Topsoil Stripping in Potentially Arable Forested Luvisols:
A Literature Review

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TOPSOIL STRIPPING DURING PIPELINE CONSTRUCTION
IN POTENTIALLY
ARABLE FORESTED LUVISOLS: A LITERATURE REVIEW

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1990

FOREWORD

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This study was commissioned to evaluate the available literature on the effects of stripping versus not stripping topsoil in Luvisolic soils that are currently forested but have the potential to be cultivated. This report was prepared by Karen R. Cannon, a private consultant, and Sandra Landsburg, a department staff member. This report may be cited as:

Cannon, K.R and S. Landsburg, 1990. Topsoil Stripping in Potentially Arable Forested Luvisols: A Literature Review. AGTD Environmental Research Monographs 1990-2. NOVA Corporation of Alberta. Calgary, Alberta. 38 pp.

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ABSTRACT

The objective of this literature review was to evaluate the available information on the effects of stripping versus not stripping topsoil during pipeline construction in potentially arable Luvisolic soils in forested areas. A profile description representative of an undisturbed Luvisol under native forest vegetation was studied to identify potential problems in terms of soil quality and soil handling associated with the soil.

A review of the literature indicates there is little information on topsoil handling techniques during pipeline construction for forested areas considered arable. However, a review of related literature suggests that topsoil stripping of forested soils and its subsequent replacement would result in horizon characteristics similar to those of the plough depth resulting from farming practices. Removal and subsequent replacement of the subsoil is expected to result in a decrease in bulk density. This should improve hydraulic conductivity and aeration thereby allowing deeper root penetration for better moisture and nutrient extraction from the soil. Subsoil replacement is not expected to result in dramatic changes in particle size distribution, exchangeable cation concentration, total nitrogen or total organic carbon. An increase in pH could occur if calcium carbonate is brought up from the Ck horizon.

With no topsoil salvage, an increase in surface bulk density, pH and clay content is anticipated. Mixing of topsoil and subsoil would most likely result in altered physical properties similar to those previously discussed for removal and subsequent replacement of subsoil. Incorporation of organic matter from leaf litter and silt from the Ae horizon is not expected to change subsoil characteristics dramatically.

Although the discussion of potential impacts of pipeline construction on Luvisolic soils suggests that topsoil conservation may not be necessary, there are insufficient relevant data in the available literature to clearly substantiate this conclusion. Further investigations are needed to ascertain the effect of stripping versus not stripping topsoil in forested areas considered arable.

ACKNOWLEDGEMENTS

This study was funded by NOVA Corporation of Alberta through the Alberta Gas Transmission Division Research Fund as Project 087312. The authors wish to acknowledge the assistance of M. Houser, AGTD, for his comments regarding pipeline construction techniques and soil conservation. As well, T. de Grosbois, L. Postlewaite and Dr. A. Fedkenheuer, AGTD, are acknowledged for their assistance with manuscript review and publication.

1.0 INTRODUCTION

Alberta is rich in oil and natural gas reserves and these industries constitute a major portion of the provincial economy. Therefore, distribution of these products, through pipelines, has become a widely accepted practice. However, conflicts have arisen concerning the impacts of pipeline construction on the quality of agricultural and potentially arable soils. There is no doubt that pipeline installation disrupts the soil. However, appropriate construction methods along with compatible reclamation procedures can only be resolved once short-term and long-term effects on the soil are known. This knowledge is important since each soil ecosystem could respond differently to various construction procedures.

There are limited data available on the effects of pipeline construction on soil properties, crop production and agricultural ecosystems. As well, there is a paucity of information in the literature on the effects of pipeline construction in forested areas. Even more limited are studies documenting handling procedures of topsoil, especially on Luvisolic soils. Frequently, topsoil is arbitrarily defined as the plough depth, which in Luvisols could include the LFH horizons, Ah horizon and a portion of the Ae horizon. The merits of topsoil stripping in Luvisolic soils have been questioned because of the marginal quality of the topsoil.

2.0 OBJECTIVE

The objective of this literature review is to evaluate the effects of stripping versus not stripping topsoil during pipeline construction in potentially arable Luvisolic soils. To achieve this objective a review of the literature on Luvisolic soils and their characteristics along with possible impacts of pipeline construction procedures is necessary. Subsequently, potential impacts of various topsoil handling procedures on Luvisolic soils can be determined and an investigation of appropriate soil handling procedures can then be initiated.

3.0 REVIEW OF RELATED LITERATURE

3.1 LUVISOLIC SOILS

3.1.1 Characteristics

Luvisolic soils develop under deciduous, coniferous, mixed forest and forest-grassland transitions in a wide range of climates across a large extent of the northern hemisphere. They occur in the cooler boreal, cryoboreal and subarctic regions of Canada (Clayton et al. 1977), and are the dominant soil of forested areas in the interior plains of western Canada. These soils do not have a Solonetzic or Podzolic B horizon, Chernozemic Ah horizon, or organic horizons and are not dominated by gleying or permafrost (Canada Soil Survey Committee 1978). Luvisols are developed on parent material such as lacustrine clays, glacial till and sandy alluvial materials. Most Luvisols in central Alberta have developed on glacial till of loam to clay loam texture (Bentley et al. 1971).

In northwestern Canada there are 11 million hectares of land suitable for agricultural production of which 9 million hectares are in the Alberta-British Columbia-Peace River region (Bailey 1981). Currently only 2.7 million hectares are used for agricultural purposes indicating that the agricultural potential for this area is three to four times its present use. At present, 100% of land in Alberta classified as either Class 1 or Class 2 is cultivated (Environment Council of Alberta 1985). As well, 80.3% of Class 3 land is cultivated while only 24.7% of Class 4 land, which is predominant in the Peace River region, is under cultivation. Further agricultural development in northwestern Canada must take place in areas that are considered marginal in terms of either climate or soils (Pettapiece and Lindsay 1981). In Alberta there are 20 million hectares of Luvisolic soils, of which 5.7 million hectares are considered arable (Holmes et al. 1976). Currently, only 15% of the total area cultivated in Alberta is on Luvisols (Bentley et al. 1971), but future expansion of arable agriculture will be into areas dominated by these soils. Therefore, the importance of Luvisols necessitates an understanding of soil characteristics, both advantageous and disadvantageous, along with suitable management practices in order to achieve satisfactory productivity.

A profile description of an undisturbed Luvisol under native forest vegetation is prerequisite to identify potential problems in terms of soil quality and handling of these soils. Some typical chemical and physical characteristics of Luvisolic soil profiles at the Breton Research Station, Breton, Alberta, have been presented and are similar to other Luvisols found in Alberta (Tables 1 and 2). The profile described in Table 1 differs from other Luvisols only in that it was deeply leached and calcium carbonate was not present until a depth of 2.5 m (Howitt and Pawluk 1985a). In the fall of 1979, the Breton plots were extensively sampled, as were several virgin profiles north of the classical plots. One of these virgin profiles is shown in Table 2. At both sites, vegetation consists of an aspen poplar stand with some spruce present. These profiles are shown to familiarize the reader with soil characteristics of undisturbed Luvisols soils.

The surface organic material consists of three layers in various stages of decomposition. The L horizon is composed mainly of fallen leaves and needles that are slightly decomposed and still recognizable as to origin. A loose to matted partially decomposed F horizon, in which the origin of material is difficult to ascertain, is underlain by the most decomposed H horizon. This horizon is fibrous to matted in nature and is unidentifiable as to origin. The LFH layer may vary from 2.5 to 12.5 cm in thickness

(Bentley et al. 1971). There is little mixing of the organic and mineral soil components as evidenced by the three organic layers that overlie the mineral soil. Organic matter decomposition and nutrient cycling processes occur primarily in the organic layer. Throughout the year the LFH layer contains more water than the mineral horizon below it and the fluctuation in moisture content is greater than for the mineral horizon (Howitt and Pawluk 1985b). The LFH horizon inhibits movement of moisture into the Ae horizon because of its high moisture holding capacity and protects the Ae from wind and water erosion.

Under the organic LFH horizon is a layer of humus and mineral matter called the Ah horizon. This layer is always less than 5 cm thick and usually is less than 2.5 cm thick in Grey Luvisols (Bentley et al. 1971). However, Dark Grey Luvisols have Ah or Ahe horizons that are more than 5 cm thick and have eluvial features such as grey streaking or platy structure (Canada Soil Survey Committee 1978).

Figure 1: Luvisolic Soils in Alberta

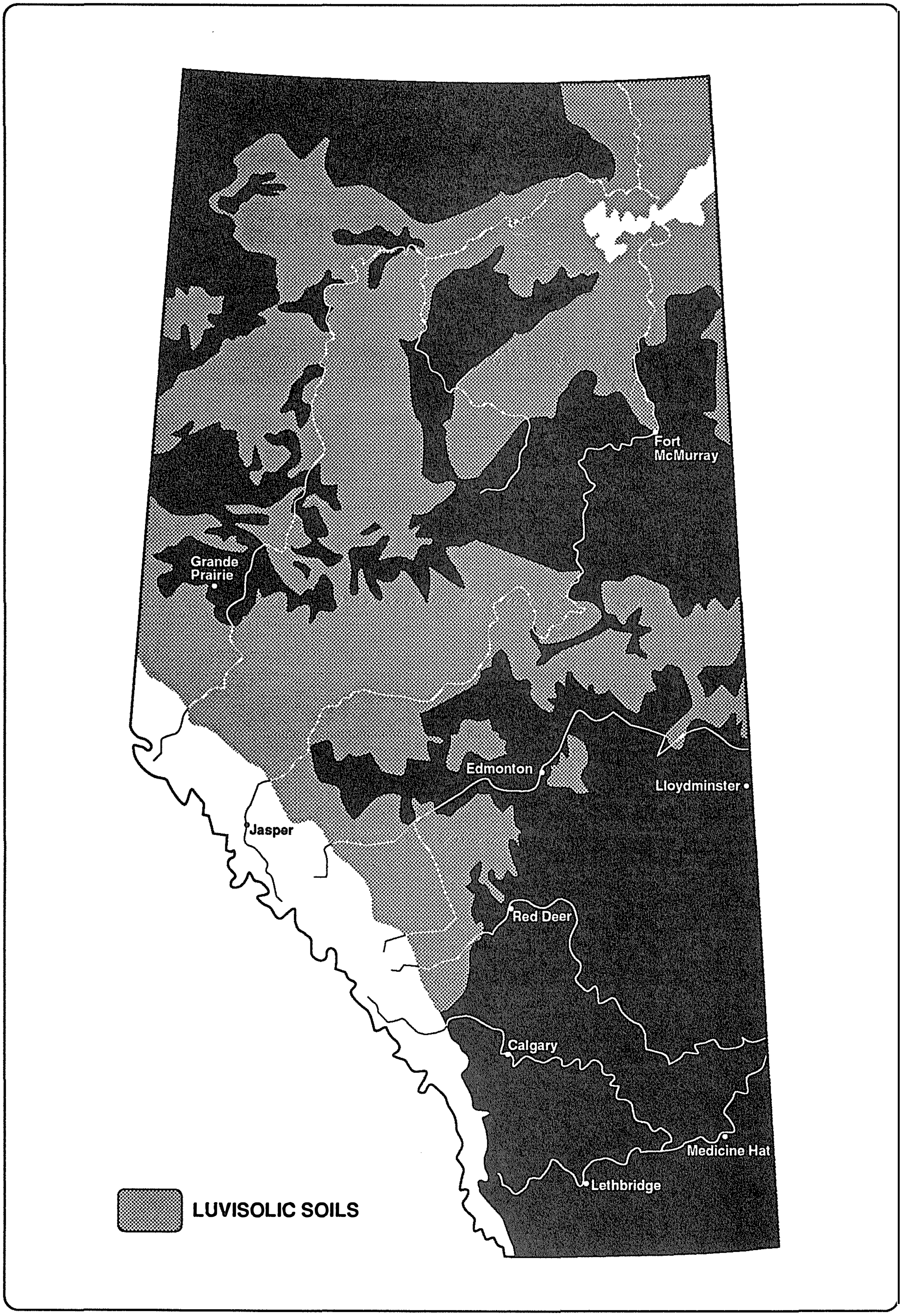


Table 1. Chemistry and Particle Size Distribution of a Virgin Grey Luvisol at Breton.

Horizon	Depth (cm)	pH	C (%)	N (%)	Exchangeable Cations (% of total CEC)				Texture %		
					Na	K	C	Mg	Sand	Silt	Clay
L	8-5	6.1	33.5	1.47	-	-	-	-	-	-	-
F	5-1	5.6	35.0	1.56	-	-	-	-	-	-	-
H	1-0	4.9	20.3	0.83	-	-	-	-	-	-	-
Aeh	0-3	4.7	2.3	0.05	0.3	12.0	73.0	20.0	32	57	11
Ae1	3-8	4.9	0.4	0.06	0.4	10.5	74.0	15.1	33	59	8
Ae2	8-13	5.1	0.2	0.04	0.4	5.1	74.3	20.2	37	56	7
AB	13-17	5.2	0.2	0.03	0.2	4.5	71.6	23.7	37	42	21
Bt1	17-23	5.2	0.4	0.05	0.2	2.8	70.8	26.3	28	39	33
Bt2	23-47	5.1	0.4	0.05	0.1	2.1	71.3	26.3	24	42	34
Bt3	47-67	4.8	0.4	0.04	0.4	1.2	69.2	29.2	28	39	33
BC1	67-81	4.9	0.2	0.04	0.3	1.7	68.2	30.0	28	41	31
BC2	81-111	4.9	0.2	0.03	0.5	1.2	67.9	30.4	29	43	28
BC3	111	4.8	0.2	0.04	0.4	0.7	68.2	30.6	32	41	27

Howitt and Pawluk 1985a. Procedures used for soil analyses included pH in 0.01 M $CaCl_2$, total organic carbon (%C) by wet oxidation, total nitrogen (%N) by macro-Kjeldahl, cation exchange capacity (CEC) by NH_4OAc and particle size distribution by pipette. All methods are described by McKeague (1978).

Table 2. Chemical and Physical Characteristics of a Virgin Grey Luvisol at Breton.

Horizon	Depth (cm)	pH	Bulk Density (g/cm^3)	N (%)	C (%)
LHF	8-0	5.5	0.15	1.06	29.60
Ae1	0-6	5.1	1.16	0.10	1.54
Ae2	6-10	4.8	1.44	0.03	0.36
AB	10-21	4.9	1.53	0.04	0.34
Bt1	21-30	4.7	1.53	0.04	0.34
Bt2	30-55	4.8	1.58	0.03	0.34
Bt3	55-83	4.9	1.64		
BCg	83-109	5.5	1.71		
BC	109-130	7.1	-		
Ck1	130-153	7.2	1.70		
Ck2	153-188	7.3	-		

Cannon et al. 1984.Procedures used for soil analyses included pH in 0.01 M $CaCl_2$, total nitrogen (%N) by Kjeldahl, total carbon (%C) by Leco induction furnace and bulk density by core method in field. All methods are described by McKeague (1978).

The most distinctive layer is the well developed platy Ae horizon which is the cause of many problems encountered in farming practices. The Ae horizon varies in depth from 10 to 30 cm (Bentley et al. 1971), and when dry is hard and crushes like a powder. When wet it acts like a paste that becomes very firm on subsequent drying. The moisture content of the Ae horizon is the lowest of the mineral horizons. Ice lenses, which form in periods of freeze-thaw cycles, help create the platy structure (Canada Soil Survey Committee 1978). Leaching occurs in the upper mineral horizon and results in reduced clay content and a slightly to strongly acid reaction. There is little buildup of organic matter in this soil layer.

Below the Ae horizon, there is often a transitional AB or BA horizon in which the ped surfaces are greyer than the ped interiors (Canada Soil Survey Committee 1978).

Fine clay-size smectite and to some degree mica has been transported from the Ae horizon into the illuvial Bt horizon. This results in higher levels of clay in the Bt horizon relative to the Ae (Howitt and Pawluk 1985a). Research into a Luvisolic soil at Breton has indicated that this process, called lessivage, is the primary soil forming process in Luvisolic soils. As well, there is an accumulation of iron, aluminum and organic carbon in the Bt horizon. Illuvial organo-clay deposition occurs on the peds and because of the freeze-thaw and wet-dry cycles (shrink-swell forces) this soil layer has a weak to strong blocky structure (vertical and horizontal lines of breakage). When dry, the Bt becomes so hard that roots can have difficulty penetrating the peds. When wet, there is occasional temporary saturation of the upper solum because of the reduced permeability of these peds.

The Cca horizon is on average 1.2 m or more below the surface (Bentley et al. 1971). Calcium carbonate that was once distributed throughout the mineral portion has been leached downward, accumulating in this horizon. If present, salts can also be leached downward to form a Csa horizon.

3.1.2 Cultivation

When Luvisols are cultivated, the LFH, Ah and part of the Ae horizon are mixed by ploughing. In some cases the Bt horizon is also incorporated. When cleared of trees and cultivated the ecosystem is altered extensively. The leaf mat quickly decomposes and the mineral soil is exposed to the direct effects of snowmelt, rain and wind. Research at Beaverlodge on several different types of Luvisols suggests that breaking should be done early in the season (June) and ploughing should not be more than 10 to 15 cm deep (Bentley et al. 1971).

The cultivated Ap horizon poses many problems including a tendency to crust, vulnerability to pulverization, clodding and compaction from tillage, low water holding capacity, low fertility (especially nitrogen and sulphur) and low pH buffer capacity (Robertson and McGill 1983). Because of these problems there is reduced aeration, water infiltration and water reserve. Due to seedbed preparation difficulties, poor germination, poor seedling emergence and poor plant development can result. As well, increased erosion and rapid soil acidification take place. Management problems for the B horizon include impeded water transmission and restricted root growth of crops.

Luvisols in Alberta are not well suited for agriculture. The growing season usually has approximately 90 frost-free days in the Beaverlodge area and only 80 frost-free days in the Peace River area (Odynsky et al. 1952). There is a tendency for drought in the early season and excessive moisture at harvest time delays and complicates harvest procedures. However, because moisture conditions are somewhat more reliable than in the grassland regions, following recommended cropping and soil management practices can result in improved soil conditions for agriculture (Bentley et al. 1971).

3.2 PIPELINE CONSTRUCTION

3.2.1 Construction Procedures

About 180,000 linear kilometres of oil, gas and other pipelines existed in Alberta in 1981 (Webb 1982). Phases of installation for pipelines are well documented by Alberta Environment (1985) as well as by Hardy Associates (1978) Ltd. (1983).

The construction activity for pipeline installation is a multi-phased linear development. Some of the more significant phases included in the summer construction sequence for cultivated soils are:

- survey;
- clearing;
- topsoil stripping;
- grading;
- pipe activities such as stringing, welding, and x-ray analysis;
- trenching;
- lowering of pipe;
- backfilling;
- topsoil replacement;
- hydrostatic testing;
- cleanup; and
- reseeding and maintenance.

3.2.2 Soil Conservation Methods

Different soil conservation procedures are advocated for agricultural land or non-agricultural land, and whether pipeline construction takes place in winter or summer. Use of soil conservation methods, which include handling of topsoil and its subsequent replacement, varies depending on soil characteristics and conditions (Alberta Environment 1985).

The two most commonly employed soil conservation procedures for cultivated land in summer are:

- trench and spoil area topsoil stripping in which soil mixing is minimized as topsoil is stored on topsoil and subsoil is stored on subsoil; and

- trench, spoil and work area stripping where soil mixing is again minimized, and is used when there is a high probability of topsoil rutting or compaction of subsoil on the work side.

For other land uses such as pasture and hay lands in summer, soil conservation methods include:

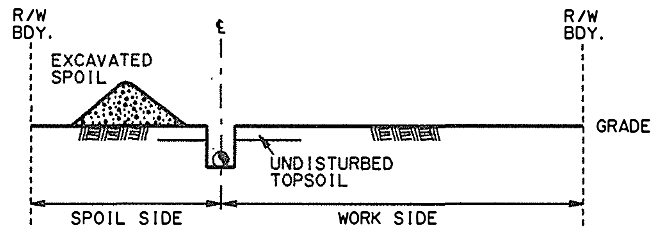
- trench width topsoil stripping, which is used when spoil can be stored and removed from a well-developed sod layer with little mixing and when backfilled spoil can be confined to the trench; and

- blade width topsoil stripping which is used when spoil can be stored and removed from a well-developed sod layer with little mixing, but when backfilled spoil cannot be confined to the trench.

Soil conservation procedures for forested land in summer depend on adjacent land use or future land use and include:

- trench and spoil area topsoil stripping as described for cultivated land; and
- trench width topsoil stripping as described for pasture and hay lands.

During winter conditions, soil conservation procedures are similar to those described for pasture and hay lands when spoil can be stored and removed from a frozen soil surface with little mixing. However, replacement of topsoil occurs in summer, after trench spoil has been allowed to thaw and subside.



NOTES:

1) EXCAVATE TOPSOIL AND SUBSOIL AS A SINGLE LIFT-PLACE TRENCH SPOIL ON SPOIL SIDE ADJACENT TO TRENCH.
2) RETURN TRENCH SPOIL TO TRENCH AND COMPACT. MINIMIZE SCALPING OF UNDISTURBED SOD LAYER IN GRASSED LANDS. LEAVE A ROACH OVER THE TRENCH TO ALLOW FOR SUBSIDENCE.
3) RESEED WITH A COMPATIBLE SEED MIX AND FERTILIZE.

Figure 2: No topsoil stripping procedure in summer conditions (Alberta Environment 1985)

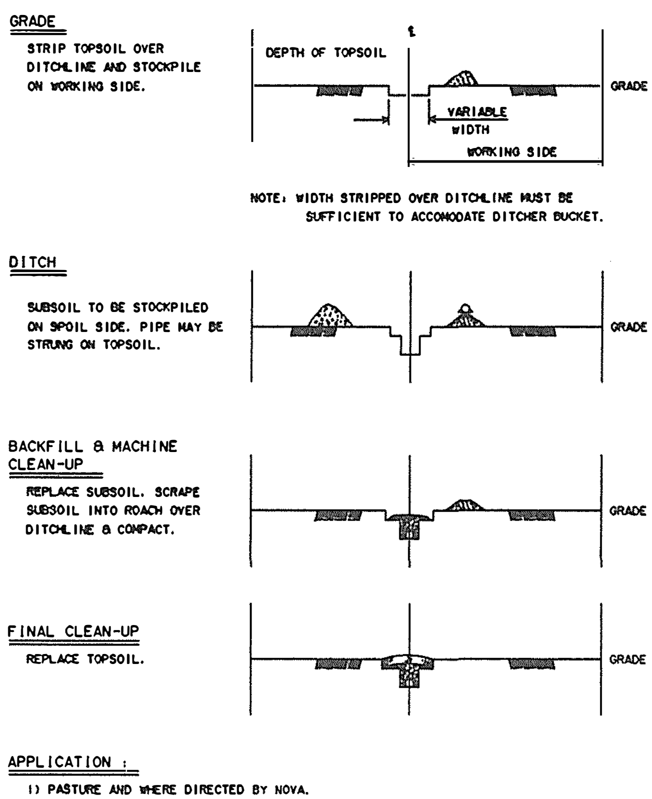


Figure 3: Ditchline stripping procedure in summer conditions (NOVA 1990)

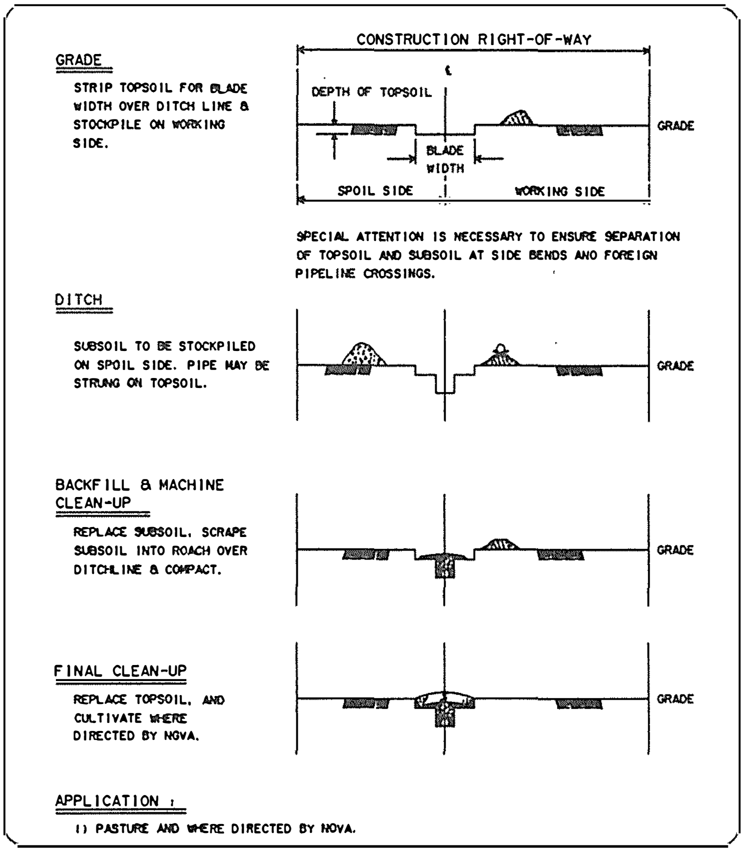


Figure 4 : Blade width stripping procedure in summer conditions (NOVA 1988)

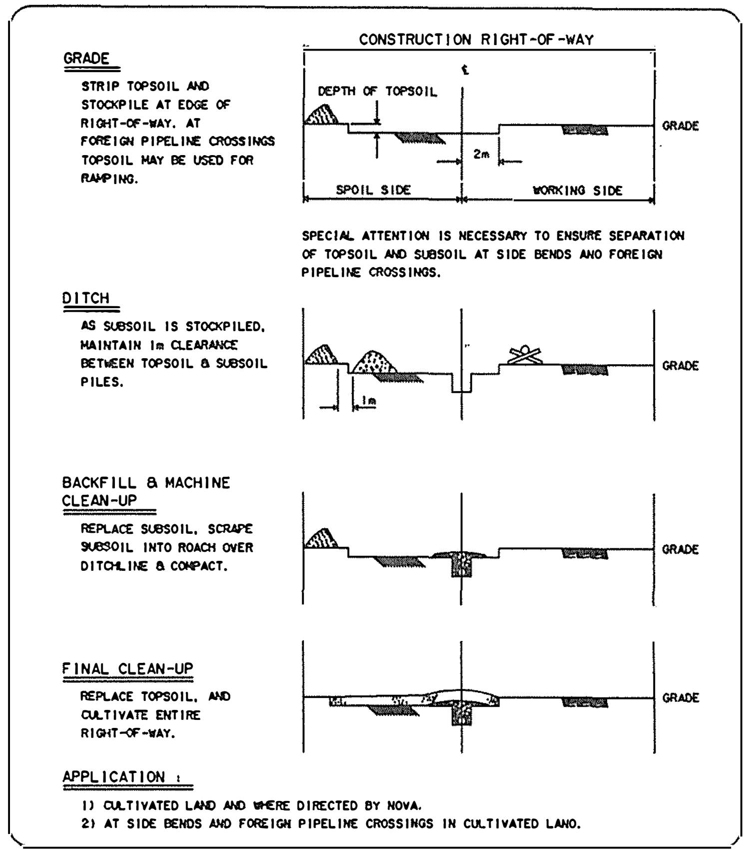


Figure 5 : Ditchline and spoil side stripping procedure in summer conditions (NOVA 1988)

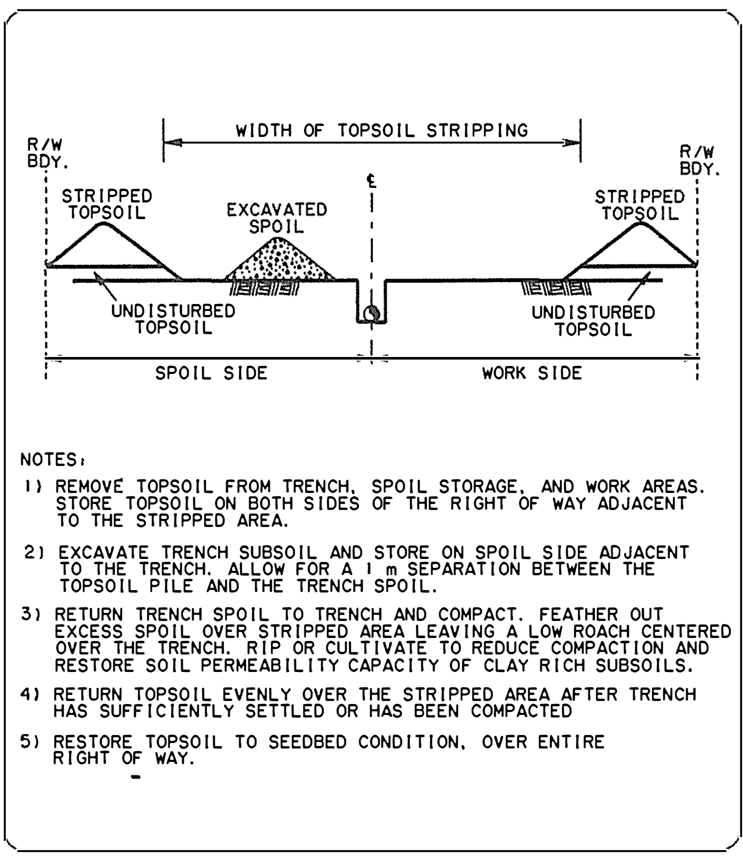


Figure 6 : Trench, spoil and workside stripping procedure in summer conditions (Alberta Environment 1985).

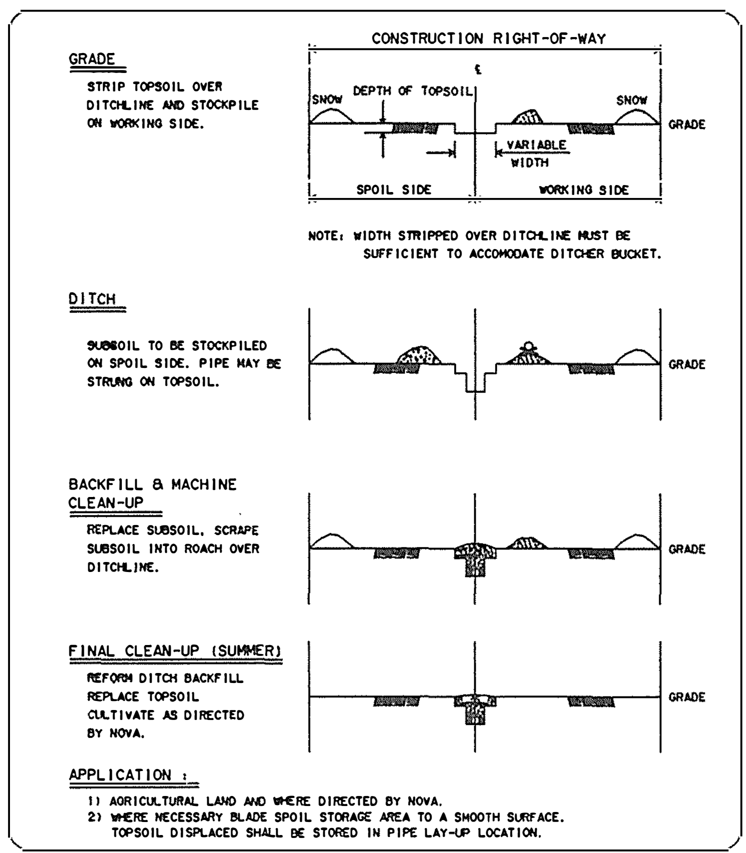


Figure 7 : Ditchline stripping procedure in winter conditions (NOVA 1988).

3.3 IMPACTS OF PIPELINE CONSTRUCTION

Impacts of pipeline construction (either negative or positive) on agricultural or potentially arable soil are inevitable. They depend largely on the quality and type of soil disturbed during construction, present land use and the environmental sensitivity of the ecosystem being disturbed. Some of the difficulties encountered during pipeline installation and subsequent reclamation of rights-of-way are subject to climate, topography, composition of topsoils and subsoils, hydrology and biological systems. Problems associated with pipeline construction include soil horizon mixing, soil compaction, topsoil loss, lowered organic contents, soil erosion, changes in soil chemistry, altered internal drainage, increased stoniness in surface horizons, weediness and changes in productivity (Button and de Jong 1970; de Jong and Button 1973; Shields 1979; Culley et al. 1982; Hardy Associates (1978) Ltd. 1983). Construction activities that affect the soil most dramatically are grading, topsoil stripping, trenching, backfilling, right-of-way traffic and cleanup. Trenching has probably the most significant effect on the soil.

3.3.1 Soil Mixing

Soil mixing occurs when soils from different horizons are mixed together. Of most concern is the mixing of topsoil and mineral subsoil. This occurrence is often the most visual impact of pipeline construction because of the colour differentiation between topsoil and subsoil soil horizons in a profile. Associated effects of soil mixing can include the dilution or loss of organics and nutrients from the rooting zone or seedbed as well as changes in chemical and physical properties of the newly formed soil when compared to the adjacent undisturbed soil. Chemical and physical characteristics of the trench soil usually reflect the inherent properties of soil materials from the horizons that were mixed together (Zellmer et al. 1985).

Soil mixing can occur at various stages of the pipeline installation process. Sources of mixing include no topsoil stripping; topsoil stripping procedures taking some subsoil along with topsoil; subsoil being stored on topsoil; replaced subsoil overflowing the trench and spreading over undisturbed topsoil; or heavy equipment rutting the soil and mixing the A and B horizons if it is too wet (Alberta Environment 1985).

Evaluation of pipeline reclamation practices on rights-of-way, varying in age from one to 19 years, in the Grey Luvisolic soil zone of the Peace River district was undertaken by Hardy Associates (1978) Ltd. (1983). Construction of the pipelines usually occurred in the summer with only four of the twenty sites examined being installed in winter. This investigation showed that topsoil was found to be thoroughly mixed with the soil parent material or even absent from the trench surfaces in 40% of the sites. In 45% of the sites there was mixing of the topsoil with the B horizon. Minimal or no mixing of the topsoil with lower horizons was found in only 15% of the sites. Similar results were reported for the stockpile areas. Generally, topsoil was salvaged from the trench on older sites and across the entire right-of-way at sites of more recently installed pipelines. Topsoil removal from the trench only, which usually took place in summer, resulted in topsoil being mixed only with the B horizon or not at all when subsequently replaced. Topsoil removal from the entire right-of-way usually occurred in the winter and was mixed with B and C horizons.

Little research has occurred in the field to determine the effect of mixing topsoil and subsoil on pipeline rights-of-way. A greenhouse experiment, using loam, silt and clay soil, was conducted in Ontario to evaluate the effect of mixing topsoil (A horizon) with subsoil (B horizon) in various proportions (Culley et al. 1981). Treatments included 55%, 50%, 25% and 0% subsoil. Results showed that there was a positive correlation between dry matter corn yields and percent topsoil for the loam and silt soil. In contrast, the clay soil demonstrated significant yield increases between treatments of 100% and 50% subsoil and declined slightly at 25% and 0% subsoil. It has also been reported that total nitrogen uptake by corn was positively correlated to percent topsoil for the treatments, suggesting that the organic nitrogen pool in the surface layer is a source of plant available nitrogen. Results of this study concluded that soil mixing adversely affected the fertility of the soil. However, another researcher has shown that topsoil stripping and replacement of 0, 15 and 30 cm in Luvisolic soils under winter construction in Alberta has resulted, for all three treatments, in little change in soil quality of the rights-of-way compared to the adjacent undisturbed soils (Cloutier 1988).

The effects of soil horizon mixing can be lessened by storing the stripped topsoil on undisturbed topsoil and storing subsoil from the trench on subsoil already stripped of topsoil. Topsoil and subsoil stockpiles should be at least one metre apart (M. Houser, personal communication). The effect of mixing soil horizons is dependent on the quality and quantity of soil involved and is reflective of the soil profile.

3.3.2 Soil Compaction

Soil compaction depends on soil moisture content, texture, the amount of organic matter present, as well as compactive effort. Soils at low moisture content resist compaction while at higher moisture contents, soil flows rather than compacts after stress is applied. Maximum compaction of soil occurs at moisture levels somewhere in between (Lull 1959). Under wet conditions the optimum level of compaction is lower than under dry conditions. Finer-textured soils, which have a higher clay content, have lower optimum levels of compaction when compared to coarser-textured soils (Swan et al. 1987). Soil horizons with organic matter are less susceptible to compaction than bare mineral soils (Lull 1959).

Compaction of the plough layer due to heavy machinery results because of contact pressure of the tires, while subsurface compaction is related to the total axle load of equipment (Swan et al. 1987).

Compaction occurs on both topsoil and subsurface materials. Alleviation of topsoil compaction is easily accomplished by cultivation. It is, however, harder to correct subsurface compaction. Natural freeze-thaw cycles will tend to slowly loosen compacted soils (Swan et al. 1987). Studies on compacted forest soils in Idaho indicate that natural processes will loosen soil over time (Froehlich 1985). This study showed that recovery from compaction on surface layers was faster than at 15 to 30 cm depths. These subsurface layers were very slow to recover from soil compaction. Similar results concerning persistence of bulk density were found in Solonetzic rangeland soils on work areas of rights-of-way (Naeth 1985). Severe compaction may require deep tillage if topsoil has already been replaced. An easier alternative would be to cultivate the subsurface soil before topsoil replacement.

Most documented studies concerned with pipeline construction have indicated that soil compaction can be a problem. Compaction results because of repeated passage of equipment on the surface of a right-of-way, because of a denser subsoil being mixed with topsoil or even because the soil was too wet when handled. Soil compaction can lead to poor root penetration; difficult cultivation; poor seedbed preparation; reduced water infiltration and water storage capability; increased surface water runoff; and decreased soil porosity which affects aeration by lowering oxygen levels and oxygen renewal and diffusion rates (Lull 1959, Swan et al. 1987).

A few benefits for plant growth are identified with moderate soil compaction. These benefits include decreased water loss by evaporation and good seed-soil contact which allows faster germination and prevention of excessive drying out around the seed (Swan et al. 1987). However, if compaction exceeds an optimal level then root growth decreases, as does the respective soil volume explored by roots for nutrient and water uptake. Severe subsurface compaction can cause losses of nitrogen through denitrification because of lower soil aeration.

A study conducted by Leskiw and Travis (1984) on Chernozemic soils in Alberta to evaluate topsoil handing practices three years after pipeline construction, found that topsoil that was not stripped on the working and spoil sides of the right-of-way was less compacted than topsoil that was stripped and subsequently replaced across the entire right-of-way. The bulk density of stripped topsoil was not shown to be greater than the bulk density of topsoil on control sites. The subsoil where topsoil was stripped across the entire right-of-way was more dense than subsoil where topsoil was not stripped and was also more dense than subsoil on the control soil. These findings were similar to those reported in an earlier report by Deloitte, Haskins and Sells Associates (1980) in which a recommendation was made that topsoil be left in place to provide a cushion against soil compaction.

Considerable soil compaction was measured across the entire right-of-way, especially on medium-textured to fine-textured soils in Ontario (Culley et al. 1982). It was shown that compaction did not appear to be a problem on coarse-textured soils. Bulk densities were 10% greater in soils on the right-of-way than in undisturbed fields.

In contrast, research in eastern Oklahoma on a fine sandy loam concluded that bulk density was not increased by pipeline installation in a semiarid environment (Zellmer et al. 1985). As well, bulk density was not increased on the right-of-way by construction traffic. In this study no attempt was made to separate or remove the topsoil during the trenching and backfilling. In 80% of the sites, bulk density was lower in the trench than on the adjacent control. Bulk density values for the control cultivated soil averaged approximately 1.56 g/cm^3 while in the trench the bulk density was 1.46 g/cm^3. Similar trends were found on pasture land as bulk density averaged approximately 1.46 and 1.27 g/cm^3 for control and trench locations, respectively. It was also shown that there was no significant difference between the bulk density of the soil in the work area and the soil in the adjacent control site.

Earlier studies by de Jong and Button (1973), revealed that the trenching operation neither harmed nor improved the physical properties of Chernozemic soils. However, in Solonetzic soils trenching improved the permeability and aeration of the Bnt horizon by decreasing its bulk density. On Solonetzic soils the trenching operation tended to decrease bulk density at depth while for the Chernozemic soils the opposite occurred. It was further shown that in Chernozemic soils the bulk density value of 1.5 g/cm^3, which is a critical value for root penetration (Button and de Jong 1970), had resulted from compaction of heavy machinery or puddling of exposed subsoil. Other research has shown similar results regarding bulk density on Solonetzic rangelands (Naeth 1985). In this investigation the clay content and surface bulk density increased, but the bulk density with depth decreased as a consequence of the trenching operation. Surface bulk density increased by 51% to 82% on the right-of-way compared to undisturbed land. The bulk density of the dense Bnt horizon was lowered because it had been broken up. However, the lowered bulk density values were still considered high enough to impede root penetration. Bulk density had increased to a depth of 55 cm on the work and stockpile areas of a more recently installed pipeline and these increases continued to persist with time. The surface bulk density had declined over the trench within 10 years of pipeline installation but was still not similar to predisturbed conditions. After 24 years, bulk density of soil in the trench was still significantly lower than adjacent prairie soil.

To further emphasize the potential severity of soil compaction, a study by Moncrieff (1984) is presented. This investigation evaluated soil damage when a right-of-way was turned into a homogeneous saturated mixture of topsoil and subsoil. Eight kilometres of trenching for a pipeline system in southwestern Ontario had occurred in 1974 when the project was postponed. A year later, the topsoil, left exposed to deteriorating weather conditions and heavy equipment movement, had been diluted with subsoil throughout the entire right-of-way. Five years later, yields on the right-of-way were still approximately 40% lower than those on the adjacent field. This study concluded that yield reductions were due to the conversion of the original structure of the B horizon into a massive structure and to the resulting reduced air and water movement and limited root penetration. Amelioration of the site by subsoiling procedures was necessary to break up the subsoil and provide surface drainage. Since then, the yields have improved dramatically and were found to be approaching, and in some cases even exceeding, those found off the right-of-way.

3.3.3 Hydraulic Conductivity, Porosity and Soil Strength

The hydraulic conductivity of soil has been shown to be altered by pipeline installation. Lowered infiltration capacity can be a problem since the erosion potential increases. After pipeline construction, medium-textured to fine-textured soils had reduced hydraulic conductivities and porosities, and increased soil strengths compared to undisturbed adjacent soils (Culley et al. 1982). Hydraulic conductivity decreased by an average of 38% in trench and work areas compared to adjacent control sites on Ontario rights-of-way. These authors also reported that soil surface layers had lower available water holding capacities than surface layers of adjacent undisturbed land. The strength of soil measured by penetrometer resistance was greater on the right-of-way than off, averaging 67% and 50% more over trench and work areas, respectively. These changes in the physical characteristics of soils were attributed to increased clay content and reduced organic matter in the surface layer.

In southwest Saskatchewan, trenching increased aeration and subsequently oxygen diffusion rates of Solonetzic soils, but had little effect on Chernozemic soils (de Jong and Button 1973). It was also indicated that at lower soil moisture contents, soil impedance may become a problem in the Solonetzic Bnt horizon. The -33 kPa moisture contents of Solonetzic and similar soils were lowered due to trenching. Consequently, available water, calculated from -33 kPa and -1500 kPa moisture contents, was also lowered. In Solonetzic rangeland studies in Alberta, total soil water in the trench increased from that of the undisturbed adjacent prairie (Naeth 1985), but these increases did not persist with time (Naeth 1985). As well, it was reported that water retention became more uniform with depth, although the available water capacity was not significantly affected by pipeline installation.

Slow transmission of water through subsoil, causing saturation of surface layers, in early spring and late winter prompted a soil mixing study conducted by Mech et al. (1967), in eastern Washington. The soil was a moderately fine-textured silt loam, developed under a coniferous forest. It had a 40 cm thick A_1 horizon with high silt content, an intensely leached 10 cm thick A_2 horizon low in clay, and a dense B horizon high in clay content. Four soil treatments included a 15 cm plough depth, mixing of the top 45 cm, removal of topsoil and subsoil separately to a depth of 1.2 m and replacement in original position, and mixing of topsoil and subsoil to a depth of 1.2 m. Mixing of the soil was done using a backhoe. Combining the A and B horizons increased the clay content in the surface 20 cm and resulted in a bulk density of 1.45 g/cm^3 throughout the entire 1.2 m. Original bulk densities for the A and B horizons were 1.31 and 1.63 g/cm^3 respectively. Soil moisture removal by crops during the growing season was greatest from the deeper depths in treatments of deep tillage and when mixing of the topsoil and subsoil was more thorough. In treatments where the B horizon was broken up, deeper root penetration occurred. These authors concluded that the deeply tilled and mixed profiles provided more moisture for plant use and better physical conditions for greater plant growth. In contrast, deep ploughing (75-90 cm) of the same soil initially resulted in severe puddling because of the high clay and low organic matter content of the exposed subsoil, and lowered infiltration rates. After deep ploughing the original A horizon was at a depth of 20 to 60 cm and was covered by the subsoil. However, water content of the profile was increased as was root penetration. The soil condition improved with the incorporation of crop residues and time.

3.3.4 Soil Chemistry

Soil mixing may result in reduced soil capability if subsoil is less fertile or of poor quality compared to topsoil. Changes in chemical properties of a soil depend to a large extent on the degree of horizon mixing and its subsequent tillage. Studies by de Jong and Button (1973), have shown that mixing of topsoil and subsoil horizons resulted in lower surface layer (0 to 15 cm) contents of nitrate nitrogen, extractable phosphorous and extractable potassium when compared to undisturbed soil. Incorporation of topsoil into the subsoil resulted in increased nitrate nitrogen, phosphorous and potassium at depths below 15 cm. In Ontario, Culley et al. (1982), ascertained that cation exchange capacity, total nitrogen, extractable phosphorous and exchangeable potassium were lower in surface soils on the right-of-way than on the undisturbed field. On semiarid agricultural land soil bases (soluble calcium, magnesium and sodium) were higher in the trench compared to adjacent controls (Zellmer et al. 1985).

In Chernozemic soils pH changed by less than 0.5 units, while in Solonetzic soils pH in the trench increased by 2.0 units (de Jong and Button 1973). This effect was also shown by Culley et al. (1982). Naeth (1985), indicated that there was no significant pH difference on Solonetzic rangeland soils at depths lower than 15 cm, but in the surface soil layer (0 to 15 cm) of the pipeline trench the pH increased from 6 to 8, which is considered high for plant tolerance. For Luvisolic soils, pipeline installation procedures increased the pH of the trench area by as much as 2.7 pH units in the 15 to 30 cm depth to a pH of approximately 6.5 (Cloutier 1988) which is considered more favourable for nutrient availability. There was a significant increase in soluble salts in the surface layers of Solonetzic soils upon mixing of topsoil and subsoil, especially for the first two years after pipeline installation (de Jong and Button 1973). Similar results were shown by Naeth (1985), for Solonetzic prairie soils.

Organic carbon was found to be lower on the rights-of-way of the Sarnia-Montreal pipeline (Culley et al. 1982), as well as on Solonetzic rangelands disturbed by pipeline installation (Naeth 1985). Organic matter loss usually results in a decreased amount of available nutrients and often in a seedbed that is difficult to cultivate. Organic matter appears to be desirable for improving tilth, aeration of soils and minimizing soil erosion (McGill 1982). Pipeline construction procedures tend to accelerate the decomposition of organic matter, but plant roots can add organic matter to the soil to help maintain a stable soil system. Increased organic carbon contents have been measured on the right-of-way for both 0 to 15 cm and 15 to 30 cm depths compared to undisturbed adjacent areas when organic matter was incorporated into Luvisolic soils that have had topsoil and subsoil mixed due to pipeline installation (Cloutier 1988). Plant roots from a developed sod layer in the seeded right-of-way were the source of organic matter added.

3.3.5 Erosion

Soils most susceptible to wind erosion are those soils in the southern part of Alberta in the Brown and Dark Brown soil zones (Goettel et al. 1981). These soils are dry, coarse-textured and have poor soil aggregation. Water erosion is more serious in the Grey and Dark Grey soil zones where soils are fine-textured and have poor infiltration (Goettel et al. 1981).

Surface layer compaction can result in soil loss because of increased runoff (Shields 1979). Pulverization of soil during stripping and replacing operations of pipeline installation may leave soil more prone to wind and water erosion. Water flow may become concentrated along the linear features of the pipeline. The berm that is placed to allow for subsidence of soil may become a barrier obstructing normal drainage patterns (Marciak and Hermans 1983). Practices that reduce the exposure of bare soil to rainfall and maintain soil in good tilth tend to increase the rate of infiltration and help prevent water erosion. Therefore, it is best to revegetate as quickly as possible and rid the trench of any linear features (Shields 1979).

Wind erosion depends on wind velocity, soil characteristics and soil surface conditions (Alberta Environment 1985). Practices that require excessive removal of vegetation cover or excessive handling of soil can increase the potential for wind erosion.

3.3.6 Soil Temperature

At depths of 60 cm and 110 cm in the right-of-way where a recently installed pipeline (1981) was located, pipeline trench soil temperatures were higher in the winter but lower in the summer compared to the adjacent undisturbed soil (Naeth 1985). Higher temperatures for the trench zone occurred between 30 cm and 110 cm depth due to the heating effect from the gas in the pipeline. Similar results were found in Ontario where soil temperatures were found to be higher in the trench zone of a right-of-way compared to undisturbed soil (Stewart and MacKenzie 1979), but the extent of area affected by the temperature change was not reported. These authors attributed the higher temperatures to changes in heat diffusivity of the soil, changes in either surface properties or plant cover as well as the heat content of the pipeline. Earlier germination of cereal crops and faster growth of forage crops in the spring could result from increased soil temperature from pipelines (Marciak and Hermans 1983). However, these authors also suggested that if moisture is limiting, soil desiccation could occur which would ultimately result in lowered productivity, especially for forage crops.

3.3.7 Stoniness and Weediness

An increase in surface stoniness was evident at 35% of the Luvisolic sites investigated after pipeline construction in the Peace River district (Hardy Associates (1978) Ltd. 1983). The increase in stoniness usually occurred over the trench area and generally was in the magnitude of one class, as measured by the Canadian Soil Survey Committee (1978), from either slightly to moderately, or moderately to very stony. On 10 out of 20 sites where the authors commented on weediness, six sites were shown to have increased weed populations on the right-of-way while four sites demonstrated lower weediness.

3.3.8 Crop Yield

Conflicting information exists in the literature on the impacts of pipeline installation on crop productivity. Some studies have shown reduced yields resulting from pipeline disturbances while other studies have demonstrated little or no yield differences. In some studies, yield increases have been reported. Most yield responses can be attributed to resultant soil characteristics from pipeline construction procedures such as topsoil removal, trenching and backfilling.

Yields on trenches and undisturbed fields were not significantly different on Chernozemic soils (de Jong and Button 1972), even though yields on trenches were a little lower the first two years. In contrast, yields for Solonetzic soils on trenches of old pipelines generally were higher than those on the undisturbed field, while yields on trenches of recently installed pipelines and adjacent controls did not differ significantly, presumably because of increased salt concentrations in the trenches. For solonetzic rangelands in Alberta, ground cover of older natural gas pipeline rights-of-way was similar to those of adjacent undisturbed land, suggesting a return to predisturbed conditions (Naeth 1985).

Researchers reported lower grain and row crop yields in the first year after pipeline construction on cropland traversed by the Sarnia-Montreal pipeline in Ontario (Culley et al. 1982). Yields were reduced, on average, by 43% for the first year and even after five years, when relative yields improved, yields were still lower by 20% to 30%. These yield reductions appeared to be linked to increased soil clay content, from mixing topsoil with subsoil, and from soil disturbance due to compaction and rutting. The researchers also reported that alfalfa growth appeared to be unaffected by pipeline activities and was perhaps due to elevated soil temperatures in the spring over the line. The difference in yield productivity responses between Saskatchewan and Ontario suggest that Ontario soils may be more susceptible than prairie soils to adverse effects of pipeline construction. Possible reasons for the differences include wetter soil conditions in Ontario and different cropping and soil factors (Culley et al. 1982).

In eastern Oklahoma wheat yields over trenches were significantly higher than yields on the working side of the right-of-way or adjacent control soils (Zellmer et al. 1985). Yield increases were attributed to increased moisture retention capacity and lower bulk density of the trench. Toogood (1974) reported that for pipeline rights-of-way, where topsoil and subsoil were, mixed grain yields were greater over the pipeline than off the pipeline right-of-way, although straw yields were not. This study evaluated cereal crop yields grown mainly on Malmo silty loam between Edmonton and Fort Saskatchewan, but included crops grown on Gray Luvisolic soils. This investigation concluded that pipeline installation did not appear to damage soil fertility and that increased yields were attributed to improved tilth and mineral nutrients that were brought up from the subsurface.

Crop productivity after pipeline construction on Luvisolic soils in the Peace River district was evaluated by Hardy Associates (1978) Ltd. (1983). Estimated live vegetation cover over the trench varied less than 10% from the adjacent control soils for 75% of the sites. Where plant height was measured, 40% of the sites recorded reductions over the trench while 20% of the sites recorded increases. Similar trends were shown over the stockpile and work areas of the right-of-way. Decreases in percent live cover or crop height were attributed to extensive mixing of topsoil with B or C horizons, shallow topsoil replacement and cracking and crusting in areas of water ponding. Increases, or little change, in plant growth occurred on soils over pipelines that were greater than four years old, where topsoil was unmixed or mixed only with the B horizon and where little compaction had occurred.

3.4 POTENTIAL IMPACTS OF PIPELINE CONSTRUCTION ON LUVISOLIC SOILS

Agricultural productivity of Luvisolic soils is limited by climate, soil structure and fertility problems. Growing seasons are short, often only 80 to 90 frost-free days, with early winter freezes and delayed spring thawing. These soils tend to be droughty in the early part of the growing season and saturated at harvest time. Because of low organic matter levels in the mineral portion of the soil, structural problems are quickly encountered upon cultivation. The Bt horizon is dense with low permeability and is compact when dry so that roots have difficulty penetrating the peds. Soil acidity is high and native fertility is low, especially for nitrogen and sulphur. However, despite their inherent problems, with proper cropping and soil management practices, Luvisolic soils can be improved to achieve good productivity. Since further expansion of cultivated land will take place mainly in areas dominated by Luvisolic soils, responsible management of this soil resource should be ensured. Therefore, it is necessary to determine the potential impacts various topsoil handling techniques could have on Luvisolic soil characteristics, so appropriate measures can be applied to future pipeline construction projects.

Review of the literature suggests that pipeline installation procedures affect both chemical and physical properties of soil in the trench. Furthermore, physical and chemical properties of soil on the work and spoil sides of the trench may also be affected. Currently, government guidelines for the conservation of soil during pipeline construction advocate the preservation of the A horizon on potentially arable Luvisolic soils, which could vary from 15 cm to 50 cm depending on the thickness of the LFH, Ah and Ae horizons. Topsoil for Luvisols is often arbitrarily defined as the top 15 cm (The Canadian System of Soil Classification 1987). Consequently, replacement of topsoil, under government guidelines, would result in horizon characteristics similar to those of the plough depth encountered in farming practices. Because the Ah horizon is thin, the Ap horizon would consist mainly of the Ae horizon, although sometimes the Bt horizon would be incorporated. The LFH layer would quickly disappear through removal of trees from the site and through decomposition when either broken up or mixed with mineral soil. Because of the low humus content, the Ap horizon would have a low water holding capacity and low nutrient status. Native soil fertility would also be low, especially for nitrogen and sulphur. The plough depth would often crust or puddle resulting in lower infiltration, increased water erosion and poor seedling emergence. An increase in surface pH due to pipeline installation is not expected if topsoil is handled separately.

Removal and subsequent replacement of the subsoil would alter soil physical properties. The impermeable Bt horizon, which tends to inhibit root growth would be broken up and therefore a decrease in bulk density would be anticipated. The lowering of subsoil bulk density has been substantiated in a study by Cloutier (1988). Decreasing the bulk density would improve hydraulic conductivity, increasing moisture penetration and availability to the plant. As well, the lowered bulk density would result in increased porosity and aeration allowing deeper root penetration for better moisture and nutrient extraction from the soil. Replacement of the subsoil is not expected to result in dramatic changes in particle size distribution, exchangeable cation concentrations, total nitrogen or total organic carbon (Table 1). However, pH could be increased if calcium carbonate is brought up from the Ck horizon. This addition of lime should not adversely affect crop growth as these forested soils are acidic and liming often has a beneficial effect (Bentley et al. 1971). If a Csa horizon is present, soluble salts may also be brought up. The effect of soluble salts is dependent on the concentration and moisture content of the soil.

The opposite extreme to preservation of the topsoil would be no conservation at all. No effort would be made to salvage the topsoil during the trenching operations. Mixing topsoil with subsoil is expected to loosen the soil and alter its physical properties in a manner similar to that in the discussion of removal and subsequent replacement of subsoil. Incorporation of organic matter from leaf litter and silt from the Ae horizon is not expected to change the subsoil characteristics dramatically. Organic matter will decompose quickly when mixed with the mineral horizons.

However, with no topsoil salvage the LFH and Ae horizons would be incorporated into the subsurface horizons, and surface bulk density, pH and clay content would be expected to increase compared to an undisturbed soil (Tables 1 and 2). Increased clay content may cause structural problems for the surface horizons, but these problems currently exist when the native soil is brought into cultivation through conventional methods and have already been discussed. Long-term additions of organic matter through legumes in a crop rotation have been reported to improve soil tilth, organic matter content and nitrogen concentrations of cultivated Luvisolic soils at the Breton plots (Cannon et al. 1984). Incorporation of organic matter into Luvisolic soils that have had topsoil and subsoil mixed due to pipeline installation, has shown increased organic carbon content of the soil (Cloutier 1988). Results of this investigation suggest that addition of fertilizers and a good seed mixture to an area where topsoil is not salvaged can result in the formation of a sod layer on the right-of-way. Plant roots, a source of organic carbon, can penetrate the subsurface soil more easily in the trench area than in the undisturbed adjacent control because of a decrease in bulk density resulting from the trenching operation. The larger root volume allows for better moisture and nutrient uptake. The addition of organic matter to Luvisols is essential to maintain good soil structure and to ensure profitable agricultural use of these soils.

Ideally, pipeline installation procedures should not affect crop yields. In fact, yields could even be increased due to improved physical conditions. Yield increases or no yield differences were shown for grain crops on Luvisolic soils disturbed by pipeline installation in the Edmonton area (Toogood 1974). In northwestern Alberta, 75% of Luvisolic sites showed no difference in yield response after pipeline construction (Hardy Associates (1978) Ltd. 1983).

The work and spoil sides of pipeline rights-of-way can also be affected by pipeline construction. The main effects for these areas result from soil mixing and compaction. Compaction can occur from repeated passage of heavy equipment, and mixing can occur with subsequent removal of topsoil and subsoil from the spoil side. Leaving topsoil in place on the work side has been reported to reduce subsurface soil compaction because the organic matter provides a buffer to reduce subsurface compaction (Deloitte, Haskins and Sells 1980). However, in the fall, when soil moisture conditions tend to be wetter, Luvisols are prone to rutting causing mixing of the soil horizons. Therefore, stripping the work side or shutting down the construction operation in wet weather may be necessary. Compaction of the work side, where topsoil was not stripped, occurred under winter construction and summer clean-up conditions on Luvisolic soils (Cloutier 1988). Further investigation of procedures to minimize and alleviate the effect of compaction on Luvisolic soils is needed.

If the spoil side is not stripped of topsoil, soil mixing can occur following removal of subsoil stored on topsoil. This mixing of subsoil with topsoil could potentially result in increased surface bulk density, pH and clay content. Structural problems for surface horizons can occur because of the increased clay content but these problems currently exist when virgin Luvisolic soils are brought into cultivation. Where topsoil had been stripped from trench, stockpile and work areas on Luvisolic sites, topsoil was mixed with B and C horizons, although it was mentioned that most of these sites were on water pipeline right-of-ways (Hardy Associates (1978) Ltd. 1983). The effect of soil mixing is dependent on the quality and quantity of soil involved.

4.0 CONCLUSIONS

Agricultural soils are a prime resource in the province of Alberta and maintenance of soil quality is essential. As well, the oil and gas industry is a major contributor to the economy of the province. Conflicts are inevitable between the two industries.

Soil conservation and reclamation should be long-term goals for maintaining soil quality. Reclamation objectives are to restore disturbed areas to a level as near as possible to prior land use conditions, both aesthetically as well as in usefulness. There is a growing concern about the deterioration of agricultural land in western Canada. New land being brought into cultivation will be mainly on Luvisolic soils in areas of marginal climate. Therefore, it is necessary to manage the soil resource responsibly to achieve agricultural productivity and conserve future productivity.

Pipeline installation procedures on Luvisolic soil are expected to affect both chemical and physical properties of soils in the trench. Removal and subsequent replacement of subsoil during the trenching operation results in the impermeable Bt horizon being broken up. The anticipated decrease in bulk density should improve hydraulic conductivity and porosity. These improvements could allow deeper root penetration for better moisture and nutrient extraction from the soil. A dramatic change in particle size distribution, exchangeable cation concentrations, total nitrogen or total organic carbon is not expected. If calcium carbonate is brought up from the Ck horizon, pH would be increased.

Stripping and replacement of topsoil is expected to result in horizon characteristics similar to those of the plough depth in a cultivated Luvisol. The cultivated Ap horizon is a source of many problems including a tendency to crust, susceptibility to pulverization, clodding and compaction due to tillage, low water holding capacity, low native fertility and low pH buffer capacity. These problems result in reduced aeration, water infiltration and available water as well as difficulties in seedbed preparation and seedling emergency. No topsoil stripping would result in topsoil being mixed with subsoil. Consequently, increased surface bulk density, pH and clay content would be anticipated. Although the increased clay content could cause structural problems for the surface horizons, these problems already exist when native soil is brought into cultivation by landowners.

A discussion of potential impacts of pipeline construction on potentially arable Luvisolic soils tended to suggest that topsoil conservation may not be necessary. Currently, there is little documented information on summer topsoil handling techniques for forested areas to substantiate this conclusion. Further studies are needed to determine the effect of stripping versus not stripping topsoil in forested areas. There is a need for information on the effects of pipeline installation on chemical and physical properties of Luvisolic soils and how different topsoil handling techniques can affect soil quality.

5.0 LITERATURE CITED

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian System of Soil Classification. Second Ed. Agric. Can. Publ. 1646. 164 pp.

Alberta Environment. 1985. Manual on Soil Conservation. Regulated Operations Branch. Land Reclamation Division. Edmonton, Alberta. 82 pp.

Bailey, W.G. 1981. The Climate Resources for Agriculture in Northwestern Canada. Agriculture and Forestry Bulletin. Volume 4 Number 1. The University of Alberta. Edmonton, Alberta. pp 11-17.

Bentley, C.F., T.W. Peters, A.M.F. Hennaing and D.R. Walker (eds.) 1971. Grey Wooded Soils and Their Management. T ed. University of Alberta and Canada Department of Agriculture Bulletin B-71-1. 89 pp.

Button, R.G. and E. de Jong. 1970. Effect of Pipeline Installation on Soil Productivity. Publication No. M-17. Saskatchewan Institute of Pedology. University of Saskatchewan. Saskatoon, Saskatchewan. 54 pp.

Cannon, K.R., J.A. Robertson, W.B. McGill, F.D. Cook and D.S. Chanasyk. 1984. Farming For the Future Project 79-0132. Production Optimization on Grey Wooded Soils. Project Manager. James A. Robertson. Department of Soil Science, University of Alberta. Edmonton, Alberta. 117 pp.

Clayton, J.S., W.A. Ehrlich, D.B. Cann, J.H. Day and I.B. Marshall (eds.) 1977. Soils of Canada. Volume 1 Soil Report. A Cooperative Report of the Canada Soil Survey Committee and the Soil Research Institute. Research Branch, Ottawa, Ontario. Canada. 243 pp.

Cloutier, C.L. 1988. Soil Handling During Winter Pipeline Construction on Luvisolic Soils in Northern Alberta. IN: Proceedings of the 25th Annual Alberta Soil Science Workshop. Lethbridge, Alberta. 11 pp.

Culley, J.L.B., B.K. Dow, E.W. Presant and A.J. MacLean. 1981. Impacts of Installation of an Oil Pipeline on the Productivity of Ontario Cropland. Land Resource Research Institute. Research Branch, Agriculture Canada. Ottawa, Ontario. LLRI Contribution No. 66. 88 pp.

Culley, J.L.B., B.K. Dow, E.W. Presant and A.J. MacLean. 1982. Recovery of of Productivity of Ontario Soils Disturbed by an Oil Pipeline Installation. Can. J. Soil Sci. 62: 267-279.

de Jong, E. and R.G. Button. 1973. Effects of Pipeline Installation on Soil Properties and Productivity. Can. J. Soil Sci. 53: 37-47.

Deloitte, Haskins and Sells Associates. 1980. Impact of Alternate Techniques of Pipeline Construction and Reclamation on Agricultural Soils. Irish Lateral Line. Prepared for: NOVA, An Alberta Corporation. Calgary, Alberta. 30 pp. Unpublished Report.

Environment Council of Alberta. 1985. Maintaining and Expanding the Agricultural Land Base in Alberta. Technical Report and Recommendations. ECA85-17/RR2. Environment Council of Alberta. Edmonton. 198 pp.

Froehlich, H.A., D.W.R. Miles and R.W. Robbins. 1985. Soil Bulk Density Recovery on Compacted Skid Trails in Central Idaho. Soil Sci. Soc. Am. J. 49: 1015-1017.

Goettel, A.W., J.C. Hermans and D.R. Coote. 1981. Degradation by Erosion. In Agricultural Land: Our Disappearing Heritage. Proc. Alberta Soil Science Workshop. Edmonton, Alberta. pp 134-158.

Hardy Associates (1978) Ltd. 1983. Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. RRTAC# 83-3. Prepared for Reclamation Research Technical Advisory Committee of Alberta Energy and Natural Resources. 186 pp.

Holmes, N.D., G.R. McNaughton, W.E. Phillips, J.G. Strothart and J. William, ed. 1976. Alberta Farm Guide 1976. Distributed by Publication Office, Communications Branch, Alberta Agriculture. 18 pp.

Howitt, R.W. and S. Pawluk. 1985a. The Genesis of a Grey Luvisol Within the Boreal Forest Region. I. Static Pedology. Can. J. Soil Sci. 65: 1-8.

Howitt, R.W. and S. Pawluk. 1985b. The Genesis of a Grey Luvisol Within the Boreal Forest Region. II. Dynamic Pedology. Can. J. Soil Sci. 65: 9-19.

Leskiw, L.A. and G.R. Travis. 1984. Analysis of Alternate Techniques of Soil Reclamation on Pipeline Right-of-ways Three Years After Construction. Irish Lateral Line. Prepared for: NOVA, An Alberta Corporation. Calgary, Alberta. 76 pp. Unpublished Report.

Lull, H.W. 1959. Soil Compaction of Forest and Rangelands. U.S. Dept. Agr. Forest Service. Misc. Publ. 768. 33 pp.

Marciak, L.C. and J.C. Hermans. 1983. The Impacts of Pipelines on Agricultural Lands in Alberta. IN: Proceedings of the 20th Annual Alberta Soil Science Workshop. Edmonton, Alberta. pp 145-153.

McKeague, J.A. (ed.). 1978. Manual on Soil Sampling and Methods of Analysis. Canada Soil Survey Committee. Soil Research Institute, Ottawa.

Mech, S.J., G.M. Horner, L.M. Cox and E.E. Cary. 1967. Soil Profile Modification by Backhoe Mixing and Deep Ploughing. Trans. Amer. Soc. Agr. Eng. 10: 775-779.

Moncrieff, I. 1984. Soil Rehabilitation After Pipeline Construction. Oilweek. November 5, 1984. pp. 16-20.

Naeth, M.A. 1985. Ecosystem and Reconstruction and Stabilization Following Pipeline Construction Through Solonetzic Native Rangeland in Southern Alberta. M.Sc. Thesis. University of Alberta. Edmonton, Alberta. 213 pp.

Odynsky, W., A. Wynnyk, and J.D. Newton. 1952. Soil Survey of the High Prairie and McLeannan Sheets. Alberta Soil Survey Report No. 17, University of Alberta. Bull. No. 59 Research Council of Alberta, Canada Department of Agriculture and the University of Alberta. Edmonton, Alberta. 112 pp.

Pettapiece, W.W. and J.D. Lindsay. 1981. Soil Resources and Agricultural Capability in Northwestern Canada. Agriculture and Forestry Bulletin. Volume 4 Number 1. University of Alberta. Edmonton, Alberta. pp. 3-10.

Robertson, J.A. and W.B. McGill. 1983. New Directions for the Breton Plots. Agriculture and Forestry Bulletin. Volume 6 Number 1. The University of Alberta. Edmonton, Alberta. pp. 41-45.

Shields, J.A. 1979. Possible Impacts of Pipeline Construction on Farmland. Land Resource Research Institute. Agriculture Canada. Ottawa, Ontario. 14 pp.

Stewart, A.J. and A.F. MacKenzie. 1979. Effect of Pipeline Construction on Soils and Crops. IV. Department of Renewable Resources, Macdonald College. Quebec. 43 pp.

Swan, J.B., J.F. Moncrieff and W.B. Voorhees. 1987. Soil Compaction: Causes, Effects and Control. AG-BU 3115. Minnesota Extension Service. University of Minnesota. Minneapolis, Minnesota. Minnesota Extension Service, University of Minnesota. 12 pp.

Toogood, J.A. 1974. The Effect of Pipeline Installations on Crop Yield. D. Hocking and W.R. MacDonald, ed. IN: Proceedings, Workshop on Reclamation of Disturbed Land in Alberta. General Services Division, Alberta Environment, Edmonton, Alberta. pp. 15-18.

Webb, C. 1982. The Impacts of Linear Developments, Resource Extraction and Industry on the Agricultural Land Base: Summary. ECA82-17/IB26. Edmonton: Environment Council of Alberta. 9 pp.

Zellmer, S.D., J.D. Taylor and R.P. Carter. 1985. Edaphic and Crop Production Changes Resulting from Installation in Semiarid Agricultural Ecosystems. Paper presented at the National Meeting of the American Society for Surface Mining and Reclamation. Denver, Colorado. 9 pp.