junceus and the two species of Agropyron continued to grow on the sewage sludge amendment until the end of the study in September 1987.

The vegetation on the topsoil was undoubtedly killed by salt (Fig. 3) because a white salt crust was clearly visible on the surface of the amendment by October 1985. The topsoil amendment was more rapidly contaminated by salt than the sewage sludge amendment (Fig. 3; Table IB). The movement of sodium in the two amendments was also accurately predicted by the Trasee/Tracon model, except for the topsoil amendment in 1986 (Table 1D). The difference in contamination rates of the two amendments was largely related to the difference in evaporation rates (Table 1C), which is similar to the conclusions of our column study and the field studies of Merrill et al. (1980) and Stark & Redente (1986).

In 1985, a contributing factor to the difference in contamination rates of the amendments was the fact that sodium concentrations in the saline layer below the topsoil amendment were higher than below the sewage sludge amendment (Fig. 3). Thus, mass flow of water carried a greater concentration of salt into the topsoil amendment compared to the sewage sludge amendment. By 1986, the concentration gradient between the saline base and sewage sludge was greater than that between the saline base and topsoil (Fig. 3) . Consequently, the difference in the rates of sodium movement into the two amendments was much less in 1986 compared to 1985 (Table IB).

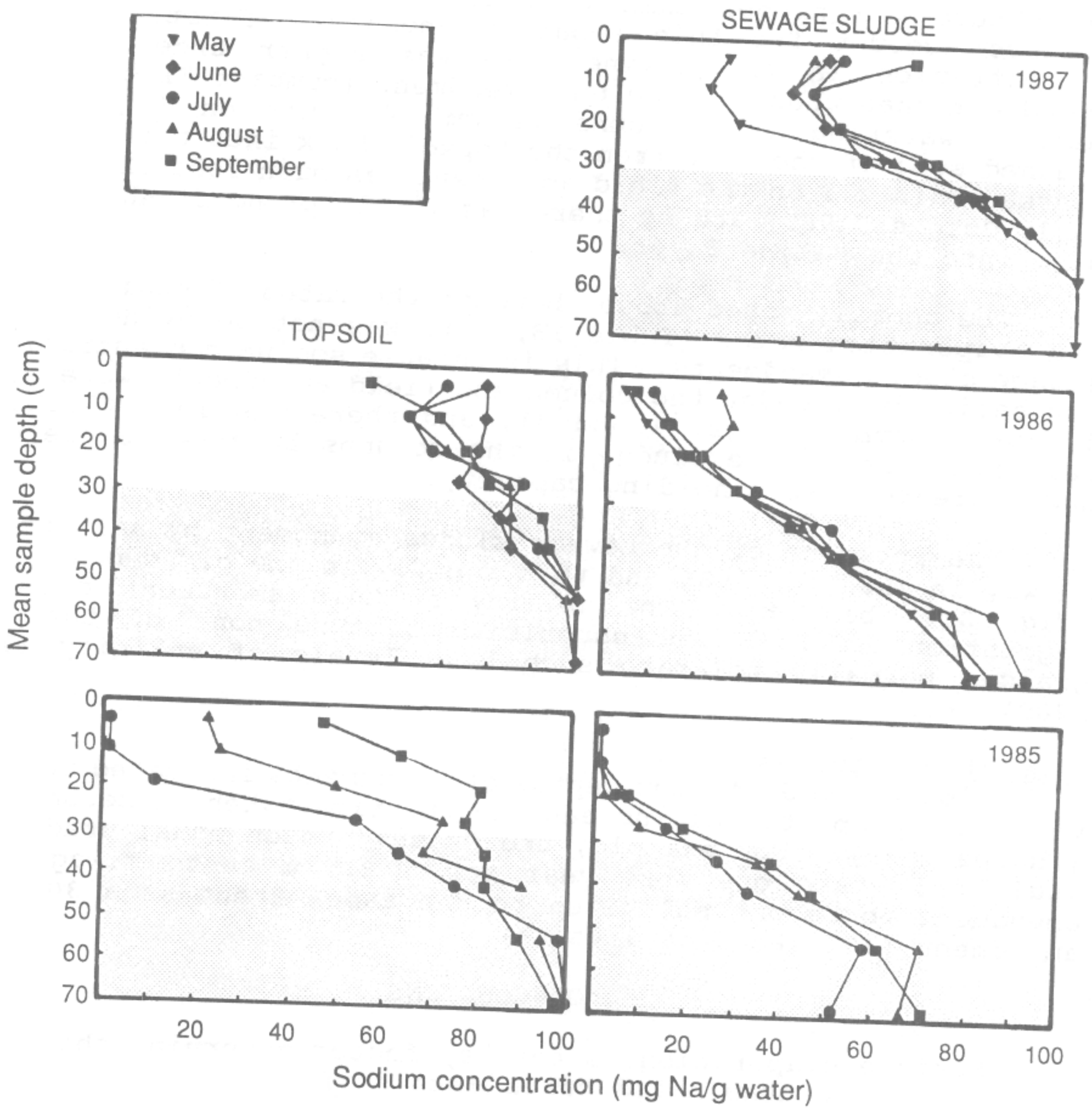

Figure 3. Profiles of soil water sodium concentrations in sewage sludge and topsoil amendments and saline base (stippled) at the mine site 1985-1987.

The rate of sodium movement into the topsoil in the field amendment in 1985 was considerably greater than into the topsoil amendment in the greenhouse column study (Table IB). However, the reverse was expected because the estimated evaporation rate in the greenhouse was higher than that in the field (Table 1C) . Two factors account for this apparent anomaly. First, the sodium concentration in the saline base was higher under the field amendment than under the column amendment (compare Figs. 1 and 3). Second, watering the columns (2 cm of water on 13 occasions) flushed some of the salt from the topsoil back into the saline base whereas rainfall on the field amendment was much less (128 mm July-early October 1985) and so there was little or no flushing of salt back into the saline layer.

The anomaly noted above, between the rates of sodium movement and evaporation rates (Table 1B, 1C) , was not so evident for the sewage sludge amendments. This is because sodium concentrations in the saline base under the column and field amendments were similar in 1985 (compare Figs. 1 and 3), and there was less flushing of salt from the sewage sludge in the columns because sewage sludge has a greater water holding capacity.

The invasion of the sewage sludge amendment by salt occurred slowly in 1985 and 1986 and then rapidly in the dry summer of 1987 (Fig. 3; Table 1B). The ability of this amendment to support vegetation in 1987 was surprising because none of the seeded grasses normally tolerate such high levels of salinity (Thorpe 1989).

Simulation studies

Simulating different depths of amendments indicated that there was not a proportional increase in the time taken to become saline (Thorpe 1989). For example, the Trasee/Tracon model predicted it would only take one more year for a 1.5 m depth sewage sludge amendment to become salinized to the same extent as a 30 cm deep amendment (4 instead of 3 years).

CONCLUSIONS

Surface evaporation is the key factor governing the movement of salt from contaminated bases into surface amendments in semi-arid regions like the Canadian prairies. Salt will increase in concentration at the surface unless the source of salt is removed or evaporative losses are balanced by flushing events (high surface water inputs) which carry salt from the amendment back into the contaminated base layer.

Long-term management and containment of potash mine tailings in Saskatchewan is required to prevent the contamination of surficial aquifers by brine. In simple terms, it is necessary to stop precipitation from reaching and eroding the tailings. This will require either a very deep cover layer or a multi-layered system (Hart 1985b). It is time to initiate pilot studies into these aspect of decommissioning the mines.

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