LONG TERM MEASUREMENTS IN RECONSTRUCTED SOILS AT A COAL MINE IN THE PLAINS REGION OF ALBERTA, CANADA[1]

Terry M. Macyk, Robert L. Faught, and Robert J. Logan[2]

Abstract: In 1983 the Alberta Research Council and Luscar Ltd. initiated a study to monitor the physical and chemical properties of newly mined and reconstructed soils at the Paintearth Mine. The objective was to determine what changes were occurring and the impact, if any, of these changes on long-term soil quality and productivity. Baseline soil sampling and neutron access tube installation were completed shortly after spoil leveling and soil replacement at six locations representing different slope positions and thickness of replaced subsoil. Monitoring sites were also established in unmined soils adjacent to the mine area. Neutron probe measurements to determine soil moisture and bulk density status in the upper 4 m were conducted annually from April to October. Forage crop harvests were completed to determine yield and forage quality in three different years. Sampling of soils in 15 cm intervals to a maximum depth of 210 cm for analytical purposes was completed in seven of the ten years of the study. Soil moisture data indicated that moisture content and distribution pattern in the reconstructed soils were similar to that of adjacent unmined soils. Bulk density at the reconstructed sites decreased with time during the term of the project and was similar to the bulk density values measured at unmined sites. The electrical conductivity data indicated salts were leached or redistributed downward in the profiles over time. Measurements to date indicate that in terms of soil moisture regime, bulk density status and forage yield the reconstructed soils are similar to unmined soils in the area. The overall improvement in the chemical properties of the reconstructed soils from the time of reconstruction could be largely attributed to leaching of salts.

Additional Key Words: soil quality, bulk density

Introduction

In the plains region of Alberta, dryland agriculture is the dominant land use before and subsequent to surface mining. As a result, one of the most important concerns related to surface mining of coal in Alberta is that the agricultural capability of reclaimed land be equivalent to that of the land prior to mining. Discussion and research pertinent to reclaiming surface mined lands in Alberta has been ongoing for more than two decades and has been driven largely by changes in legislation. The Land Conservation and Reclamation Act enacted by the province in 1973 (Alberta Government 1973) outlined a number of new requirements for rehabilitating lands impacted by resource development. The Coal Development Policy for Alberta (Alberta Energy and Natural Resources 1976) stated "the primary objective in land reclamation is to ensure that the mined or disturbed land will be returned to a state which will support plant and animal life, or be otherwise productive or useful to man to the degree it was before it was disturbed".

Measurement of reclamation success emphasized the concept of capability which included consideration of soil reconstruction (salvage, replacement, quality and depth considerations) as well as compaction and the potential for soil salinization.

The information presented in this paper provides some of the results from a study initiated in 1983 to initially and characterize subsequently monitor change in newly mined and reconstructed soils with time.

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Objective

The objective of the study was to monitor the physical and chemical properties of reconstructed soils to determine what changes were occurring and the impact, if any, of these changes on long-term soil quality and productivity. Specifically, the subobjectives were to:

- monitor soil moisture and determine if perching of water, especially at material interfaces, was occurring to an extent that soil quality and crop productivity might be impaired at different slope positions;
- determine the change with time in bulk density of the reconstructed soils;
- monitor salt content with emphasis on movement in relation to soil interfaces and slope position. If salt movement does indeed occur, determine the effects of such movement on soil quality and crop productivity;
- determine productivity levels at various locations and relate to unmined field productivity.

Materials and Methods

Field activities were initiated in the latter part of October, 1983 when the initial sampling of the replaced subsoil and leveled spoil was completed. In 1984 topsoil was placed on the surface and a forage mixture with oats as a nurse crop was seeded. The forage crop was seeded at the rate of 15 kg/ha and was comprised of brome grass (36%), crested wheatgrass (36%), and alfalfa (28%).

Baseline soil sampling of the entire reconstructed soil profile was completed at sites 2, 4, 5, 9, 10, and 12 (Figures 1 and 2) which involved removal of soil cores from three holes approximately 1 m apart at each site. The sampling interval was 0 to 15, 15 to 30, 30 to 45, 45 to 60, 60 to 75, 75 to 90, 90 to 105, 105 to 120, 120 to 135, 135 to 150, 150 to 180 cm and variations thereof. Sampling the same depth intervals, at the same locations, was completed in 1985, 1986, 1987, 1990 and 1993 to provide data for comparison purposes. Soil replacement included 15 cm of topsoil and approximately 1 m of subsoil over leveled spoil at sites 2, 4, 5 and 9. At sites 10 and 12 replacement included 15 cm of topsoil and approximately 50 cm of subsoil over leveled spoil.

Access tubes for measuring soil density and soil moisture were installed to a depth of 4 to 5 m at the six reconstructed soil sites and at several undisturbed soil locations including three located 1 to 5 km from the reconstructed soil study area. The undisturbed sites 1 and 46 are located in Halkirk (Dark Brown Solodized Solonetz (Natric Mollisol) on moderately fine textured till) soils and site 48 in Torlea (Dark Brown Solodized Solonetz (Natric Mollisol) on fine textured residual) soils both of which were present in the study area prior to mining and used in the salvage and reconstruction operations. The tubes with an outside diameter of 5 cm were pounded into a pre-cored hole with a diameter of 4.95 cm. The hole was purposely made slightly smaller in diameter than the pipe to ensure good soil-tube contact to preclude air spaces and the opportunity for water to run down along the wall of the pipe. Volumetric moisture and density measurements were made in June and September of 1985 and then approximately once a month from May to October in the remaining years of the study using a Campbell Pacific 501 moisture/density probe.

Yield at each of the sites was determined in the latter part of June in 1985, 1986 and 1987. A number of subplots were harvested and the air-dry weight of the plant material and feed quality were determined.

The soil samples collected were delivered to and processed by the Resource Technologies Laboratory immediately following field sampling. The pH was measured in a paste (Doughty 1941) and in a 2:1 slurry of 0.01 M $CaCl_2$ (Peech 1965). Saturated pastes were prepared according to the USDA Soil Salinity Laboratory method (Rhoades 1982, USDA 1954). Extracts were filtered through a 0.45 μm filter and analyzed for electrical conductivity (EC) using a Yellow Springs Instruments conductivity cell and Model 32 conductance meter. Soluble ions (Na, K, Ca, Mg, S) were measured using an ARL Model 3680 Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES). The sodium adsorption ratio (SAR) was calculated from the soluble ion data. Particle size was determined by the simplified hydrometer method (Gee and Bauder 1979).

Precipitation was measured at a site 2 km from the study area. Monthly totals for May to October were recorded in 1984 to 1990 and again in 1993.

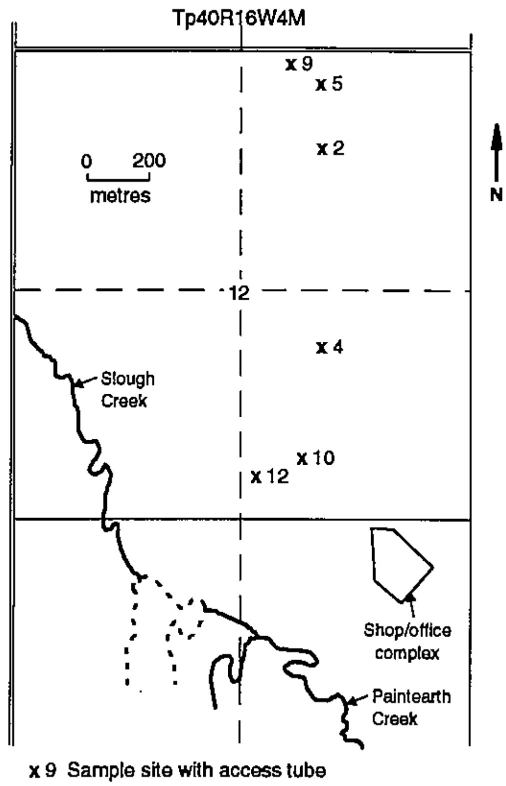


Figure 1. Location of reconstructed soil monitoring sites at Paintearth Mine.

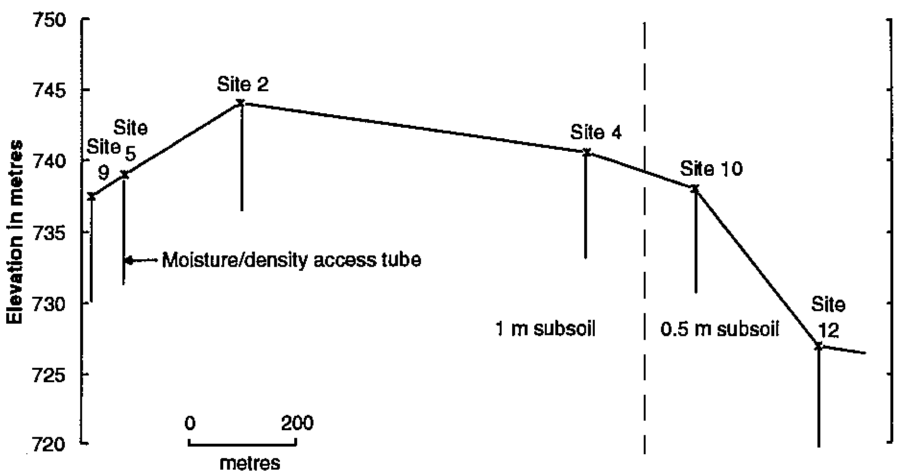


Figure 2. North-south topographic section through reconstructed soil monitoring area.

Results and Discussion

Precipitation

The data in Figure 3 indicate a range of 213 to 425 mm of total precipitation for the six-month period over the eight years of record. Monthly totals were generally highest for the months of June and July and were relatively low in May. Precipitation had a major impact on the forage yields obtained and the characteristics of the reconstructed soil profiles.

Soil Moisture

The moisture values reported and plotted are expressed as percent by volume and represent the moisture content for a depth interval. For example, the value given for the 45 cm depth actually represents the moisture content in the 30 to 45 cm interval.

Moisture distribution curves were prepared for all sites for the 1986 to 1993 period. Since only three readings were completed in 1985 the data were not included in the overall annual comparison. Due to paper length restrictions, data in the form of figures are presented for only 1987 and 1990 for site 9 (1 m subsoil replacement depth), site 10 (0.5 m subsoil replacement depth) and site 46 (unmined soil) which is representative of the soil material that was salvaged and replaced during the mining process. However, comments are made based on interpretation of the entire data set.

The moisture distribution patterns in Figures 4 and 5 indicate that moisture was generally higher in the spoil than the subsoil, however it should be noted that the moisture contained in the spoil is less readily available for plant use. The moisture patterns at the sites were similar between years. The widest fluctuations occurred in the topsoil and upper subsoil with little change in the spoil except for the uppermost portion. The effect of rainfall on downward moisture movement varied at the different sites. The maximum depth of apparent moisture change was 90 to 105 cm at site 9, 60 to 75 cm at site 10, and 45 to 60 cm at unmined site 46 (Figure 6). It is difficult to relate this depth of effect to specific factors such as slope position or soil depth. Bulk density of the subsoil and extent of crop root development play a major role in moisture movement in this context. Observations during sampling indicated that rooting into the spoil was limited, likely due to the physical characteristics and sodicity of the spoil, suggesting a major portion of total plant moisture is extracted from the subsoil in the reconstructed soils.

Moisture content, distribution pattern and potential availability in reconstructed soils is similar to that of adjacent unmined soils.

Bulk Density

The bulk density values reported represent dry soil bulk density for a given depth interval as recorded for soil moisture. The data collected annually indicated some variation in readings during the course of the April to September or October period (Figure 7). These seasonal variations generally were greatest in the topsoil and upper subsoil down to the 60 to 75 cm depth which accounts for the major portion of the root mass. There is no definite explanation for the seasonal variation in density values however it could be attributed, at least in part, to soil moisture content and root activity.

For the purposes of data interpretation a mean value for each year was calculated. Figures 8 and 9 provide mean annual values for 1986 to 1993 at the six reconstructed soil sites. The reconstructed soils bulk density values were higher in the subsoil than in the topsoil or spoil for most of the sites. The mean values for 1986 were higher than the values obtained in subsequent years. One reason for this is the soil reconstruction procedure promotes some degree of compaction because of the replacement of material in lifts by heavy equipment. With time and the effects of plant growth and moisture movement, the soil density levels are reduced.

Secondly, access tube installation may also increase the density of the soil material surrounding the tube. Since the reconstructed soil was relatively moist when the pipes were installed the pounding procedure may have

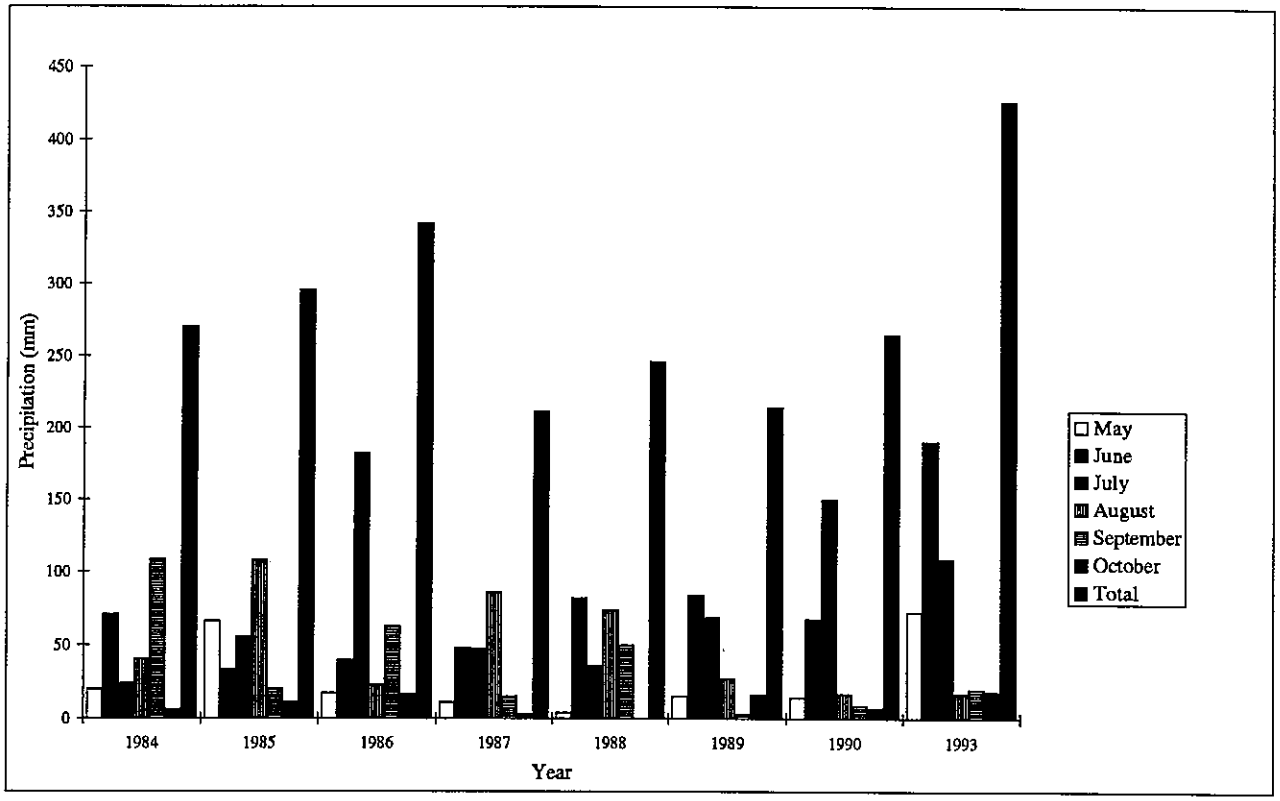
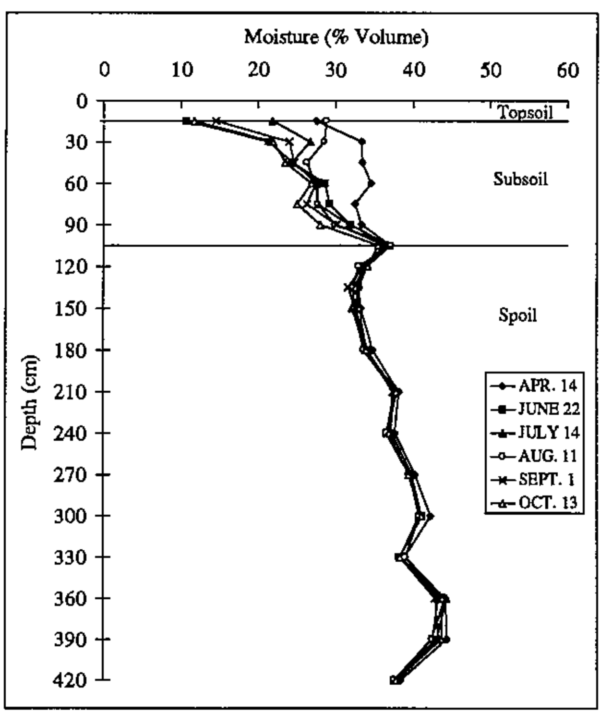


Figure 3. Monthly (May to October) Precipitation for 1984 to 1993.

Site 9



Site 10

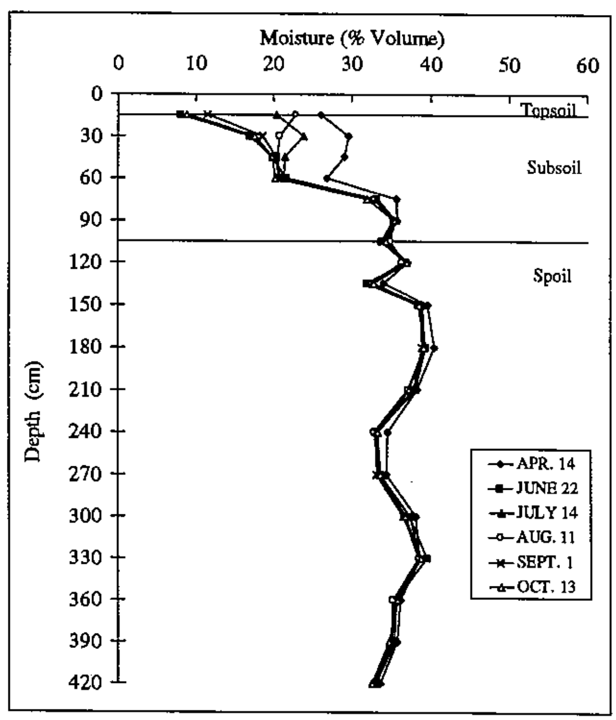


Figure 4. Soil Moisture at Site 9 and Site 10 in 1987.

Site 9 Site 10

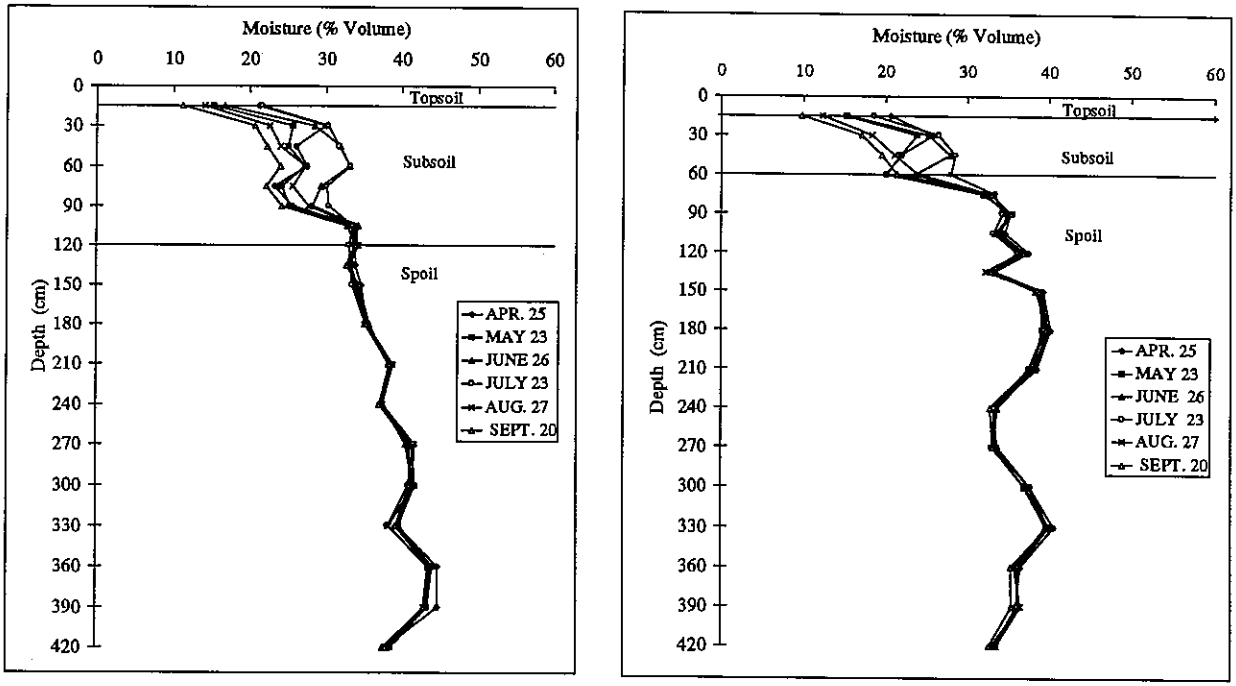


Figure 5. Soil Moisture at Site 9 and Site 10 in 1990.

Site 46 in 1987 Site 46 in 1990

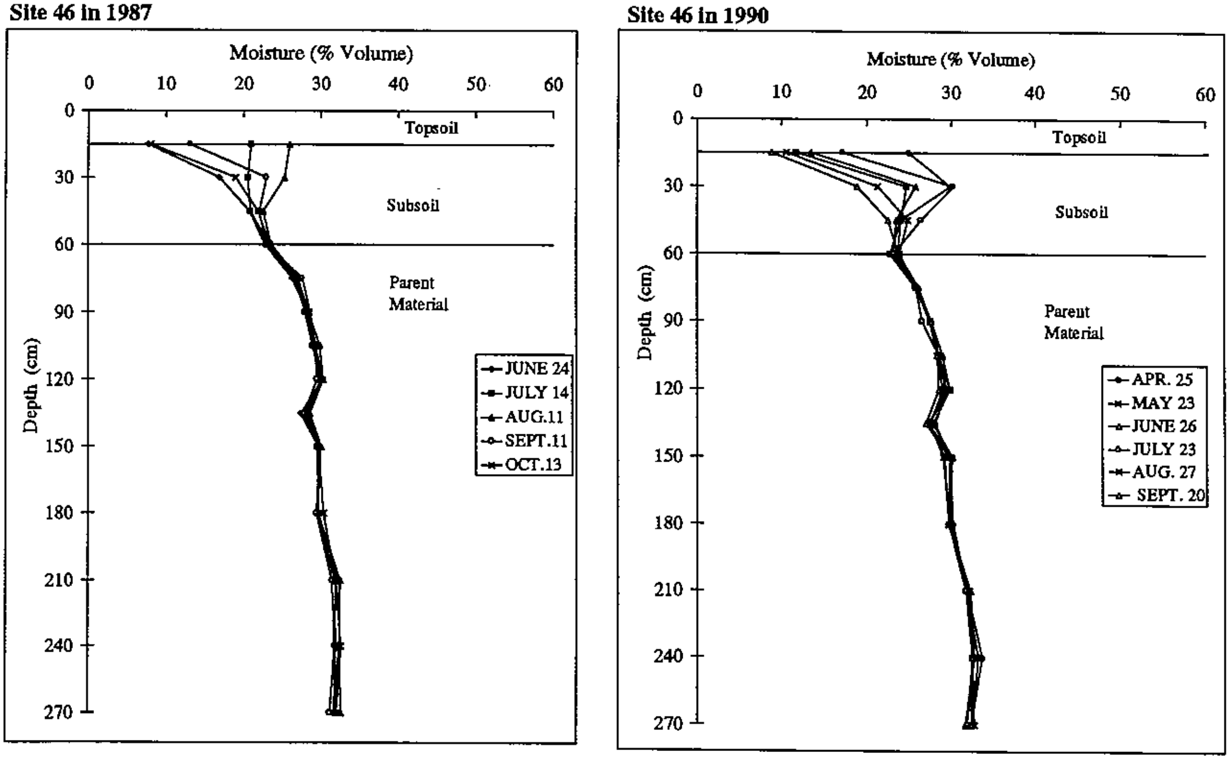


Figure 6. Soil Moisture at Unmined Site 46 in 1987 and 1990.

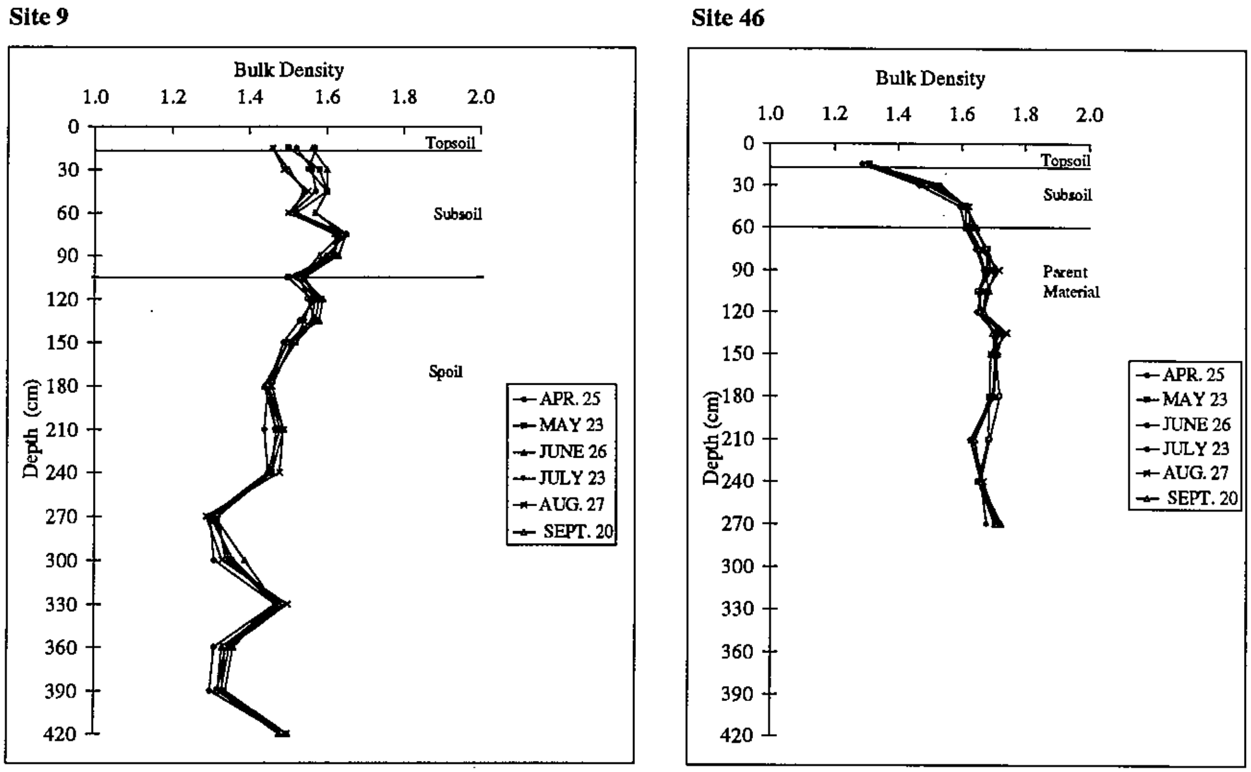


Figure 7. Bulk Density Values at Site 9 and Site 46 in 1990.

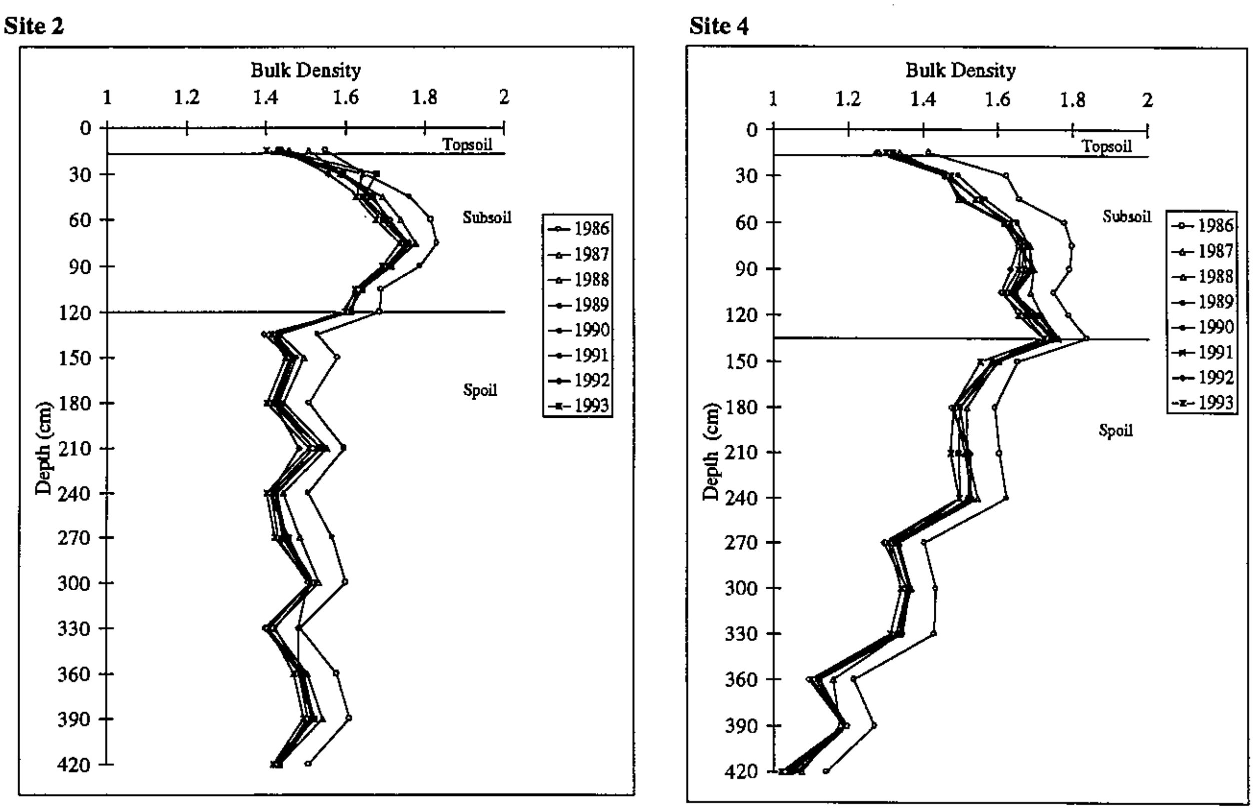
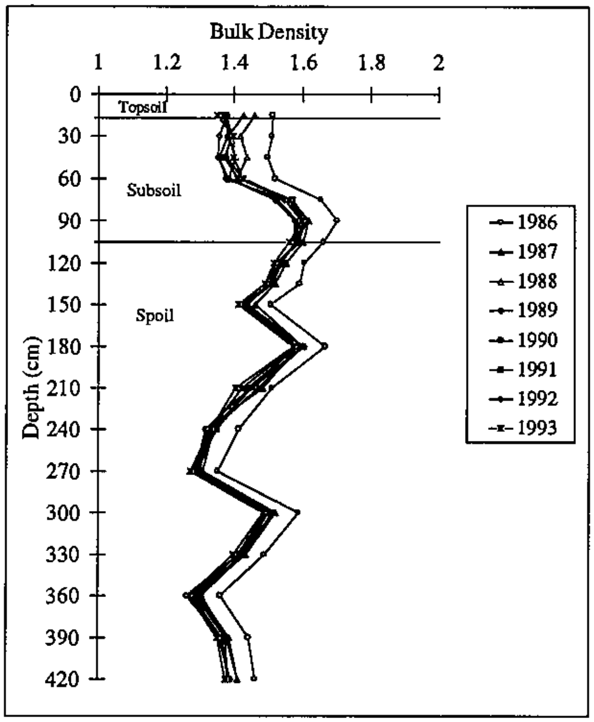
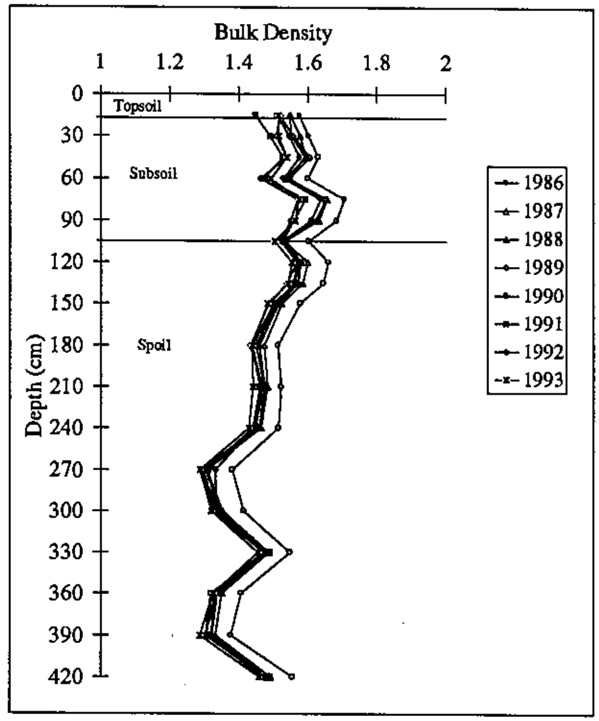


Figure 8. Mean Annual Bulk Density Values at Site 2 and Site 4 for 1986 to 1993.

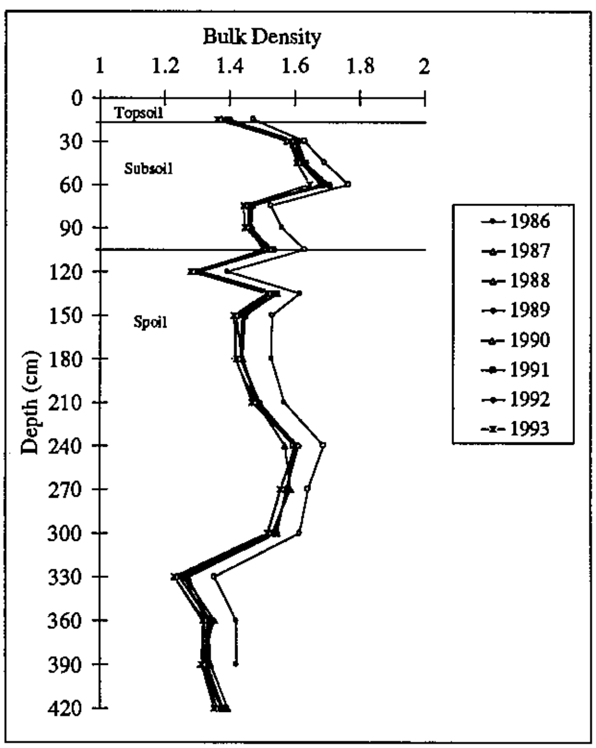
Site 5



Site 9



Site 10



Site 12

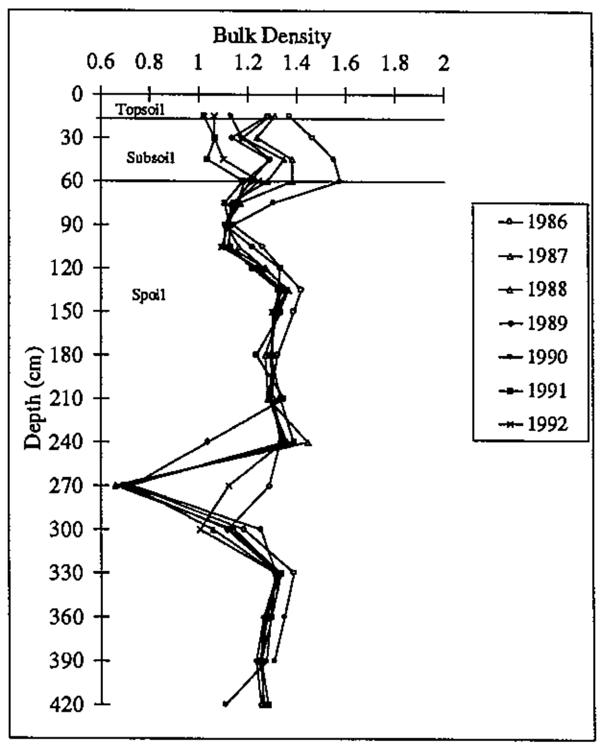


Figure 9. Mean Annual Bulk Density Values at Sites 5, 9, 10 and 12 for 1986 to 1993.

resulted in a squeezing of the material adjacent to the pipe and consequently increased the density. Increased density adjacent to the pipe wall is critical because the sphere of influence of the density measurement does not exceed a radius of 3 to 4 cm outside the pipe wall.

The data obtained for all sites indicate mean bulk density decreased as time from reconstruction increased. There was little change in mean bulk density from 1988 to 1993 which suggests that the density of the reconstructed soils is "stabilizing" and that any further changes are not likely to be significant.

As mentioned previously, bulk density was also measured at a number of unmined sites adjacent to the mined area. Mean annual values for sites 46 and 48 are provided in Figure 10. In addition, Figure 11 provides mean values for reconstructed sites 2, 4, 5, 9, 10 and 12 and unmined sites 46 and 48 in 1993. These data indicate that the bulk density of the reconstructed soils is similar to or lower than that which occurs in the unmined soils of the area. This suggests that bulk density should not limit reconstructed soil capability.

Chemical Properties

Analytical data pertinent to the chemical properties of the reconstructed soils were obtained in 1984, 1985, 1986, 1987, 1990, and 1993. The mean annual EC values for the six sampling events for sites 2, 9, 10, and 12 are presented in Figure 12.

Electrical conductivity values in the topsoil layer were lower in 1993 than for the previous years at all sites. The EC levels in the subsoil at site 2, which has a 1 m thick subsoil layer and is located on a level or crown position, demonstrated a general downward redistribution of salts. It was also evident that salts were not perching at the subsoil/spoil interface. A similar trend was observed at site 9 which has a 90 cm subsoil layer and is located in a slope position. Site 10 which is characterized by relatively level topography and a 45 cm subsoil replacement layer also demonstrated a downward movement of salts with time and no evidence of perching of salts at the subsoil/spoil interface. However, site 12 which is characterized by level to depressional topography and a 45 cm subsoil layer demonstrated subsoil EC values for 1990 and 1993 that were consistently higher than those reported for previous years. Perching of salts could be considered a concern at this site. The trend in EC values and in particular the perching of salts at the subsoil/spoil interface could be explained, at least in part, by the relative wetness of the site which would promote upward migration of salts. Furthermore, differential subsidence depressions have developed within 10 to 15 m of the site during the term of the monitoring program.

Figure 13 provides EC data obtained in 1993 for the soils at three unmined sites as well as a comparison with the reconstructed soils. The data indicate the reconstructed soils are comparable to the unmined soils and based on EC, soil quality is not degraded with the exception of low lying or depressional sites such as site 12, where salts migrated upward.

Figures 14 and 15 provide mean annual SAR data for sites 2 and 9 and sites 10 and 12 respectively. The trend of reduced values in the upper subsoil and increased values in the lower subsoil were similar for the sites. Figure 16 provides data for the three unmined sites and six reconstructed sites in 1993. This data indicates that based on SAR, reconstructed soil quality is not degraded when comparing the reconstructed soils to the unmined soils.

Forage Production

The forage mixture comprised of brome grass, crested wheatgrass, and alfalfa was seeded with a nurse crop of oats in the spring of 1984. Fertilizers applied included 100 kg/ha 34-0-0 (broadcast) and 50 kg/ha 11-51-0 (drilled). Drought conditions during 1984 had a deleterious effect on initial forage establishment. The crop was refertilized with 50 kg/ha 46-0-0 and 100 kg/ha 11-51-0 in 1985, 90 kg/ha 28-28-0 in 1986, and 100 kg/ha 46-0-0 in 1987. Harvests to determine yield were completed in the latter part of June in 1985, 1986, and 1987 and yield values are presented in Table 1.

Conditions were relatively dry leading up to the time of harvest and the forage crop was under some moisture stress in each of the three years of assessment, particularly in 1985 and 1987. The average yield of 4846 kg/ha obtained in 1986 was approximately three times greater than the 1475 kg/ha yield obtained in 1985, likely due to the fact that the crop had an additional year to become better established and the 1985 crop was under considerably more severe moisture stress.

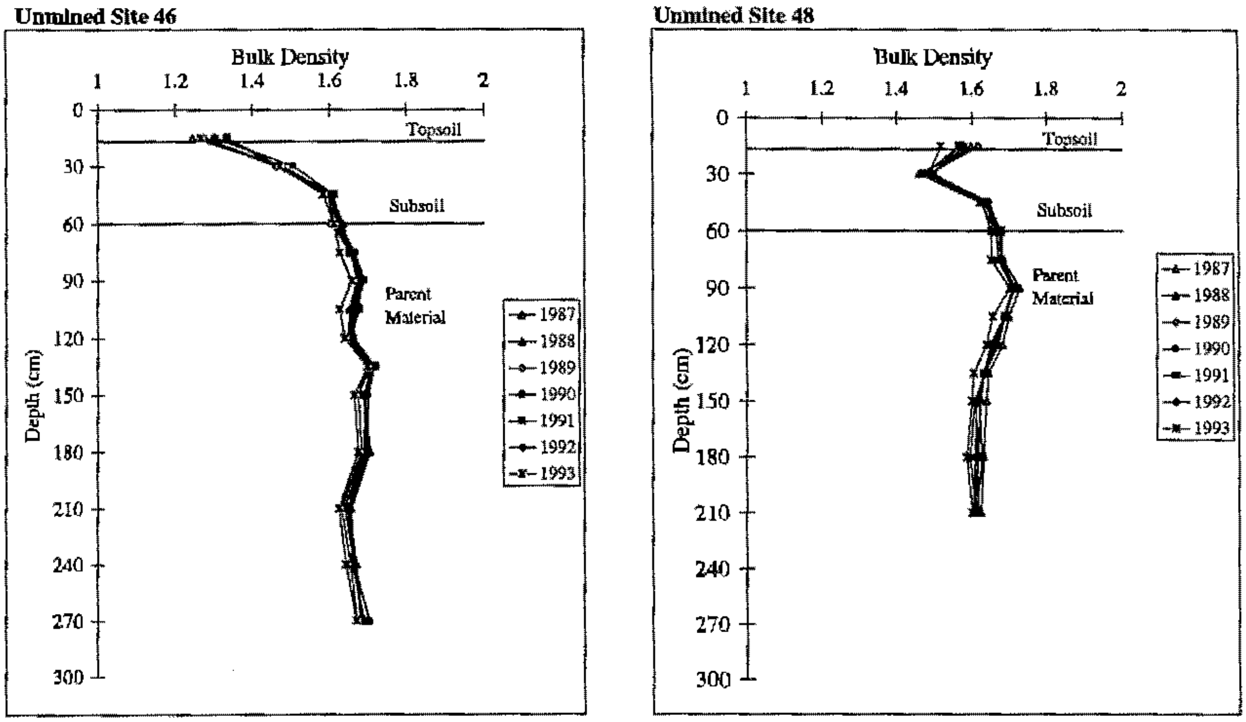


Figure 10. Mean Annual Bulk Density Values at Unmined Sites 46 and 48.

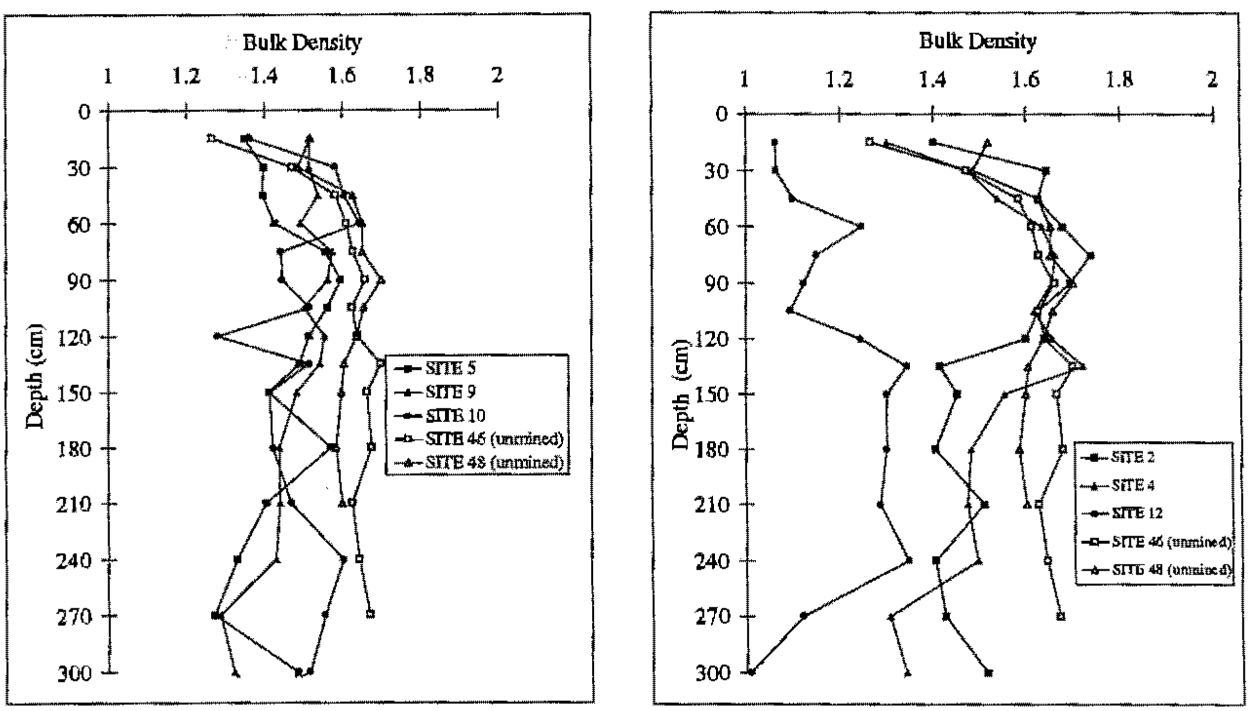


Figure 11. Mean Bulk Density Values for Reconstructed and Unmined Soils in 1993.

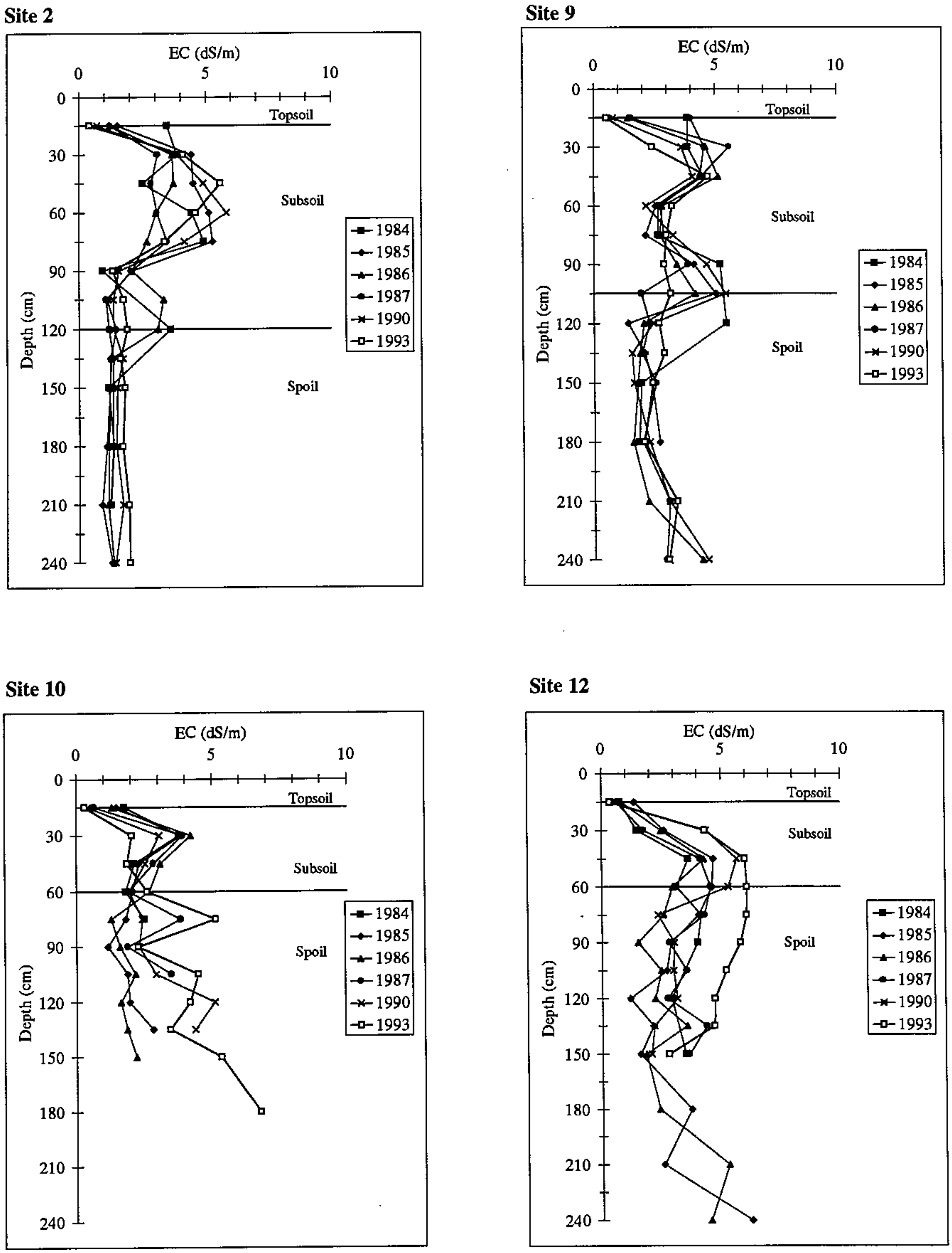
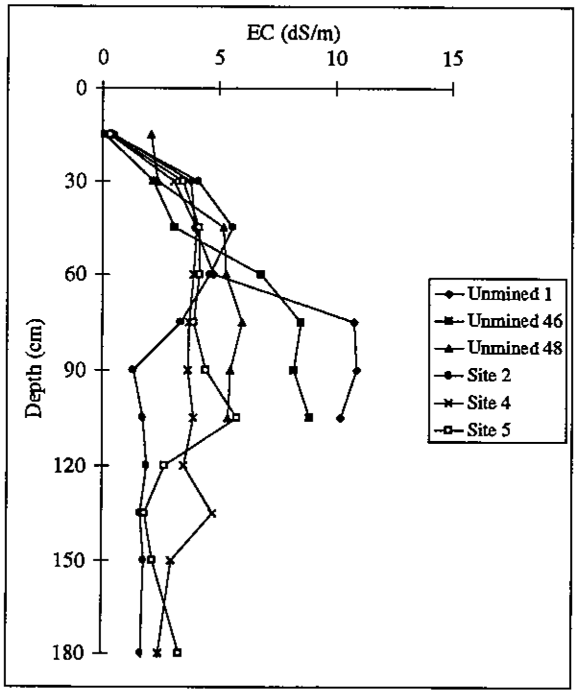


Figure 12. Mean Annual EC Values at Sites 2 ,9 , 10 , and 12 for 1984 to 1993.



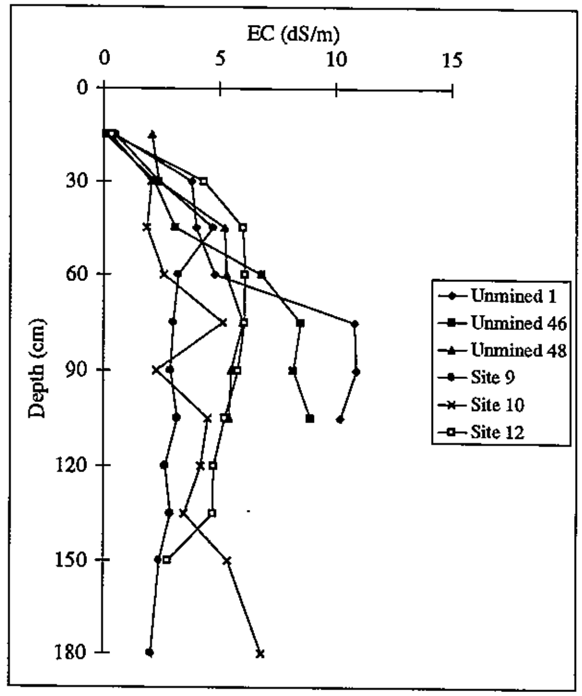
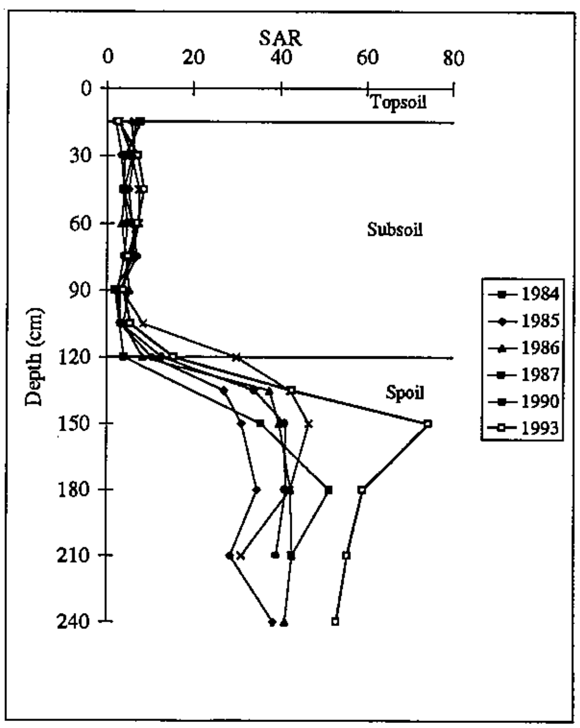


Figure 13 . Mean EC Values at Unmined and Reconstructed Sites in 1993.

Site 2



Site 9

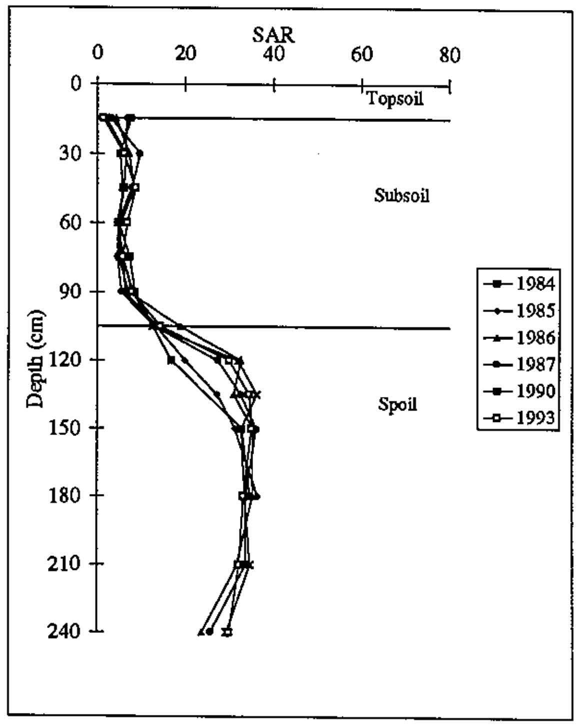


Figure 14 . Mean Annual SAR Values at Site 2 and Site 9 for 1984 to 1993.

Site 10 **Site 12**

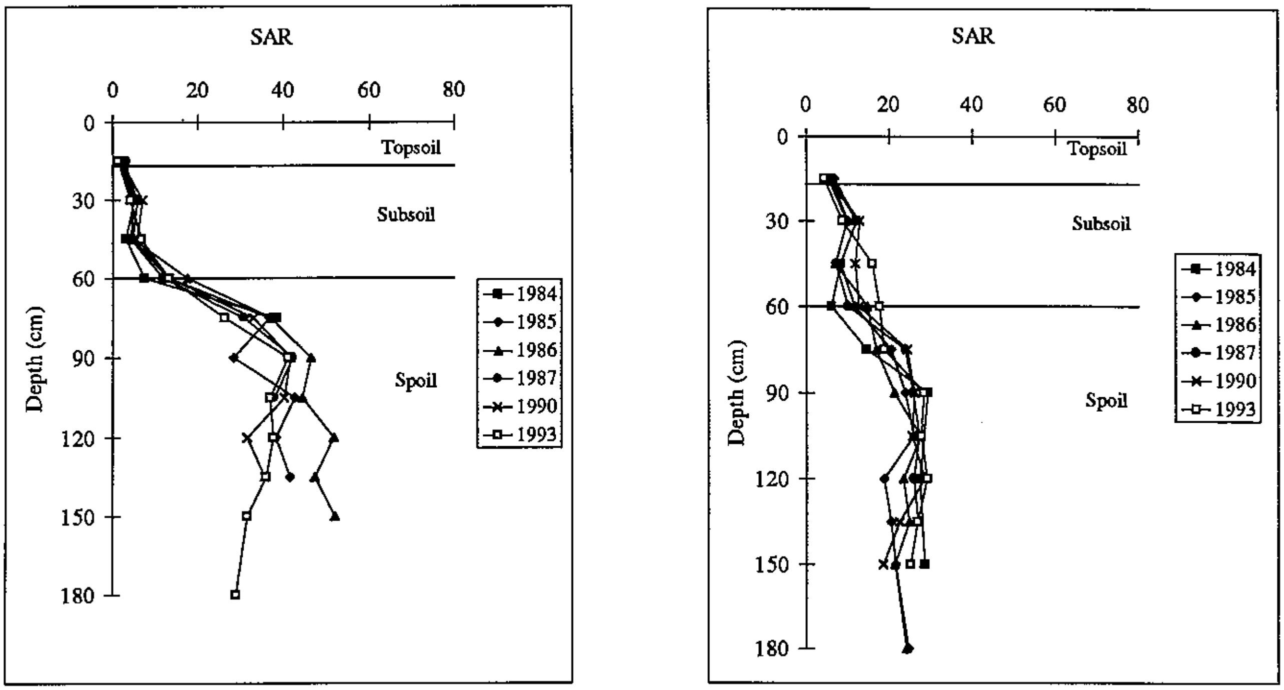


Figure 15. Mean Annual SAR Values at Site 10 and Site 12 for 1984 to 1993.

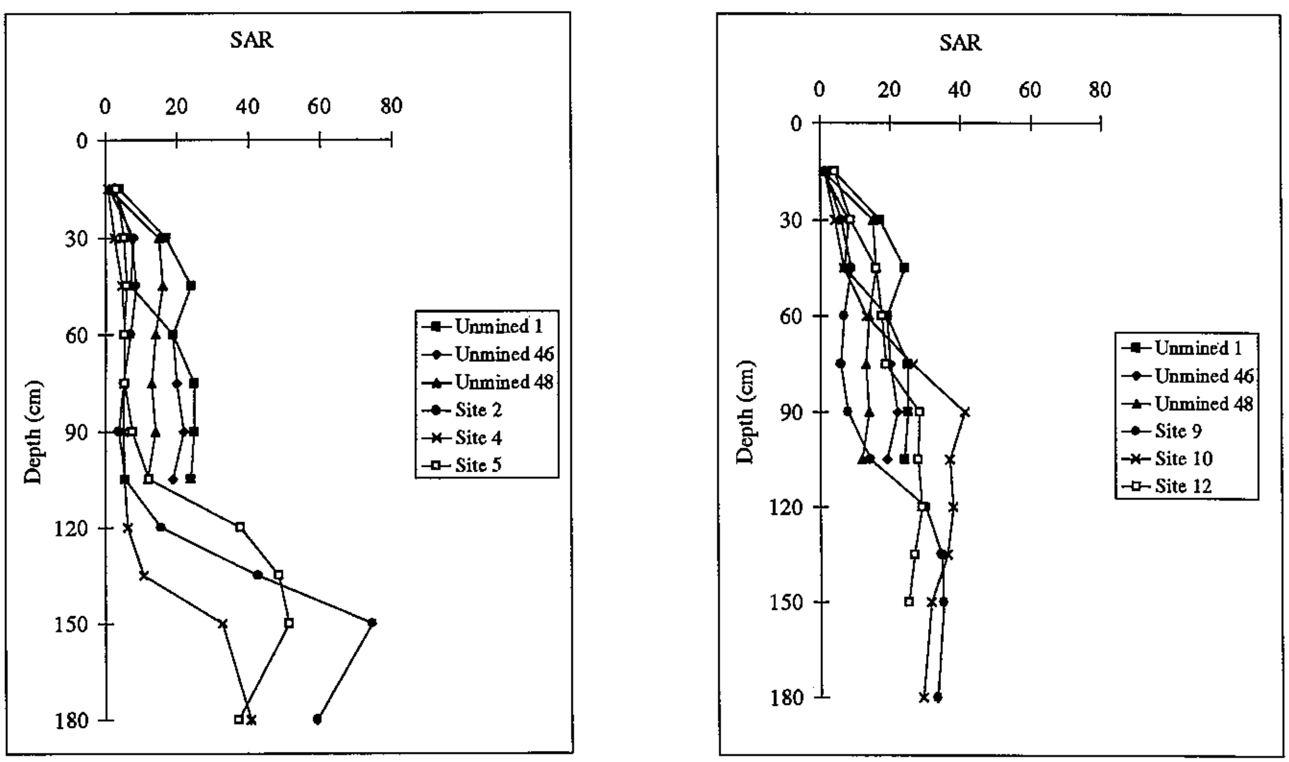


Figure 16. Mean SAR Values at Unmined and Reconstructed Sites in 1993.

It should be noted, site 10 had the lowest yield value in 1987 and the next to lowest yield in 1985. Severe drought conditions prevailed up to the time of harvest in both these years. Moisture levels at site 10 were below wilting point to a greater depth and for a longer period of time than at the remaining sites. It was apparent the shallow subsoil layer contributed to greater moisture stress for the forage in the vicinity of site 10. Under more average moisture conditions in 1986 the yield at site 10 was second only to the yield at site 4.

Table 1. Forage yield (air dry weight) for 1985, 1986 and 1987.

Site	Subsoil Thickness (cm)	Equivalent Yield (kg/ha)		
		1985	1986	1987
2	105	1575	4416	2054
4	120	1775	5610	1828
5	90	1700	4594	1714
9	90	1625	4886	1692
10	45	1175	5314	1476
12	45	1000	4254	2214
Mean		1475	4846	1835

Site 12 is located in an area of shallow subsoil replacement but is also on a low position in the landscape. Subsidence depressions are present and ponding occurs in the area. The low yield in 1985 and 1986 can be explained by poor initial crop establishment and the presence of weeds in addition to drought. The high yield in 1987 can be attributed to the proximity to subsidence depressions which tend to pond and retain water.

The average yield obtained for the six sites in 1986 was very similar to the 1970-79, 10-year average yield of 5113 kg/ha for this region (Alberta Agriculture 1981).

Conclusions

The sampling and monitoring program conducted at Paintearth Mine has provided detailed information relative to the changes that occurred regarding the physical and chemical properties of the reconstructed soils in the study area. Similar measurements conducted on adjacent undisturbed soils allowed for a comparison of performance of the reconstructed soils which are a product of the salvage and replacement procedures associated with the mining operation.

In general, moisture content, distribution pattern, and potential availability in reconstructed soils was similar to that of unmined soils in the area. Furthermore, perching of water was not evident in the reconstructed soils.

Bulk density decreased as time from reconstruction increased. Within five years following soil replacement the bulk density of the reconstructed soils was similar to, or lower, than the values recorded in the unmined soils of the area.

Soil reconstruction utilizing the shallow subsoil (45 cm) layer rather than the thicker (90 cm+) subsoil layer can result in the increased potential for upward movement of salts and crop production limitations due to less available moisture. However, the analytical data obtained indicated landscape position and moisture regime have much more bearing on salt movement and salinity status than the thickness of replaced subsoil. In relatively well drained positions there is the potential for greater moisture deficit or stress on vegetation to occur in the shallow subsoil areas, however with average precipitation levels, this did not appear to be a problem. Furthermore, with average growing season precipitation levels received in the study area, the reconstructed soil sites produced yields comparable to the long-term yields of unmined soils in the region.

There was no significant difference in the EC and SAR status of the lower subsoil in the 0.5 m replaced subsoil zone, versus the 1.0 m replaced zone in upland or better drained landscape positions. Overall the data indicated that based on EC and SAR, reconstructed soil quality was not degraded relative to the unmined soils in the area.

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