REPORT #
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REVIEW OF THE EFFECTS

OF STORAGE ON TOPSOIL QUALITY

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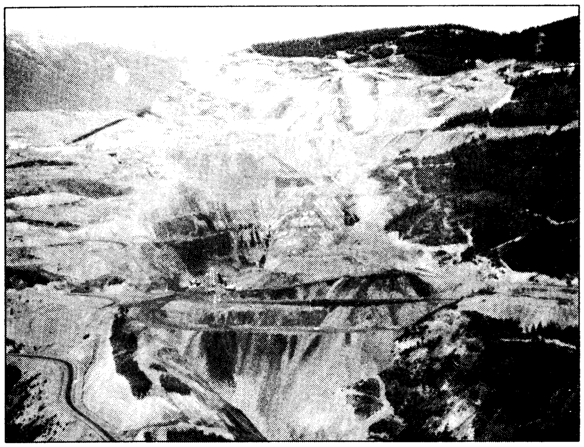

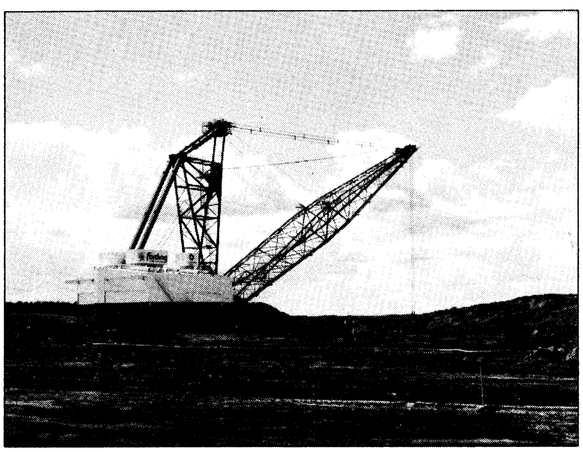

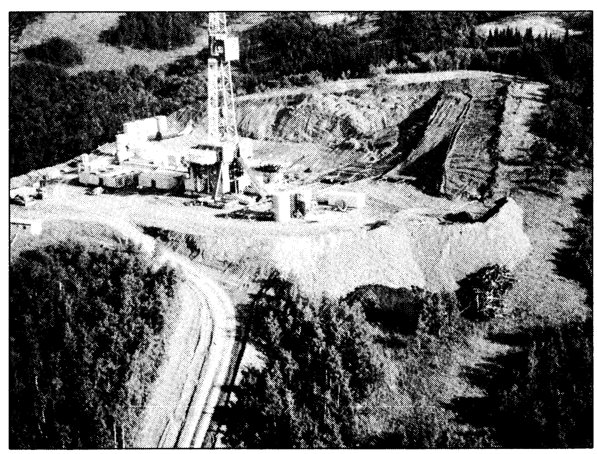

DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

REVIEWS

This report has been reviewed by members of the Reclamation Research Technical Advisory Committee. RRTAC also thanks Mr. A. Janz, Alberta Environment, Land Reclamation Division for reviewing the report.

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ABSTRACT

A review of pertinent literature was conducted to examine the effects of long term storage on topsoil quality in Alberta in order to determine optimum storage methods and periods of storage. Exhaustive computer data searches were conducted to establish the literature base, which was subsequently collected, categorized, and thoroughly examined. In addition to the literature review, a survey of appropriate Alberta companies and government services was conducted to focus on the Alberta experience.

The effects of topsoil storage on soil quality was examined with respect to soil chemistry, soil physics, soil biology, and soil zone. These effects were directly applied to current Alberta topsoil storage practices in the mining, oil and gas, and aggregate industries.

Conclusions from the literature review indicated that topsoil storage does not appear to have any severe and long term effect on topsoil quality. Chemical changes can be rectified with the judicious use of chemical fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with stripping and respreading operations. Soil biota revert to pre-disturbance levels of activity within predictable time frames, a knowledge of which will assist in storage pile design.

The primary recommendation for improvement of topsoil storage in Alberta pertains to native pasture and forestry post industrial land use. The soil biota for such areas can be maintained in a highly viable state if storage piles are broad and shallow to maintain aeration, and the use of agrochemicals is carefully considered so as not to destroy soil biota by overuse of fertilizers and herbicides. For cultivated agriculture and industrial plantsite areas, current storage practices comply with recommendations within the report. Once again, however, precautions with respect to herbicide use should be considered.

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1. INTRODUCTION

This project was commissioned by the Reclamation Research Technical Advisory Committee (RRTAC), in response to a need for a review of the literature to examine the effects of long term storage on topsoil quality in Alberta, in order to determine optimum storage methods and periods of storage. This report includes a detailed review of the literature on the effects of time and storage methods, equipment and conditions on soil chemical, physical and biological properties. Because very little published information exists on topsoil storage in Alberta, the study also includes the results of a survey of situations in Alberta where topsoil storage is required, methods used and reclamation success after stored topsoil has been re-spread.

Virtually all of the literature deals with topsoil storage in large stockpiles, associated with mining operations, often under climate and soil conditions which are very dissimilar to those in Alberta. Storage conditions in these stockpiles may differ considerably from those in shallower piles, such as wellsite berms which are common in the oil and gas industry in Alberta. Storage in the latter case may be required for much longer periods of time, 25 years or more, compared to most mining operations, which are often progressively reclaimed. Little or no published information is available on these methods of storage, including land spreading, storage in small berms, or burial, all of which are used in the oil and gas industry in Alberta. Where possible, available information has been used as a basis for speculation on the effects of topsoil storage under these conditions.

1.1 BACKGROUND

Topsoil has been defined in a number of ways. Agriculture Canada's published definition includes "(i) the layer of soil moved in cultivation, (ii) the A horizon, (iii) the Ah horizon, (iv) presumably fertile soil material used to topdress roadbanks, gardens, and lawns" (Canada Department of Agriculture 1976). Because of the range of interpretations of the term, there is often confusion in the literature. Some studies called all unconsolidated materials topsoil, including A, B, and sometimes C horizon materials. Others dealt with Ah materials or their equivalent only. In some cases it was not too clear exactly what type of materials were being discussed. For the purposes of this review, the topsoil was generally considered to be restricted to A horizon material, although in a few cases it seemed appropriate to include some upper B materials as well. Peat materials, although not normally considered topsoil, were included in the discussion where available information was directly applicable to the Alberta situation.

The value of topsoil in the reclamation of land disturbances has long been recognized. It not only provides nutrients, a good seed bed, and increased water holding capacity, but can also serve as a source of seeds which is particularly important when native habitats are being restored. In Alberta, topsoil salvage on all land disturbances and its subsequent replacement during reclamation is required by law.

The type of disturbance, quantities of materials to be salvaged, equipment available for stripping and storage operations, long term plans in the case of mining operations, space available, length of time materials are to be stored, and the economics of various storage alternatives, must all be considered when deciding on the details of topsoil storage for any given operation. The direct re-spreading of topsoil materials on areas to be reclaimed, immediately after stripping, termed successive reclamation, is usually the most efficient and cost-effective method of topsoil handling. It is not possible in all situations however. Relatively small disturbances like compressor stations or plant sites cannot be successively reclaimed. Topsoil stripped from the site must be stored for the lifetime of the installation, before it can be replaced. In some mining situations, such as in sub-alpine areas in Alberta, direct replacement of topsoil is often not an option, because of the difficult conditions under which these operations are being carried out. In other cases, topsoil materials stripped from the first area to be mined often will be stored for an extended period of time, if no sites are available for immediate replacement at the time of storage.

There are many ways for topsoil to deteriorate during storage, all of which have to some extent been studied in work reported in the literature.

Loss of organic matter may occur because the natural cycle of its formation and decomposition has been interrupted. Plant nutrients made available by mineralization can be lost from the stored material. Changes in soil physical properties during storage could affect soil water properties, soil structure and bulk density when materials are re-spread. The biological component of topsoil which to a large extent controls nutrient cycling and availability, soil aggregation, and to some degree water characteristics, is particularly subject to change or degradation during storage, changes which could ultimately affect reclamation success.

Topsoil buried deep in a storage pile may become anaerobic. If so, its physical structure, chemistry and its biological component will all undergo changes which can affect its quality in terms of reclamation. The concept of soil quality implies quality for some particular use. Properties of high quality soil for roadbed construction are quite different from those of high quality agricultural soils for example. For the purposes of this study, it is the quality of topsoil for revegetation after reclamation which has been considered. Soil quality criteria, including criteria specifically for topsoil used in reclamation, have been developed by the Alberta Soils Advisory Committee (1987) for some critical chemical and physical parameters. These have been used where appropriate. Similar criteria for biological parameters, and some of the physical parameters which are difficult to measure routinely are not available. A more subjective approach has been taken in evaluating the effect on topsoil quality of possible changes in these parameters during storage.

2. EFFECTS OF TOPSOIL STORAGE ON SOIL QUALITY

2.1 SOIL CHEMISTRY

Soil chemical parameters were measured in a number of studies in five different countries. Table 1 summarizes the parameters examined, and comments on some of the characteristics of each study.

2.1.1 pH

Since soil microbiological activity, plant growth and nutrient availability are markedly affected by soil pH (Alexander 1977; Buckman and Brady 1969), change in topsoil pH during storage may affect the final reclamation outcome after re-spreading. In general, changes in soil pH are the result of low soil buffering capacity and can be related to reactions involving carbonate dissolution, or to decomposition of organic matter. Extreme changes in pH are most likely to occur due to incorporation of calcareous subsoil into topsoil storage piles during construction. In Alberta, topsoil materials are considered to have moderate to severe limitations for use as a plant growth medium when pH values do not fall within a range of 6.5 to 7.5 in agricultural areas. In forested areas, this range extends from 5.0 to 6.5 or 7.0 (Alberta Soils Advisory Committee 1987).

Only one study of the effects on soil chemistry of topsoil storage has been carried out in Alberta. Fujikawa (personal communication) studied changes in soil chemical and biochemical characteristics of topsoil stored under semi-arid conditions in a pile 12 m long, 6 m wide and 2.5 m high. Two control plots, one cultivated and one under native pasture, were established adjacent to the storage pile. Soils were loam textured eluviated Brown Chernozems, located at Bow City in south central Alberta. No agronomically significant changes in pH were recorded, either with depth in the pile or over the 5 year period of the study. All pH values were nearly neutral.

In the United Kingdom (UK), eighteen storage heaps representing soil textures ranging from sandy to clayey, and lengths of storage of 1.5 to 7 years were examined by Abdul-Kareem and McRae (1984). They noted a very

Table 1. Summary of Papers Discussing Chemical Parameters.

Authors	Year	Location	pH	Salts	OM	N	CEC & Other Nutrients	Comments
Abdul-Kareem & McRae	1984	United Kingdom	*		*	*	*	a,e,f,g
Harris & Birch	1988	United Kingdom	*		*	*	*	a,e,f,g
Anderson et al.	1988	Australia	*	*	*	*	*	b
Widdowson et al.	1982	New Zealand	*		*	*	*	a,e,f
Fresquez et al.	1985	New Mexico	*	*	*	*	*	c,e,f,g,h
Lindemann et al.	1989	New Mexico				*		c,e,f,g
Miller & Cameron	1976	North Dakota	*	*	*	*		d,e,f,g,h
Fujikawa	in progress	Alberta	*	*	*	*		
Ross & Cairns	1981	New Zealand				*		a,e,f
Kong et al.	1980	Alberta			*			peat materials

a/ more humid and warmer climate than Alberta
b/ warmer climate than Alberta, distinctly seasonal precipitation
c/ warmer climate than Alberta
d/ climate similar to areas of Alberta
e/ no statistical analyses carried out
f/ no or questionable controls used
g/ topsoil stockpiles apparently contaminated with subsoil
h/ overall poor quality information
* refers to coverage of this soil parameter by this particular author

general increase in pH with depth in the storage pile, although it was neither pronounced nor consistent in most piles; pH values varied from slightly acid (6.2) to nearly neutral (7.0) in all cases. A lack of statistical analyses of data associated with this study makes it difficult to assess results of most chemical parameters, including pH.

Harris and Birch (1988), also working in the UK, found that pH values approached neutrality (7.0) with depth in the topsoil storage piles examined. Most pH values were within a narrow band of 6.6 to 7.1, except where notable quantities of subsoil had been mixed into topsoil materials. Earlier research in Britain (quoted in Widdowson et al. 1982), indicated a decrease in pH, large enough to affect nutrient availability, associated with anaerobic conditions during storage.

In Australia, topsoil stockpiles formed under wet and dry conditions, from a clay textured Vertisol and a clay loam Mollisol, were examined over a 3 year period (Anderson et al. 1988). No change in pH was recorded on the 'dry' clay-textured stockpile. The pH of the equivalent stockpile formed under wet conditions declined with time of storage from slightly alkaline to near neutrality (7.8 to 7.2). They speculated that this decline could be the result of increased production of CO_2 from higher microbial activity in the 'wet' stockpile.

The clay loam textured stockpiles showed no significant effect of length of storage on pH, although the mean pH of the 'wet' stockpile was higher than the 'dry', 8.6 and 8.1 respectively. Unlike the clay-textured stockpiles, there was an increase in pH with depth on both of these stockpiles (mean 8.1 at 0.50 cm and 8.5 at 200 to 300 cm) which was attributed to the presence of carbonates. All pH values were within the moderately alkaline range.

Two 10 year old topsoil storage piles resulting from lignite and ceramic clay extraction in New Zealand were studied by Widdowson et al. (1982). They reported few differences in chemical properties with depth in the piles that were not associated with the inclusion of subsoil materials during topsoil stripping and handling operations. pH measurements ranged from 5.6 to 6.1 in surface samples, increasing to a range of 6.5 to 6.7 in samples taken from the middle of the piles, with one exception where a decrease in pH was recorded.

This study was the only study to include an assessment of the undisturbed topsoil underlying the storage piles. The pH of these buried topsoils was closer to that of materials taken from the middle of the piles, than to the pH of adjacent topsoil that was not buried.

No clear trends in pH of stored soil emerged from studies in the United States. In New Mexico, no differences in pH were recorded between stored topsoil and adjacent undisturbed topsoil, which were both slightly alkaline. Unfortunately, the control soil chosen appears to have had very different properties than the stored topsoil. Only the surface of the stockpiles was tested (Fresquez et al. 1985) and conclusions drawn from this study are considered questionable. Preliminary data available from a study carried out in North Dakota (Miller and Cameron 1976) indicated a general increase in pH with depth to 300 cm (7.0 to 7.8) on a 10 month old pile, but no consistent trend with depth on a pile stored for 29 months. Problems due to obvious subsoil mixing into topsoil piles during construction tend to invalidate results of this study.

In the studies carried out in humid climates, or where stored piles were constructed with wet, acidic soil, there appeared to be a general increase in pH to near neutrality, with associated ammonium production. Fujikawa (personal communication) found no agronomically significant changes in pH during storage of soil in south central Alberta.

In summary, no significant changes occurred with length of time of topsoil storage, material type or depth of storage within the pile, in the studies reviewed. Results of some studies were questionable, however, due to a lack of proper controls or mixing of subsoil into topsoil piles. No clear relationship emerged from the studies discussed above between initial chemical and physical properties and conditions of storage of topsoil to changes in pH within stored materials.

2.1.2 Soluble Salts

Calcium, sodium and magnesium cations, with sulphate and to a lesser extent, carbonate, bicarbonate or chloride anions, are the most common components of soluble salts found in Alberta soils. Electrical conductivity (EC), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are often used as indicators of the effect of soluble salt content of a soil on plant growth. A saline non-sodic soil is dominated by soluble salts other than sodium. EC values are high, and SAR values are low. A solonetzic soil is dominated by soluble sodium salts. EC values may be low, but SAR values are high. Soils are frequently both saline and sodic.

In Alberta, limitations to plant growth are rated moderate to severe where the EC of topsoil exceeds 2 dS/m, or the SAR exceeds 4, on both agricultural and forested lands (Alberta Soils Advisory Committee 1987). There are three main mechanisms by which changes in soluble salts within stored topsoil may occur (Baver et al. 1972; Merrill et al. 1980):

1. leaching of existing salts down through the stored material;
2. capillarity, by which dissolved salts may move some distance upwards in the soil profile above the water table; and
3. chemical diffusion which can move salts in proportion to differences in concentration.

Several studies of stored topsoil included an assessment of salinity or sodicity. At the Bow City site in Alberta, some variability in EC was reported within the pile, probably due to the non-homogeneity of materials used during stripping and storage operations. A slight movement of salts upward through the pile may have occurred during a very wet spring. However, this could not be confirmed with sampling, and was not of a magnitude to affect revegetation (Fujikawa, personal communication). Topsoil materials remained non-saline.

Fresquez et al. (1985), working on stored, piled topsoil in New Mexico, measured EC and SAR on stockpiled topsoil and adjacent undisturbed topsoil. Stored materials were more saline (EC 2.6 dS/m) and more sodic (SAR 6.8) than undisturbed materials (EC 0.6 dS/m, SAR 1.1). Unfortunately, insufficient information is given to determine if these differences were the result of storage, or were caused by mixing saline and sodic subsoil into topsoil during initial stripping and handling operations.

EC was also measured by Anderson et al. (1988) in their study of topsoil piles formed under wet and dry conditions in Australia. No changes occurred with time, water content, or depth of storage in the clay-textured material. Statistically significant differences occurred in the clay loam soil between 'wet' (mean 0.48 dS/m) and 'dry' (mean 0.29 dS/m) stockpiles. Values were statistically significantly higher at depth (mean 0.52 dS/m) than at the surface (0.23 dS/m), but in neither case high enough to cause effects on plant growth.

Studies on salt movement into non-saline and non-sodic topsoil replaced over highly saline and sodic spoil materials in North Dakota indicated diffusion to be the main mechanism of upward salt movement (Merrill et al. 1980). Such movement is likely to be significant only within about 30 cm of the topsoil/spoil interface (Merrill et al. 1980).

If topsoil were stored in an area within capillary rise of the water table, there is some potential for translocation of soluble salts upward into the stored material (Baver et al. 1972). Leaching, on the other hand, has the potential only to move salts already existing in stored topsoil materials. The amount of water percolating through stored topsoil will be dependent on the quantity of water present, configuration of the storage area, infiltration capacity, and hydraulic conductivity of the materials. Depending on the amount of water percolation, the original soluble salt content, and depth of stored topsoil, salts could be leached out of the material altogether, or could form a zone of accumulation at some depth below the surface of the topsoil store. None of these processes was confirmed in any study examined.

2.1.3 Organic Matter

Soil organic matter includes plant and animal residues at various stages of decomposition, stabilized humus, living tissue and substances synthesized by the soil population. The presence of organic matter affects plant growth in a number of ways:

1. it maintains soil structure and aggregate stability;
2. it acts as a plant nutrient 'reservoir', preventing leaching of elements necessary for plant growth due to the relatively high cation exchange capacity of humified organic materials;
3. it buffers soils against rapid pH changes;
4. it forms stable complexes with some metals, affecting their availability to plants and micro-organisms;
5. it acts as a source of N, P, and S made available to plants during mineralization; and,
6. it increases water holding capacity (Vaughn and Ord 1985).

Changes in organic matter were not the focus of any available studies of the effects of topsoil storage. None of the authors examined changes in the quantity or quality of organic matter taking place during storage. However, several of them measured organic matter content and commented on results. Comparing stored topsoil with undisturbed soils in Britain, Abdul-Kareem and McRae (1984) noted that stored topsoil had from 32% to 85% less organic matter than similar undisturbed topsoils. However, lack of statistical analyses makes this change difficult to assess. Fresquez et al. (1985) in New Mexico, noted slightly higher levels of organic matter in topsoil samples taken from the surface of topsoil storage piles (6.4%) relative to undisturbed topsoils (5.4%), but noted that coal and other humic materials may have been incorporated into topsoil piles during handling operations. As pointed out previously, results of this study may be affected by the lack of a good control.

Several authors have commented on changes in organic matter content with depth. Anderson et al. (1988) working in Australia, found no change with depth in percent organic carbon of stored topsoil materials originating from a clay-textured Vertisol, nor were there any changes with time or water content. On stockpiled clay loam Mollisol materials, materials within the surface 50 cm of the stockpile increased in organic matter content, probably due to growth of vegetation on the surface. Below 50 cm, organic matter content declined from top to bottom by about 33%, from 1.8% to 1.2% on the 'dry' stockpile, and from 1.7% to 1.1% on the 'wet' stockpile. This decline was attributed to increased microbial decomposition.

Other authors have reported variations in organic matter content with depth in a stockpile. Harris and Birch (1988) noted increased organic carbon content between 100 and 125 cm depth, and a corresponding increase in total N level in the UK. Widdowson et al. (1982) found no change with depth at one site in New Zealand, but an increase in organic carbon from 2.5% to 3.4% with depth at a second site. Miller and Cameron (1976) found variable levels of organic carbon ranging from 0.66% to 3.48% through topsoil stockpiles examined in North Dakota. None of these studies were able to distinguish between changes in organic matter content which may have taken place during storage, and the variability of materials originally stored in the piles.

Fujikawa (personal communication) examined levels of soluble simple sugars in soil samples taken from a topsoil storage pile in south central Alberta, as a measure of the more labile components of soil organic matter.

Levels in surface samples taken from the storage pile were slightly less than in samples taken from the middle and bottom of the pile, and in cultivated and native range control topsoils. Levels of soluble sugars at the surface apparently fell, while levels in materials stored deeper in the pile were not changed.

Results of many of these studies are questionable, due to the confounding factors of subsoil mixed with topsoil in the piles, lack of good controls, and a lack of statistical analyses of data. Increases in organic carbon with depth reported in two studies are difficult to explain. Non-homogeneity of materials originally stored in the piles are a more likely cause of these differences, than changes taking place within the pile during storage.

A study of peat materials stored for use as a soil amendment during reclamation of areas mined for oil sands was carried out in northwestern and central Alberta (Kong et al. 1980). Results indicated that the storage of peat in piles, incorporation of mineral soil materials and fertilization resulted in increased decomposition of peat materials. Where peat was mixed with mineral soil, loss of carbon due to decomposition was four times greater than where stored peat was relatively pure. In general, decomposition was highest at the surface of the storage piles. This was attributed to higher temperatures, aerobic conditions and the application of fertilizers.

To summarize, a decrease in organic matter content with depth was found in a number of studies, particularly in wetter climates or where stockpiles were formed under wet conditions. Increases in organic matter on the surface of piles due to additions from plant growth, and variable amounts of decomposition of organic matter within piles account for decreases with depth. No change was recorded in several other studies.

2.1.4 Nitrogen

Nitrogen is one of the most common limiting nutrients for plant growth. Deficiencies drastically reduce crop quality and yield. Unlike other nutrients, it can be lost through leaching and volatilization. A number of chiefly microbial transformations convert the element into various forms, as part of a cycle, which can be divided up into several types of processes.

Immobilization occurs when nitrogen is converted from an inorganic to an organic form in microbial tissue, so that the element is not readily available to other organisms or to plants. Mineralization processes convert nitrogen tied up in organic compounds to an inorganic state as ammonium through microbial decomposition. Ammonium-N can be transformed in several ways:

1. utilized again and tied up by micro-organisms;
2. taken up directly by higher plants;
3. fixed in the form of NH_4 to clay minerals and organic matter; and,
4. oxidized by nitrifying bacteria to nitrate. The process is termed nitrification. Nitrate nitrogen may be lost from the rootzone through leaching, taken up by higher plants, or volatilized to N_2 gas by denitrifying bacteria (Goh and Haynes 1986; Tisdale and Nelson 1975).

For revegetation success after reclamation, it is vital that nitrogen cycling mechanisms be restored as quickly as possible. Micro-organisms responsible for the mineralization of organic N must be preserved in sufficient numbers to make organic N available to higher plants as ammonium or nitrate. Nitrogen and its transformations within stockpiled topsoil were the subject of study by a number of researchers.

Nitrogen mineralization potential was determined on samples taken from a topsoil storage pile at Bow City in Alberta (Fujikawa, personal communication). In general, there was a decline in mineralization potential in the upper 15 cm of the pile. A small increase in NO_3-N occurred in the centre of the pile at 100 to 150 cm depth. Anaerobic conditions did not appear to be present at any time. All changes in nitrogen content were considered minor, and were not expected to affect revegetation after re-spreading in any way.

Lindemann et al. (1989) carried out incubation experiments to compare N mineralization potential of a low organic matter soil (0.29% C, 0.041% N).

Results indicated that virtually identical amounts were mineralized from undisturbed 'topsoil' and soil stockpiled for 9 years. No measurements were made at different depths in the stored material. However, it is not made clear in the paper which is the topsoil control and which is the stockpile. Also, control samples were taken only to a depth of 2.5 cm, which brings the validity of the comparison into question.

Total N was determined on samples taken from topsoil piles formed from 2 soils during 'wet' and 'dry' periods in Australia (Anderson et al. 1988). Total N of topsoil samples was not affected by length of storage, depth of storage or water content for a clay-textured Vertisol. On a clay loam textured Mollisol, no difference in total N was found on surface samples taken from the 'wet' and 'dry' piles. However, there was a general decrease in total N in the 'wet' pile over time, from about 1300 mg/kg to about 1200 mg/kg after 30 months in surface samples; a difference of this magnitude is close to the least significant difference by Kjeldahl analysis. However, samples taken from all depths had lower total N than surface samples, although the difference was greatest in the 'wet' pile. It was suggested that these results indicate that mineral N is being denitrified at depth to N_2 and N_2O.

Anderson et al. (1988) noted rapid initial increases in NH_4-N following stockpiling on both soils. Concentrations were significantly higher in the stockpiles formed under wet conditions than in the stockpiles formed under dry conditions. NH_4-N contents peaked after 5 months on the 'wet' sides of both soils, but after 15 months on the 'dry' piles. Over the 40 month period of this study, the concentration of NH_4-N gradually declined. Nitrification to NO_3-N and subsequent denitrification was thought to be the cause of this reduction in concentration. No information was presented which described changes in NH_4-N content with depth in the topsoil piles.

Increases in ammonium-N (NH_4-N) with depth have been reported in stored topsoil piles. Ross and Cairns (1981), working on stored topsoil in New Zealand, found up to 400 mg/kg of NH_4-N at depths greater than 180 cm. Low oxygen supply was cited as one of the factors responsible for very low levels of nitrification at depth in the piles. These storage piles were considered to have an adequate supply of available N for initial plant growth upon re-spreading.

Harris and Birch (1988) found up to 70 mg/kg of NH_4-N at 100 to 125 cm depth in a topsoil storage pile in the UK. These high NH_4-N values remained relatively constant to the bottom of the pile. Nitrate-N levels were constant down the profile, but peaked slightly at about 12 mg/kg soil at about 100 cm before declining again, above the depth where NH_4-N increased. They attributed this to leaching of nitrate-N from the upper layers of the pile, which was subsequently converted to NH_4-N in the anaerobic areas of the pile during storage. An alternative explanation is that, below a critical depth, oxygen supply was so low that nitrification was inhibited, but that denitrification occurred.

In summary, several types of changes to the nitrogen content of stored topsoil may occur during stockpiling. If piles are large enough, anaerobic conditions will develop in the centre of piles regardless of water content at time of storage. Soil texture is an important factor in determining the depth at which anaerobiosis occurs. Ammonification of soil organic matter nitrogen will likely occur under such conditions resulting in elevated levels of NH_4-N in these materials. When re-spread, this should provide a good source of plant available N for initial revegetation.

2.1.5 Cation Exchange Capacity and Other Nutrients

Cation exchange capacity (CEC) is the total number of cations that a soil can retain on negatively charged inorganic and organic exchange sites. It is a measure of the ability of a soil to retain cationic nutrients such as ammonium, potassium, calcium, sodium, and magnesium. In general, CEC increases with clay and organic matter content and with the amount of and degree of humification of organic matter present in the soil. None of the studies of stored topsoil examined dealt with CEC in any detail.

There is no information in the literature to indicate potentially large changes in cation exchange capacity in topsoil during storage. If changes do occur, they will be due to changes in organic matter content and quality.

Very little information is available on the effects of topsoil storage on nutrients other than nitrogen. Several studies determined various nutrients such as potassium, calcium, magnesium, and sodium in stored topsoil (Miller and Cameron 1976). In addition to these, phosphorus and sulphate were also measured (Fresquez et al. 1985; Widdowson et al. 1982) on stored topsoil samples for characterization purposes only. In a UK study of topsoil storage piles of different texture Abdul-Kareem and McRae (1984) found that amounts of extractable P, K, and Mg tended to increase slightly with depth in a sandy textured soil pile, but decreased slightly with depth in loamy and sandy loam textured piles. Difference may have been due to topsoil/subsoil mixing in the storage piles.

Sulphate sulphur was determined by Anderson et al. (1988) in their study of 'wet' and 'dry' stockpiles in Australia. In a clay-textured Vertisol stockpile, formed under dry conditions, little SO_4-S change occurred. In piles formed under wet conditions, from both clay-textured Vertisol and clay loam textured Mollisol soils, there was a rapid increase in SO_4-S initially, due to mineralization of organic matter following disturbance. In the clay-textured pile, for example, SO_4-S of surface samples increased from about 18 mg/kg after 5 months to 40 mg/kg after 30 months. This sulphate accumulated at the surface because of capillary rise of water to the surface. However, increases in SO_4-S concentrations were found at depth in the 'dry' clay loam textured Mollisol topsoil pile. This was attributed to mineralization in the subsurface organic matter.

Extractable manganese and ferrous iron were determined on samples of stored topsoil in the UK by Abdul-Kareem and McRae (1984). Dramatic increases in ferrous iron to potentially toxic levels occurred with depth in two of the three piles described. For example, in a clay-textured pile, ferrous iron increased from 7.2 ug/g at 40 cm, to 580 ug/g at 50 cm. Manganese contents consistently, but less dramatically, increased with depth as well. This is a clear indication of the presence of anaerobic conditions within the piles. Abdul-Kareem and McRae (1984) noted that topsoil materials with a high ferrous iron content returned to low levels within 2 weeks of re-spreading. The presence of reduced metals in topsoil piles was confirmed by Harris and Birch (1988).

In summary, increases in soluble manganese and ferrous iron contents may occur whenever conditions become anaerobic. Reoxidization should return levels to normal after restoration of aerobic conditions, and no long term effects on reclamation are expected. No large change in cation exchange capacity is likely during topsoil storage.

2.2 SOIL PHYSICS

Table 2 summarizes the soil physical parameters examined in a number of studies and comments on some of the characteristics of each. When topsoil is salvaged from disturbed sites and stored in stockpiles for future use, soil quality can be affected through mechanical handling, or compaction by heavy earth-moving machinery, both during topsoil removal as well as during the storage of topsoil. Soil physical characteristics that might be affected by topsoil removal, storage and replacement include bulk density, particle size distribution, aggregate size and stability, soil structure, water holding capacity, hydraulic conductivity, and soil strength. It is necessary to know the magnitude and time dependence of these effects in order to develop stockpiling techniques to minimize soil quality deterioration.

2.2.1 Bulk Density

Soil bulk density can be defined as the mass of dry soil per unit bulk volume, including air space. Changes in bulk density of a given soil can be affected by soil factors like moisture content and texture, and equipment factors like size and type of equipment. Increased bulk density, as a consequence of soil compaction, could be a problem in reclamation of sites since it can lead to poor root penetration, difficult cultivation, reduced permeability, lower water holding capacity, decreased soil porosity, increased soil strength, and increased soil erosion. Because of the complexity of the

Table 2. Summary of Studies on Soil Physical Properties.

Authors	Year	Location	Bulk Density	Thermal Properties	Porosity	Aggregate Structure	Water Holding Charac-teristics	Hydraulic Conduct-ivity	Strength	Comments
Abdul-Kareem & McRae	1984	UK				*				a,d,e,f
Miller & Cameron	1976	North Dakota	*				*			c,d,e,f,g
McQueen & Ross	1982	New Zealand	*		*	*			*	a,d,e
Potter et al.	1988	North Dakota	*		*			*		c
Kong et al.	1980	Alberta	*	*	*					
Anderson et al.	1988	Australia		*		*		*		b
Hunter & Currie	1956	UK			*	*		*		a,d,e
Arnal & Chevasu	1984	France				*				a,d,e

a/ climate more humid and warmer than Alberta
b/ climate warmer than Alberta, distinct seasonal precipitation
c/ climate similar to areas of Alberta
d/ no statistical analyses carried out
e/ no or questionable controls used, or not enough information given
f/ topsoil stockpiles apparently contaminated with subsoil
g/ overall poor information
* denotes the presence of subject information by each author

No references dealt specifically with particle size.

relationships between bulk density, soil moisture, soil structure, compaction, and plant growth, it is very difficult to determine reliable limiting values for plant growth.

Bulk density was measured for two topsoil storage piles and adjacent undisturbed areas at a lignite mine in North Dakota (Miller and Cameron 1976). One 10 month old topsoil storage pile had a silty loam texture, and a second 29 month old pile had a sandy loam texture. Both of the stockpiles had higher bulk densities than adjacent undisturbed soils, and density increased with depth in both stockpiles (Table 3). The validity of these results is questionable however, since topsoil piles appear to have been contaminated with subsoil materials, and there is some confusion as to which control was used for each storage pile.

Table 3. Bulk Density (g/cm^3) of Stockpiled Soil (Miller and Cameron 1976).

	Stockpile Age	
Depth (cm)	10 Months	29 Months
0 to 2.5	1.07*	1.20*
30	0.95	1.33
100	1.26	1.30
200	1.27	1.56
300	1.47	1.61
400	no measurement	1.51

* adjacent undisturbed soil had density 0.99 g/cm^3

Bulk density was also determined on undisturbed and reclaimed sites at a lignite strip mine in North Dakota (Potter et al. 1988). The undisturbed site consisted of a mixture of fine silty and fine loamy soils. The reclaimed sites were constructed on similar soil materials, one 4 years and the other 11 years after reclamation. Topsoil removed, stored, and subsequently replaced was a mixture of A and B horizon soil materials and was 0.4 m deep for the 4 year old reclaimed site and 0.19 m deep for the 11 year old site. Bulk densities of the two reclaimed sites were greater than that for the undisturbed soil. At 0 to 15 cm, bulk density measured for the undisturbed soil was 1.03 g/cm^3, but bulk density measured for the 4 year old reclaimed site was 1.35 g/cm^3 and for the 11 year old reclaimed site was 1.39 g/cm^3.

Two silt loam topsoil stockpiles (Lorneville and Mataura) and adjacent control soils were analyzed for bulk density in Southland, New Zealand (McQueen and Ross 1982). Surface bulk density of the Lorneville stockpile was lower than that of the undisturbed control soil, but values were similar to surface samples taken from the Mataura stockpile and its control. Bulk densities increased with depth in both stockpiles compared to controls (Table 4). Bulk densities above 1.3 g/cm^3 were considered by McQueen and Ross (1982) to indicate soil physical conditions below optimum for plant growth. They concluded that the bulk densities of the stockpiles were generally satisfactory. Bulk density increases were believed to have been caused by earth moving operations during stockpile formation. This study suffers from the use of questionable controls, and non-homogeneity of materials in the stockpile.

In Alberta, bulk densities of undisturbed peat, peat stored for 2 years and peat stored for 9 years were measured (Kong et al. 1980). Although bulk densities of the undisturbed peat were lower than those of both peat piles, there were no significant differences between the peat piles.

Table 4. Bulk Density (g/cm^3) of Stockpiled Soil (McQueen and Ross 1982).

	Stockpile	
Depth (m)	Lorneville	Mataura
0 to 0.05	no measurement	1.13 to 1.19*
0.5 to 0.7	1.26 to 1.45	no measurement
1.8 to 2.0	no measurement	1.24 to 1.33
2.3 to 2.6	no measurement	1.25 to 1.35
2.5 to 2.6	1.19 to 1.21	no measurement
3.3 to 3.4	1.14 to 1.21	no measurement

* undisturbed surface soil at Lorneville and Mataura had bulk density of 1.04 and 1.16 g/cm^3 respectively.

To summarize, bulk density of stockpiled topsoil appears to increase with depth in the pile in general, and is usually greater than that of undisturbed adjacent control soil. These differences have been generally attributed to compaction during earth-moving operations during stockpile formation. The only study which measured bulk density after re-spreading of stored topsoil indicated that the greater value could persist for some years after re-spreading.

2.2.2 Particle Size Distribution

Particle size distribution and soil texture measure the relative amounts of sand, silt and clay in a soil sample. Possible mechanisms for change within a stockpile over time would include:

1. very strong leaching action by water, and resulting mobilization of clays, which is highly unlikely on a sloped stockpile or during the lengths of time topsoil is likely to be stored;
2. physical sorting, in very dry piles; or
3. loss by wind or water erosion, the most likely of the three.

No reliable data could be found in the literature. It seems unlikely that significant changes in texture will take place during storage, provided stockpiles are protected from erosion, and mixing with subsoil of a different texture has not occurred.

2.2.3 Thermal Characteristics

Thermal characteristics of stored topsoil materials are important since rates of microbial activity, organic matter decomposition and the resulting nutrient availability dynamics are all affected by temperature. Freeze/thaw cycles and depth of frost penetration may affect soil structure. Aspect, slope and size of stockpile, as well as climatic factors will affect the temperature profile of topsoil stored in piles.

Two studies examined the thermal characteristics of topsoil stockpiles. In Alberta, Kong et al. (1980) examined temperature regimes of peat stored in piles, and carried out laboratory work aimed at determining the effects of alternating freeze/thaw cycles. They found that optimum temperature conditions for microbial activity were restricted to the surface layer (0 to 50 cm) of the storage piles. In general, temperature of the 0 to 7 cm layer of piles at both sites remained about 10°C for 97 to 106 days each year; at 20°C for 51 to 71 days; but that below 50 cm, temperatures were always below 10°C. There was no evidence of a temperature rise in the centre of piles due to anaerobic decomposition. Length of time for optimal microbial activity was shorter on undisturbed control sites possibly due to shading effects of forest cover.

To simulate natural freeze/thaw cycles, peat samples were subjected to 3 cycles of 24 hours freezing at -10°C followed by thawing and incubation for 6 days. Microbial activity was, not surprisingly, reduced in all cases.

Soil temperature profiles were determined on two soils, a clay and a clay loam, in Australia (Anderson et al. 1988). Stockpiles of each soil were formed from the surface horizon (0 to 29 cm) in both wet (April to May) and dry seasons (September). Soil temperature profiles were determined for each stockpile in both summer and winter from 0 to 300 cm depths. There were minimal differences in soil temperature profiles between soil types and between 'dry' and 'wet' stockpiles. Major variations in temperature associated with seasonal changes (6 to 37° C) were limited to the 0 to 100 cm surface layer. Soil temperatures at greater depths were buffered against seasonal and diurnal changes. The temperature range at depths greater than 100 cm for both stockpiles was 21 to 28°C. Climatic conditions in this area of Australia are much warmer than Alberta, with winter temperatures rarely, if ever, dropping below freezing. There is a general lack of data on the subject for climatic conditions similar to those in Alberta.

2.2.4 Porosity and Pore Size Distribution

Soil porosity is the volume percentage of the total soil bulk occupied by air and water. In general, sands have lower porosity than clays or organic soils, although porosity is affected by degree of soil aggregation as well. Pore size distribution, particularly the total volume occupied by larger pores and their configuration, is an important characteristic since it is the larger pores which control the degree of aeration of a soil (the porosity or macro-porosity). The pore size that will hold water under 1/3 bar tension is the basis for separating aeration porosity from water porosity. In general, a soil should have a roughly equal mix of aeration and water porosity for optimal root and plant growth (Baver et al. 1972). For adequate root growth and respiration, aeration porosities should exceed 10% to 12% (Grable and Seimer 1968). During topsoil storage and subsequent re-spreading, factors such as excessive compaction by heavy equipment during earth-moving operations, degradation of organic matter, destruction of soil structure at depth in a storage pile, and inappropriate tillage or other cultural practices after re-spreading could adversely affect soil porosity and pore size distribution. Several studies involving topsoil stockpiles have been carried out to demonstrate how topsoil stockpiling and its subsequent replacement can affect soil porosity and pore size distribution.

Porosity was determined on heavy boulder clay soil of an open cast coal site returned to agricultural use and a corresponding control in England (Hunter and Currie 1956). There was a marked decrease in porosity for topsoil after it had been removed, stored, and subsequently returned to the mine site. Total porosity at 0 to 7.5 cm, 7.5 to 15 cm, and 15 to 22.5 cm depth for the unworked (control) soil was 50.1%, 49.7%, and 52.7%, respectively and for the worked soil was 32.8%, 36.4%, and 35.5%, respectively.

Macro-porosity and total porosity were determined for two silt loam topsoil stockpiles (Lorneville and Mataura) and their adjacent control soils in Southland, New Zealand (McQueen and Ross 1982). Results are given in Table 5.

The Lorneville stockpile showed some reduction in total porosity compared to adjacent undisturbed farmland, but the Mataura stockpile had reduced macro-porosity compared to the control.

Regardless of whether changes to topsoil porosity and pore size distribution take place during storage, severe degradation can occur during re-spreading and subsequent cultivation operations, if care is not taken. For example, Potter et al. (1988) measured pore volumes on 4 and 11 year old reclaimed mine areas in North Dakota, and compared them to undisturbed soils.

Table 5. Total Porosity of Samples from Two Topsoil Stockpiles in New Zealand. (McQueen and Ross 1982).

Depth (m)	Lorneville Stockpile		Mataura Stockpile	
	Total Porosity %	Macro-Porosity %	Total Porosity %	Macro-Porosity %
Site 1				
0.7	46 ± 5*	11 ± 4	57 ± 1	7 ± 3
2.6	54 ± 2	5 ± 3	53 ± 1	1 ± 1
3.3	53 ± 2	5 ± 3	49 ± 1	1 ± 1
Site 2				
0.5	52 ± 4	8 ± 3	55 ± 2	8 ± 4
2.5	53 ± 2	1 ± 1	49 ± 1	3 ± 3
3.4	56 ± 1	6 ± 2	52 ± 2	2 ± 2
Control				
0	58 ± 1	6 ± 1	55 ± 2	10 ± 1

* Values are means ±1 standard deviation

Macro-porosity was significantly lower on the reclaimed sites than on the undisturbed site. Small pore volume was not significantly different between reclaimed and undisturbed sites.

In Alberta, Kong et al. (1980) compared pore volume and air capacity (pore volume - total space of water) on peat from stockpiles stored for 2 and 9 years, and undisturbed peat. Air capacity of the surface layer was statistically significantly higher on the 9 year old pile compared to the 2 year old material and the control. Increased numbers of freeze/thaw and wetting drying cycles on the older pile were cited as a possible explanation. Increased aeration of surface layers could speed up degradation processes but on the other hand would prevent formation of toxic substances such as nitrite and sulphide.

Although few data are available, it is possible that topsoil storage in a stockpile may reduce total porosity, and macro or aeration porosity. Inappropriate re-spreading methods may have more drastic negative effects than actual storage, however. No information for mineral topsoils stored under Alberta conditions could be found.

2.2.5 Soil Structure, Aggregate Size and Stability

Soil structure and the size and stability of soil aggregates are important factors in infiltration, retention and movement of the soil water, wind and water erodability, crusting and soil aeration. They are affected by the quantity and nature of soil organic matter present, types of adsorbed cations and clay minerals, wetting and drying and freeze/thaw cycles and microbial and other biological effects. Any degradation of soil structure or aggregation during storage could adversely affect revegetation, plant productivity and erodability.

Aggregate size and stability are difficult to measure, and a number of methods are in common use (Baver et al. 1972). Dry-sieving has been used as an estimate of wind erodability. Clogging of sieves and the breakup of weak aggregates by the mechanical action of the sieve are two potential problems. Wet-sieving has been more widely used, particularly for the separation of larger aggregates. Problems arise since air drying and subsequent re-wetting affect aggregate stability to some degree. Sedimentation methods can be used for aggregate sizes less than 1 mm, but problems of flocculation and varying aggregate densities can confound results.

Soil structure is more difficult to measure. Several classification systems are currently in use. One system developed by McKeague et al. (1986) provides detailed guidelines for description and interpretation of soil macrostructure. Techniques such as scanning electron microscopy have been used to examine soil micro-structure.

Aggregate stability on 1 to 2 mm aggregates was determined on undisturbed and stockpiled soils in England (Abdul-Kareem and McRae 1984). Three topsoil heaps were monitored representing soils of sandy texture, loamy texture and clayey-texture. Samples removed from the topsoil storage heaps were compared to similar topsoils on adjacent undisturbed land. Aggregate stability was much lower on stored sand and clayey topsoil heaps when compared to the undisturbed soil. The percentage of stable aggregates for the unworked sandy soil was 34.4%, but for the stockpile ranged from 0.6 to 15.9% at soil depths of 0 to 2.0 m. In the clayey soil, aggregate stability for the unworked soil was 95.7%, but for the stockpile ranged from 33.9 to 77.9% for the surface 2.0 m. There was little effect on aggregate stability due to stockpiling the loamy soil. Aggregate stability for the unworked soil was 8.6%, but for the stockpile was 2.8 to 18.4% for the surface 2.0 m. The reliability of these data is questionable however, since the possibility of mixing of subsoil into topsoil heaps and unreliable choice of controls cannot be ruled out. No results of statistical analysis were presented.

Scanning electron microscopy was also used to study the micro-structure of these unworked and stockpiled soils. Loss of micro-structure in stockpiled soils was noted by these researchers, but results were not given. These researchers were uncertain as to how much of the soil structure damage was due to stockpiling or to the effect of compaction by heavy equipment during topsoil removal and construction of stockpiles.

A study of soil physical properties on reclaimed heavy clay soils returned to agricultural use in the UK was initiated by Hunter and Currie (1956) because of observed poorer tilth, erosion and gullying on steeper slopes, and shallow rooting, cracking and negligible earthworm activity on reclaimed areas compared to undisturbed lands. Water stable soil aggregates greater than 0.2 mm and dispersion ratios were determined. Both reclaimed soil and its corresponding undisturbed control soil were monitored. Table 6 gives results of water stable aggregate analysis.

Table 6. Water Stable Aggregates for Reclaimed Clay Soils in the UK (Hunter and Currie 1956).

	Blagdon Site		Milkhope Site	
	% Particles < 0.27 mm		% Particles > 0.27 mm	
Depth (inches)	Worked	Unworked (control)	Worked	Unworked (control)
0 to 3	53.3	60.4	30.6	46.9
3 to 6	18.1	67.5	37.0	44.8
6 to 9	16.0	62.3	37.4	48.2

Undisturbed soils had notably higher percentage of water stable particles >0.27 mm than the worked soils at all depths to 9 inches.

Dispersion is the process in which soil aggregates and other compound particles have been broken up into individual component particles. The dispersion ratio was determined on reclaimed and undisturbed soils, a higher dispersion ratio being an indication of poorer aggregation. Results presented in Table 7 show higher dispersion ratios on all worked soils compared to unworked controls. No statistical analysis was reported for this study.

Table 7. Dispersion Ratios for Reclaimed Clay Soils in the UK (Hunter and Currie 1956).

	Blagdon Site		Milkhope Site	
	Dispersion Ratio		Dispersion Ratio	
Depth (inches)	Worked	Unworked (control)	Worked	Unworked (control)
0 to 3	22.1	10.9	28.0	12.9
3 to 6	37.6	8.7	26.6	11.9
6 to 9	43.7	11.1	24.6	13.2

Anaerobic incubation of these heavy clay boulder soils increased dispersion ratios when compared to aerobic incubation (Hunter and Currie 1956). Samples of unworked air dry topsoil were prepared by separating the 1 to 2 mm and 2 to 4 mm aggregates for the Blagdon soil and only the 2 to 4 mm aggregates for the Milkhope soil. Moisture content was maintained at 30% and samples were incubated at 20°C; half being sealed (anaerobic conditions) and the other remaining open (aerobic conditions). Samples were incubated for 2 to 16 weeks and dispersion ratios determined. There was no relation between time of incubation and dispersion ratio. Average dispersion ratios for the 1 to 2 mm aggregates of Blagdon soil were 2.39 under aerobic conditions and 4.83 under anaerobic conditions. For the 2 to 4 mm aggregates, the ratios were 2.62 for aerobic conditions and 4.09 under anaerobic conditions. Similar increases in dispersion ratio due to anaerobic storage were measured for the 2 to 4 mm aggregates of the Milkhope soil with mean dispersion ratios of 7.41

under aerobic conditions and 9.45 under anaerobic conditions indicating lower aggregate stability. These results may be significant because anaerobic conditions can occur in topsoil stockpiles and could cause some deterioration in soil aggregate stability.

Aggregate size distribution was determined for two silt loam topsoil stockpiles in Southland, New Zealand (McQueen and Ross 1982). Aggregate size distribution was measured for each sample on air-dry soil in a nest of sieves ranging in size from 32 mm to 64 mm. Each stockpile was sampled twice.

A change from aerobic to anaerobic conditions was found to occur at a depth of approximately 2.0 m for the Mataura stockpile and 3.0 m for the Lorneville stockpile (McQueen and Ross 1982). Aggregate size appeared to increase under anaerobic conditions. It was speculated that the formation of large aggregates may occur because low oxygen contents may inhibit the microbial activities that contribute to the maintenance of friable soil structures (McQueen and Ross 1982).

Mean weight diameter, an index of aggregation which is defined as the proportion by weight of a given size fraction of aggregates multiplied by the average diameter of the fraction, was determined on samples of stockpiled soil in Australia (Anderson et al. 1988). Stockpiles of each soil were formed from the surface horizons of a clay and a clay loam soil during wet and dry seasons. There was little effect of depth on the mean weight diameter of water stable aggregates. The mean weight diameters for the 'wet' and 'dry' clay stockpiles (0.93 mm and 0.87 mm, respectively) were not significantly different. For the clay loam soil, the 'wet' stockpile had significantly larger mean weight diameter of aggregates than the 'dry' stockpile (1.91 mm and 1.03 mm, respectively), indicating better aggregation. However, some of this difference may be due to a higher clay content in the 'wet' stockpile compared to the 'dry' (42% and 37%, respectively).

Anderson et al. (1988) used a dispersion rating, which they do not define, to assess the degree of dispersion of samples taken from 'wet' and 'dry', clay and clay loam stockpiles, at different depths. Dispersion rating of aggregates for the 'wet' clay stockpile was significantly higher at 2.0 than for the dry clay stockpile at 1.5. Dispersion rating of aggregates for the 'wet' clay loam stockpile was 1.8, significantly higher than for the 'dry' clay loam stockpile at 0.7. This increased dispersion tendency was greatest for samples collected at depth (300 cm). This study concluded that the clay soil which consisted mainly of montmorillonite appeared to be somewhat resistant to structural degradation. However, the clay loam soil, consisting of a mixture of montmorillonite, kaolinite and illite was more prone to structural breakdown when stockpiled. This effect was reduced when stockpiles were formed in relatively dry conditions. However, 'wet' and 'dry' stockpiles of both the clay and clay loam soil had mean gravimetric water contents similar to or lower than the permanent wilting point (15 bar suction). Water content at the permanent wilting point for the clay soil was 37% and the 'dry' and 'wet' stockpiles had water content that ranged from 18% to 20% and 21% to 29%, respectively at depths of 200 to 300 cm. The mean gravimetric water content of the 'dry' and 'wet' stockpiles of the clay loam soil at this same depth ranged from 9% to 10% and 17% to 19%, respectively compared to the permanent wilting point of 17% (Anderson et al. 1988).

Scanning electron microscopy was used to study the micro-structure of unworked and stockpiled soils in England (Abdul-Kareem and McRae 1984). Loss of micro-structure in stockpiled soils was noted by these researchers, but results were not shown in the research paper. These researchers were uncertain as to how much of the soil structure damage was due to stockpiling or to the effect of compaction by heavy equipment during topsoil removal and construction of stockpiles. No other data on the effects of topsoil storage on soil structure were found. Arnal and Chevasu (1984) commented on changes in structure within two topsoil storage piles in France, 10 years and 6 months old. They noted that soil materials were well structured within the first metre of the younger stockpile. Only the surface of the older pile was well structured. However, the older pile had a much higher sand and silt content (84%) compared to the younger pile (53%), which makes the results more difficult to interpret.

In summary, there is some evidence that soil aggregates are less stable, and soils more dispersed on stored and reclaimed topsoils than on undisturbed areas. Loss of organic matter by mixing with subsoil, and mechanical destruction of structure during earth-moving activities were cited as possible causes. If true, this has important implications for the restoration of productivity after reclamation. Aggregate size may increase under anaerobic storage conditions. This may relate to decreased microbiological activity, or to changes in the nature and amount of organic matter present.

2.2.6 Water Holding Characteristics

The water holding characteristics of a soil are important since large quantities of water must be supplied to plants. Any change during storage or re-spreading will affect revegetation. This is particularly true in the drier areas of Alberta. Maximum moisture holding capacity is the percentage of water remaining in a field soil 2 or 3 days after the soil has been saturated and free drainage has ceased. Water holding characteristics may also be measured in the laboratory by determining the amount of water held under different suctions. The available water holding capacity is generally measured as the difference in water held at 15 bar (equivalent to "wilting point") and 0.3 bar (equivalent to "field capacity"). Water holding capacity was determined for two topsoil storage piles and their adjacent undisturbed areas at a lignite mine in North Dakota (Miller and Cameron 1976). One topsoil storage pile was a 10 month old silt loam stockpile and the other was a sandy loam 29 month old stockpile. The undisturbed soils at 0 to 2.5 cm averaged around 75% moisture at their water holding capacities. Stockpiling appeared to have reduced the water holding capacity of the soils (Table 8).

Water holding characteristics were determined for two soils in Australia, one a clay and one a clay loam (Anderson et al. 1988). Stockpiles of each soil were formed from the surface horizons (0 to 29 cm) in both wet (April to May) and dry (September) seasons. This study concluded that the water content of the stockpiled soil at depths greater than 50 cm remained relatively constant and reflected the initial water content of the topsoils used to form the stockpiles. In contrast, the surface (0 to 50 cm) water

Table 8. Water Holding Capacities (%) of Stockpiled Soils (Miller and Cameron 1976).

	Stockpile Age (Months)	
Depth (cm)	10	29
2.5	56.7	40.1
30	50.9	41.9
100	54.3	41.2
200	65.6	45.8
300	56.5	43.1
400	no measurement	48.4

content of each stockpile reflected the variations in precipitation. The available water of the clay soil was 22% and for the clay loam was 15%. There was no significant effect on available water holding capacity for either the clay or clay loam.

Since water holding characteristics of a soil are related to such things as bulk density, structure and porosity, it is difficult to assess effects of decreased water holding capacity of stockpiled topsoils after they are re-spread. The conditions under which the operation is carried out, equipment used, and methods of working the soil after re-spreading are more likely to affect the final water holding characteristics of the topsoil, than their storage conditions.

2.2.7 Hydraulic Conductivity

The ability of a soil to allow transmission of water is called its hydraulic conductivity or permeability. Hydraulic conductivity of a soil is related to the amount and continuity of pore space available. Pore space is related to the bulk density, relative aggregation and structure of a soil. Soil compaction, the destruction of soil structure or aggregation, and dispersion can reduce total porosity as well as pore size and therefore can influence the hydraulic conductivity. Because it is sensitive to changes in soil structure, hydraulic conductivity can be used as an index of soil deterioration (Baver et al. 1972). Decreased hydraulic conductivities can lead to reduced water infiltration and increased surface water runoff, soil erosion and reduced water availability to plants.

Several methods are commonly used for measuring hydraulic conductivity. In the laboratory, saturated hydraulic conductivity can be measured using undisturbed cores taken from the field. Rates of flow from a fixed head of water are measured after saturation. In the field, rates of change of water levels in piezometer tubes or cylindrical wells can be measured. McKeague et al. (1986) developed a method to estimate saturated hydraulic conductivity from detailed descriptions of soil macro-structure. In general, saturated hydraulic conductivity may be considered low if $<0.8X10^{-2}$ cm/sec, medium if $0.8X10^{-2}$ cm/sec to 0.25 cm/sec, and high if > 0.25 cm/sec (McKeague et al. 1986).

Hydraulic conductivity was measured for two soils in Australia, one a clay and the other a clay loam (Anderson et al. 1988). Stockpiles of each soil were formed from the surface horizons (0 to 30 cm) in both wet (April to May) and dry (September) seasons. All values were very low. The mean hydraulic conductivity for the dry undisturbed clay soil was $0.66X10^{-4}$ cm/sec, for the dry stockpiled clay soil was $1.3X10^{-4}$ cm/sec and for the wet stockpiled clay soils was $0.57X10^{-4}$ cm/sec. There were no significant differences in hydraulic conductivities between control and stockpiled soils, nor was there any significant effect of time of storage, water content or depth of storage on the hydraulic conductivities for the clay soil. However, the mean hydraulic conductivity of the dry stockpiled clay loam soil ($0.50X10^{-4}$ cm/sec) was significantly greater ($p<0.05$) than that for the wet stockpiled clay loam soil ($0.29X10^{-4}$ cm/sec) (Anderson et al. 1988). Also, mean hydraulic conductivity of the dry undisturbed clay loam soil ($0.74X10^{-4}$ cm/sec) was significantly greater ($p<0.05$) than that for the wet undisturbed clay loam soil ($0.24X10^{-4}$ cm/sec). The lower conductivities of the wet undisturbed clay loam soil and wet stockpiled clay loam soil were attributed to the slightly higher clay content in the soil used to form the wet stockpiles.

Permeability was measured on a heavy boulder clay soil of an open cast coal site after it had been stored and returned to agricultural use and the adjacent undisturbed soil in England (Hunter and Currie 1956). Permeability at 0 to 7.5, 7.5 to 15 and 15 to 22.5 cm for the undisturbed soil was 0.01, 0.09 and 0.03 cm/sec, respectively, and for the worked soil was $1.27X10^{-4}$, $0.6X10^{-2}$ and $1.69X10^{-4}$ cm/sec, respectively. This decrease was attributed to mixture of subsoil and topsoil, mechanical movement of soil under favourable moisture conditions and loss of organic matter.

Like porosity, decreases in hydraulic conductivity during topsoil stripping and re-spreading operations are likely to be more serious than changes taking place during storage. Potter et al. (1988) for example, determined hydraulic conductivity on undisturbed and reclaimed sites at a lignite strip mine in North Dakota. The undisturbed site consisted of a mixture of fine silty and fine loamy soils. The two reclaimed sites (one 4 years old and one 11 years old) were reconstructed with similar materials. Topsoil salvaged, stored and replaced on the mine site was a mixture of A and upper B horizon soil material. Saturated hydraulic conductivity of the 0 to 15 cm depth for two reclaimed soils (0.31 and 0.34 cm/sec) was less than for the undisturbed soil (1.46 cm/sec).

In summary, hydraulic conductivity of stockpiled topsoil may decrease during storage. Decreases during stripping, moving and re-spreading operations are more likely to be significant than deterioration in the stockpile.

2.2.8 Soil Strength

Soil strength is important as an indicator of increased bulk density and compaction, resistance to root penetration and crusting or cementation. In the field, a penetrometer is the most common method of soil strength determination. Penetration resistance of soils is affected by moisture and organic matter content and texture. Because of this, it is very difficult to develop definitive critical limits for plant growth. Generally, an increase in soil strength would be considered detrimental to plant growth.

Soil strength was measured for two topsoil stockpiles in Southland, New Zealand (McQueen and Ross 1982), using a cylindrical pocket penetrometer. Soils of both stockpiles were silt loams. Results indicated that both stockpiled soils had greater soils strengths than the adjacent farmland topsoils. Results are summarized in Table 9.

Table 9. Penetration Resistance on Two Stockpiled Topsoils in New Zealand (McQueen and Ross 1982).

	Lorneville Stockpile (kPa)			Mataura Stockpile (kPa)	
Depth (m)	Stockpile	Control	Depth (m)	Stockpile	Control
0 to 0.5	no measurement	90	0	100 to 120	130
0.5 to 0.7	420 to >450	no measurement	1.8 to 2.0	360 to 400	no measurement
2.5 to 2.6	230 to >450	no measurement	2.3 to 2.5	310 to 320	no measurement
3.3 to 3.4	370 to >450	no measurement			no measurement

They suggested that values over 300 kPa could indicate soil physical conditions below optimum for plant growth. Therefore, soil strengths of stockpiled soils could be a problem at all depths measured below the surface. However, once re-spread, topsoil strength will change. If carried out carefully under good soil moisture conditions, and with proper soil tillage, soil strength can be kept within favourable limits.

2.3 SOIL BIOLOGY

2.3.1 Introduction

Soil is not simply an inorganic medium for supporting roots; it has a distinct biological component. The soil biota have a major influence on soil chemistry and structure, and therefore, on topsoil quality. Soils are teeming with many life forms, ranging from one-celled bacteria and protozoa to insects, seeds and rhizomes of higher plants. From a biological point of view, stripped topsoil may be regarded as a potential source of inoculum for the re-establishment of the soil biota.

This section will outline the major biological components of topsoil and review the available literature on the effects of stockpiling on these components. The following must be kept in mind:

1. Species composition and numbers vary with soil type, climatic conditions and vegetation of the study area. However, from the literature, certain trends are apparent which may be applicable to Alberta;

2. The importance of a particular biological component may vary from soil to soil. For example, the presence of mycorrhizal fungi in soils is likely more critical for plant survival in arid regions than for moister areas;
3. For certain groups, discussion of the effects of soil storage would be incomplete without paying attention to soil handling during and immediately after re-spreading. Earthworm populations, for example, are reduced when soil is stockpiled but will likely recover if soil is not excessively disturbed during re-spreading and during the next 2 years. Thus, soil treatment after re-spreading might be more critical for survival than the actual stockpiling.
4. Very little information is available about the effects of large scale topsoil storage on populations of algae, protozoa, nematodes, and actinorrhizae. They will not be discussed here. This is not meant to indicate that they are not important components of the soil biota. Any discussion of what might occur under storage conditions would be considered hypothetical at best.

2.3.2 Effects of Storage on Seeds in Topsoil

Higher plants are propagated by seeds, but they can often also be propagated asexually, by rhizomes, tubers or sections of stems. There is little information available on viability of these asexual propagative materials in stored topsoil. Viability of these other propagules is particularly important in forested areas, and would seem directly applicable to restoration of many disturbed areas in Alberta.

2.3.2.1 Quantity and distribution of seeds in soil. Most undisturbed topsoils contain large numbers of viable seeds. "This seed bank represents the past, present and potential future vegetation of a site." (Rabinowitz 1981).

Several studies have demonstrated the quantities and distribution of viable seeds in soil. In most, the procedure has been to collect soil samples, incubate them under conditions favourable for seed germination, then count the seedlings that emerge. Limitations of space/time/labour often mean that too few samples were taken for proper statistical analysis (Dickie et al. 1988). Incubation methods and timing may also be limiting, since some seeds require a specific treatment like scarification or stratification, for germination to occur. Using the germination technique for example, Budd et al. (1954) working in Saskatchewan found that numbers of viable seeds increased from spring to fall in cropped land, but decreased on fallowed land. There was a general reduction in numbers of viable seeds over winter, possibly due to removal of seeds by wind, loss of vitality of dormant seeds, partial germination and deep burial of seeds of low vitality, particularly if susceptible to fungal pathogens.

In a few studies, a flotation technique was used to separate the organic fraction. This organic fraction was dried, seeds were removed manually, soaked, and stained with tetrazoleum chloride, allowing identification of viable seeds.

Several workers, cited in Jastrow et al. (1984), as well as Iverson and Wali (1982), and Miller (1984), have demonstrated that in undisturbed soils, the numbers and diversity of viable seeds decreases with depth.

2.3.2.2 Seed survival in topsoil in situ. Seeds of some species remain viable in soil for years; others are not long lived. Budd et al. (1954) reported that Russian thistle, Salsola kali L. var tenuifolia Tausch, has a short period of dormancy and thus is controlled effectively by summer fallowing, whereas tumbling mustard, Sisymbrium altissimum, has a very long period of dormancy, and therefore summer fallowing is not an effective control method. Beauchamp et al. (1975) stated that viability of seed in soil depends at least partly on inherent dormancy, durability of the seed coat, and response to moisture. Seeds with hard coats likely persist longer in soil, requiring some kind of abrasion for imbibition and initiation of germination (Brophy 1980). Several other mechanisms for seed dormancies, including mechanical barriers, chemical inhibitors, biological clocks, or other time or temperature related mechanisms were noted by Jastrow et al. (1984). Seed dormancy is an important survival strategy, particularly in arid regions. However, as Howard and Samuel (1979) point out, disruption of the soil surface may break dormancy by exposing seeds to light, fluctuating temperature and reduced CO_2 concentration. Compaction, cultivation or disturbances such as topsoil removal and stockpiling, and re-spreading could thus influence seed survival.

Numerous predators (particulary insects), as well as microbial pathogens, attack seeds in soil. Some seeds are readily invaded before germination but, for most species, mortality is highest during germination. This occurs most often when soil becomes either too wet or too dry shortly after germination occurs.

2.3.2.3 Seed survival in stored topsoil. Brophy (1980) determined the number of seeds, diversity, and dominant species from seed banks in reclaimed topsoil at 6 sites in a North Dakota coal mining area. These were compared with the seed bank in topsoil which had been stockpiled and re-spread 1 year previously. The "stockpile" soil contained very low numbers of viable seeds and fewer species compared to soils from the other 6 sites. Melilotus sp., which has a hard seed coat and requires scarification, was the most numerous species present in the "stockpile" soil. Brophy (1980) hypothesized that the low numbers of seeds may have been due to "inversion" whereby the seed-rich surface layer of soil would have been stripped first and buried deep within the stockpile, whereas the originally deeper soil, with the fewest seeds, would be closer to the stockpile surface.

Iverson and Wali (1982) counted seedling emergence over a 16 month period from soils collected from a coal mine site near Benton, North Dakota. The sites were: grazed rangeland; ungrazed rangeland; a 1 year old topsoil stockpile; a topsoil stockpile constructed 1 week before sampling. Sites 1 and 2 were sampled at three depths (0 to 15 cm); stockpiles at 0 to 7.5 cm. Results in Table 10 indicate that the numbers of viable seeds in the stockpiles were not significantly different from each other at $p \leq 0.001$, but were significantly fewer than numbers for grazed and ungrazed sites. A drastic reduction in numbers of viable seeds was noted as a result of stockpiling, which may have been due to loss of vitality over time (for seeds in the 1 year old stockpile) or the "inversion" effect reported by Brophy (1980).

Table 10. Numbers of Viable Seeds in Undisturbed and Stored Topsoil in North Dakota (Iverson and Wali 1982).

Site	Seed Count #Seeds/#Species	Viable Seeds per m^2 (0 to 7.5 cm depth)
Grazed Rangeland	319/26	2900 seeds/m^2
Ungrazed Rangeland	140/23	7200 seeds/m^2
1 Year Old Stockpile	14/ 9	520 seeds/m^2
1 Week Old Stockpile	14/ 9	255 seeds/m^2

For all sites, most of the seedlings emerged within 4 months of incubation; after the first 4 months, the seeds which germinated most frequently on the grazed and ungrazed sites were those generally found at the lowest depth sampled (7.5 to 15 cm). It was suggested that seeds with long dormancy periods are more likely to survive at greater depths than seeds with short dormancy periods.

Dickie et al. (1988) studied the effects of stockpile age and depth on populations of viable seeds in stored heavy moist soil in Erin, Derbyshire, Great Britain. Topsoil samples were taken from a 3 month old stockpile with no vegetative cover and a 4 year old stockpile covered with several vegetative species. Surface, 1 m and 2 m core samples were collected, and viable seeds were extracted and counted using the tetrazoleum chloride method. The results were highly variable, for both total numbers and species present. This suggested that, unlike undisturbed soils where seed density decreases with depth, and contrary to results presented above by Iverson and Wali (1982), the population of viable seeds in stockpiles is distributed heterogeneously throughout.

There was a significant interaction between the effects of age and stockpile depth. Table 11 shows a slight increase in numbers of viable seeds in the 3 month old stockpile at 1 m depth, possibly from seed dispersal immediately before construction in the summer of 1985. In the 4 year old stockpile, there was a statistically significant reduction in numbers of viable seeds at 1 m and 2 m depths. If it is assumed that the stockpiles originally contained similar numbers of seeds, this reduction at depth would be expected, since no additional seeds were being added, and the viability of the stored seeds would have decreased substantially over 4 years.

Table 11. Total Numbers of Seedlings/m^2 Emerging from Samples from Topsoil Stores. (Dickie et al. 1988).

Age of Store	Depth (m)		
	0	1	2
3 Months	3,300	5,000	1,700
4 Years	3,600	280	610

Statistical analysis showed that seedling numbers were strongly dependent on stockpile age and depth of sampling. The main conclusions from this study were:

1. In topsoil stored for several years (not months), the viable seed population may be significantly reduced except near the surface of the stockpile, where invading and/or seeded vegetation will contribute additional seeds;
2. With time there is a reduction in the number of species present in viable seed population in stockpiled topsoil; and,
3. It appears that the soil seed bank of stored topsoil can be maintained throughout the stockpile as long as the soil is stored for only a few months. For longer periods (years), seed survival at depth is not reliable; it may vary from species to species.

However, significant soil mixing, with the occasional inclusion of subsoil, occurred during construction of stockpiles. These results must be treated with caution.

Dickie's coworkers, Harris and Birch (1988), suggested that the decline in the number of viable seeds at depth may have been due to germination during stockpile construction, microbial pathogens, or natural loss of vitality. In germination tests, the seedlings which emerged after incubation of the deep samples tended to be weedy species.

To summarize, survival of seed populations in stored soil depends largely on the following: (1) the vegetation present before soil stripping (number of seeds and species present); (2) the seed characteristics of the species present (e.g., dormancy period and type of seed coat); (3) the location of the seeds in the stockpile (viability decreases with depth); (4) the time the soil is stored (viability decreases with time); (5) the vegetation cover during storage; and, (6) soil texture and moisture status during storage.

2.3.2.4 Stored topsoil as an inoculum source for reclamation. There is considerable interest in the use of topsoil as a source of inoculum in revegetating disturbed soils. In rangeland, forested and alpine areas, the native vegetation is often better adapted to climatic conditions than the grass/legume mixtures commonly used in reclamation. The goal of reclamation is generally to return the vegetation of the area to its original state as quickly as possible, but most native species are either unavailable commercially or their cost is prohibitive.

Beauchamp et al. (1975) evaluated undisturbed Wyoming topsoil as a seed source for reseeding strip mine spoils. They found that, although the top 2 inches of soil contained viable seed of desirable species (enough to reach the required degree of productivity specified by the State of Wyoming Regulatory Agency), the species which most often emerged were those which would normally be found in secondary succession. Using topsoil as a seed source would therefore result in a change in the quality of the vegetation; they concluded that seeding or transplanting of desirable species would be necessary to meet government specifications.

Howard and Samuel (1979) found that fresh stripped topsoil directly placed over regraded overburden at Kemmerer, Wyoming, resulted in introduction of native plants from seeds, but more often rhizomes. However, after two seasons plant density was too low to meet revegetation standards without additional seeding.

Brophy (1980), in North Dakota, concluded that, considering the very low numbers of viable seeds in stockpile samples, re-spread topsoil from stockpiles probably did not contribute many seeds at the six reclamation sites assessed.

However, Iverson and Wali (1982) reported from North Dakota that spreading topsoil was beneficial for introducing a few range species which do not colonize new areas readily. They suggested that seeds from some species may lie dormant in the seedbank until establishment is possible, for example, until they are brought closer to the surface. They recommended that pre-mined surface soils be replaced at the surface of post-mined areas. However, revegetation by species invading from the surrounding area was likely more important.

Tacey and Glossop (1980) examined three different topsoil handling strategies for rehabilitation of bauxite mined land in the northern Eucalyptus marginata forest of south-western Australia for erosion control, conservation needs and aesthetic reasons.

Seedling density and subsequent community diversity was compared after topsoil was handled in three different ways: (1) 40 cm of topsoil was stripped, stockpiled for 2 years in a 10 m high pile, then re-spread to a depth of 40 cm (stockpiled); (2) 40 cm of topsoil was stripped then immediately re-spread to 40 cm on a mined area (direct); and (3) topsoil was stockpiled for 2 years, re-spread to 40 cm, then covered with 5 cm of freshly stripped surface topsoil (double stripped). An adjacent undisturbed site was used as a control. All work was done in the summer (dry season).

Seedling emergence was significantly greater on the site which received the double-stripped topsoil. There was no significant difference between seedling emergence on the direct return and stockpiled treatments. After 4 years, the highest species richness, diversity and equitability was on the double-stripped treatment which were similar to those of the undisturbed forest plot. There was no significant difference in species richness, diversity and equitability between the stockpiled and direct return treatments. For all sites, live plant cover was highly variable. Values for mean live plant cover doubled from stockpile to double-stripped sites, and doubled again for the undisturbed site.

Trials in the area indicated that 93% of germination occurred in the surface 2 cm of soil. Since the smaller the seed, the shallower it must be planted for emergence to occur (Tacey and Glossop 1980), soil mixing during handling likely resulted in burial of many seeds to depths from which they could not emerge. Double-stripping was the recommended soil handling method; however, they recommended that topsoil should be stripped to 2 cm rather than 5 cm in order to reduce seed losses, requiring vacuuming or some method other than using scrapers. Alternatively, topsoil could be stripped to 5 cm but immediately re-spread to 1 to 2 cm. The feasibility of these methods for large scale operations is questionable. Stripping immediately after summer seed drop could also improve the viable seed load.

Jastrow et al. (1984) conducted several studies on sage-wheatgrass vegetation in a coal mining area in Wyoming. Results indicated that:

1. The rate of native plant re-establishment from seeds and/or propagules in the topsoil is probably improved by the elimination of topsoil storage.
2. It may be possible, by using direct applied topsoil, to achieve native plant cover equivalent to that on undisturbed areas within a 10 year period. Although native seed and vegetative propagules in replaced topsoil do have some revegetation value, additional seeding with native species and/or planting of container shrub material is probably required to achieve species diversity. Short term irrigation and/or fertilizer application may also be required.

Dickie et al. (1988) studied seed viability in 3 month and 4 year old topsoil stockpiles in Great Britain. Results showed that:

1. Reliance on buried viable seed from re-distributed topsoil would not guarantee rapid establishment of complete vegetation cover but would provide more opportunity for weedy species to become established;
2. Stockpiling tends to reduce the number of species present, which is undesirable from a conservation viewpoint; and,
3. For important species it is preferable to collect seeds prior to topsoil stripping rather than to rely on seed survival deep within a stockpile.

2.3.2.5 Summary.

1. Before topsoil is stripped, most seeds and other plant propagules are within the surface 0 to 5 cm of soil. Unless this surface layer is stripped separately, stockpile construction results in dilution of the seed population within the stockpile. The seed-rich surface layers may be buried deep within the stockpile.
2. The viability of seeds within stored topsoil sites decreases as duration of storage increases. This occurs both in stockpiles and shallow-stored soils.
3. The viability of seeds decreases with depth within a stockpile.
4. The seeds which germinate immediately after re-spreading are often those of secondary plant species, not the species which were dominant before soil stripping, a problem if return to original vegetation cover is required.
5. Native species may enhance revegetation procedures following re-spreading of stored topsoil. However, supplementary reseeding may also be required to provide an acceptable plant cover.

2.3.3 Mycorrhizae

2.3.3.1 Introduction. The presence of fungal hyphae within the cortical cells of orchid roots was first reported in 1847 (Khan 1979). This was subsequently observed in other plants, and in 1885, the term mycorrhizae ("fungus root") was given to this apparently symbiotic association between fungus and plant root. It is now known that most plants growing under natural conditions in soil possess mycorrhizae in association with roots; in fact, "under natural soil conditions...a non-mycorrhizal plant is the exception rather than the rule" (Khan 1979). Most agronomic crops and forest trees form abundant mycorrhizae. There is a large body of work available on the classification and morphology of mycorrhizal fungi, but a detailed discussion of these aspects is beyond the scope of this review. However, background information is presented here to make the discussion of the effects of topsoil storage on mycorrhizae more meaningful for the reader.

There are three types of mycorrhizae: Ectomycorrhizae, Endomycorrhizae and Ectoendomycorrhizae, as well as variants within each type. The first two groups are the most important and are described in the following sections. No information was found on Ectoendomycorrhizae.

2.3.3.1.1 <u>Ectomycorrhizae</u>. In this association, the main body of the fungus forms a mantle (sheath) surrounding the plant roots, with hyphae entering the plant between the cells of the root cortex. Ectomycorrhizae (mostly Basidio-mycetes or Gastromycetes) produce fruiting bodies (often mushrooms) outside the body of the host, usually above soil level. The spores produced in the fruiting bodies are spread by wind and, to a lesser extent, birds, mammals and insects. Ectomycorrhizal cells utilize carbohydrates, acids and vitamins produced by the host. In return, they act as a nutrient reservoir for the host plant, by storing nutrients such as phosphorus in the fungal sheath, and translocating them to the plant at a constant rate. This "reservoir" effect makes ectomycorrhizae particularly important for plant survival in nutrient deficient soils. Ectomycorrhizae may also enhance water and nutrient absorption, increase the tolerance of the host to physiological and chemical stress, and reduce plant disease incidence by antibiotic production and acting as a physical barrier to root pathogens (Khan 1979; Loree and Williams 1984). Since Ectomycorrhizae occur mainly on gymnosperms such as pine, spruce, fir and larch and on a few (mainly woody) angiosperms (including poplar and willow), their survival is most important on forest sites undergoing disturbance.

2.3.3.1.2 Endomycorrhizae. In this association, the main body of the fungus is within the cells of the plant root and only a few hyphal strands extend into the surrounding soil (Alexander 1967; Khan 1979). Hyphae of these fungi are either septate or nonseptate, but the most widespread type is the nonseptate, or Vesicular-Arbuscular Mycorrhizae (VAM). These are commonly present in ferns, Gymnosperms (except Pinaceae), and many angiosperms. Most of the economically important agronomic and forage crops, fruit and nut trees, and many forest trees form VA endomycorrhizae. In the absence of a host, spores (usually chlamydospores) can survive for many years in the soil. Most of the VAM fungi have a very broad host range (Khan 1979). Hyphae extending from the body of the fungus (within the root) serve as extensions of the root system. These extensions are more effective, both physiologically and geometrically, for nutrient absorption than the root itself, and can absorb minerals more than 4 cm away from the nearest host root and translocate them to the root (Trappe 1981). Other effects of VAM are: increased uptake of P, N, Zn, Cu, and other elements; improved drought tolerance; changes in phytohormone levels and rate of photosynthesis; decreased susceptibility to root diseases; and increased tolerance to salinity and high temperatures (Trappe 1981). Indirectly increased growth of the plant root system enhances the activity of micro-organisms in the rhizosphere which are responsible for organic matter decomposition and nutrient cycling (Call and McKell 1982). Consequently, VAM play a vital role in the reestablishment of plant growth in disturbed eco-systems. VAM can infect host plants from spores, hyphae within existing mycorrhizae or from hyphae in dead host root fragments (Powell 1976; Tommerup and Abbot 1981). The procedure to assess VAM infection in current use was developed by Moorman and Reeves (1979; cited by Reeves et al. 1979). A bioassay is conducted by growing seedlings of a susceptible host in the soil under study and counting the number of infected plants after a specified interval. The Mycorrhizal Infectivity Potential (sometimes called Mycorrhizal Inoculum Potential or MIP) obtained from the bioassay is thus a reflection of all the potential infective units present in the soil. It gives an idea of the relative, but not absolute quantity of inocula indigenous to soil (Liberta 1981). The bioassay is usually accompanied by spore counts and microscopic examination of a subsample of root material from the soil under study, for the presence of VAM fungal hyphae. VAM fungi differ in their requirements; the presence of the fungus and a suitable host does not ensure formation of mycorrhizae. Factors which enhance the development of VAM include: predominance of a host plant species (Miller 1979; Reeves et al. 1979); high light intensity; soil moisture near field capacity; and low to moderate soil fertility, especially phosphorus (Khan 1979). Unfavourable factors for development, specifically those of importance in a reclamation situation are: dilution of topsoil by mixing with subsoil or mine spoil (Loree and Williams 1984; Parkinson 1979; Zak et al. 1982); severe soil compaction (Reeves et al. 1979, cited by Trappe 1981); mechanical disturbance like discing (Allen and Allen 1980); high levels of soil fertility, especially high P; high Na levels; and fungitoxins including oil, heavy metals and saline water (Trappe 1981).

2.3.3.2 <u>The effects of storage on mycorrhizal infectivity potential (MIP) of soils</u>. The importance of hyphal material in infectivity has been demonstrated (Loree and Williams 1984; Tommerup and Abbot 1981); therefore we have reviewed only those studies which include a bioassay as part of the experimental procedure.

2.3.3.2.1 <u>Effect of storage time on MIP</u>. Length of time in storage is an important factor in determining potential effects on reclamation and revegetation. A number of studies from several areas examined the effects of storage and length of time in storage on the MIP of stockpiled topsoils.

Rives et al. (1980) working in North Dakota, examined the MIP from a 3 year old storage pile, and from an undisturbed site approximately 27 m from the storage pile. The pile was approximately 5 m high and consisted of A and B (0 to 60 cm) horizons. The undisturbed site was sampled at 0 to 30 cm depth. Both soils were silty loams, pH 7.9. The storage pile was sampled 1.2 m to 1.8 m below a newly exposed surface, below the rootzone of the surface vegetation, primarily Kochia scoparia. For each sample, Glomus fasciculatus spores were counted; a corn seedling bioassay was also conducted at three dilution levels.

Assuming that initial VAM fungal levels in the undisturbed and stored topsoil were approximately the same before storage began, the results indicated that the number of viable propagules in the undisturbed soil was eight to ten times greater than that in the stored topsoil. Thus, storing topsoil for 3 years considerably reduced the level of viable VAM inoculum. However, the level of inoculum in the stored soil remained high enough to produce 81.7% infection in the corn roots. Infection levels were 91.7% in the undisturbed soil. Spore counts were higher in the stored topsoil than in the undisturbed soil, however. The authors therefore concluded that topsoil storage was more detrimental to the infective material in root fragments than to the spores. This was confirmed by a second experiment which showed that mycorrhizal fragments from undisturbed soil were more effective as a source of inoculum than mycorrhizal fragments from stored soil.

The above work was continued by Gould and Liberta (1981). The same stockpile and undisturbed site was sampled 15 months later (stockpile age 4 years and 3 months) to redetermine the MIP. Soil samples were obtained as reported previously. Samples were analyzed and the corn bioassay was repeated. Their results showed:

1. The MIP of the stockpile topsoil (50.1%) was significantly lower than that of undisturbed soil (98.1%), and of the MIP 15 months previously (81.7%); and
2. The infectivity of the mycorrhizal fragments was higher in the stockpiled topsoil than in the undisturbed soil, even though it had not changed significantly from levels previously reported. Since samples were collected in June instead of March, results of this study are difficult to assess. This may indicate that these fragments are sensitive to seasonal variations in the soil microclimate, especially soil moisture and temperature, as are spores. The fragments in the storage pile may be "buffered" from these

temperature and moisture changes, and thus little change would occur over 15 months.

Since stored materials were a mixture of topsoil and subsoil materials to 60 cm, and the stockpile was non-homogeneous, it is difficult to distinguish between decreases in MIP due to subsoil/topsoil mixing, non-homogeneity of samples, and storage effects.

Liberta (1981) compared MIP in soil samples from stockpiles of three different ages with that of a nearby undisturbed site. Four sampling locations were chosen: (1) an undisturbed site of mixed vegetation cover; (2) a 1 year old stockpile, 4 m high; (3) a three year old stockpile; and (4) an area reclaimed 1 month before sampling, by re-spreading topsoil stored for 2 years. Samples were collected from Sites 1 and 4 at 0 to 30 cm depths (at Site 1 this included the rootzone). At Site 2, the upper 30 cm of soil was removed to remove surface root material, and samples were obtained at 30 cm to 50 cm below the original surface. At Site 3, samples were obtained from the newly cut surface. Sampling sites and results of bioassay tests are given in Table 12. A corn bioassay conducted on samples from each site showed that at least five VAM fungal species were present in the soils.

Table 12. Summary of MIP of Stockpiles and Reclaimed Topsoil in Illinois (Liberta 1981).

Soil	pH	OM %	Texture	MIP
Undisturbed Control	7.0	2.9	SiL	85.3%
One Year Stored	6.5	3.7	SiL	57.3%
Two Year Stored, reapplied	6.5	3.3	SiCL	40.7%
Three Year Stored	7.0	2.3	SiL	12.0%

Spore counts of one of the mycorrhizal fungi present, Glomus fasciculatus, revealed that spore numbers for Sites 1 (undisturbed) and 2 (1 year stored) topsoil were similar, supporting the conclusion of the previous study (Gould and Liberta 1981) that disturbance and storage disturbed other forms of inocula e.g., mycorrhizal fragments.

The basis of this study is the assumption that, before stockpiling, soil from all sites had mycorrhizal infectivity and that subsequently, infectivity levels decrease with storage time. This was confirmed by Williams et al. (1981) who noted that infective potential of stored topsoil was negatively correlated with stockpile age (cited by Loree and Williams 1984).

Several workers have considered that since plants may be more dependent on the mycorrhizal symbiont in the early stages of growth, particularly where moisture is often limiting and plants must respond quickly to rainfall events, the rate at which grass seedlings become mycorrhizal, rather than inoculum levels or percent VAM infection at isolated sampling times, was considered to provide a better indication of how stockpiling could have potentially detrimental effects on plant establishment and growth (Abbott and Robson 1981; Mosse et al. 1981; Visser et al. 1984b).

Visser et al. (1984b), working in Alberta, conducted a greenhouse study to determine the effects of stockpiling prairie grassland topsoil for 3 years on mycorrhizal development and root and shoot production of slender wheatgrass (Agropyron trachycaulam (Link) Malte).

The soil was stockpiled at Bow City, Alberta, within the mixed grass prairie of the eastern Alberta plains. Three years after stockpiling, soil was sampled from the stockpile (0 to 15 cm, 100 to 150 cm, and 150 to 200 cm depths), and an adjacent undisturbed grassland site. Slender wheatgrass seedlings were transplanted into soil samples, and at one, 3 and 5 days after planting, one seedling was assessed for growth characteristics, and the root examined microscopically. The number of VAM "infection units", defined as the presence of internal mycelium resulting from a single infection point (Cox and Saunders 1974, cited by Visser et al. 1984b) were then counted. At 3 and 8 weeks, shoot and root length were measured. Spores were counted after 8 weeks. They found that:

1. There was a two day lag in development of infection units in stockpiled soil compared to the undisturbed soil. However, after 3 weeks, VAM infection levels were similar in both soils.

2. Total root length infected with VAM fungi was significantly lower for stockpiled soil seedlings than for undisturbed soil seedlings during the first week but, by the third week, there were no significant differences between treatments.
3. After 8 weeks, VAM spore levels were high in both the stockpile and undisturbed treatments. However, spores produced on grasses grown in the undisturbed soil were produced mainly by Glomus fasciculatum, while those produced on the grasses in the stockpiled soil were primarily Glomus mosseae. Therefore, although stockpiling did not apparently affect spore production, it did alter the proportion of spores produced by the two species. They suggest that this was due to the greater number of G. mosseae spores produced in the stockpiled soil which may have a greater capacity for surviving stockpile conditions than G. fasciculatum, the dominant type in the undisturbed prairie soil. It was thought that the shift in VAM species must also account for the initial lag in infection observed for plants grown in the stockpiled soil, since different VAM species are known to have different infection rates (Visser et al. 1984b).

The authors concluded that although storing topsoil for 3 years would result in a delay in initial VA mycorrhizal development, and also in a shift in the VA fungal species dominant in the root system, these changes would not be significant enough to alter soil productivity. However, they pointed out that dominance of early infectivity species may be significant to seedlings grown in the field, particularly when they are under drought stress. For instance, it has been found that G. fasciculatum increased drought tolerance of winter wheat while G. mosseae did not (Allen and Boosalis 1983, cited by Visser et al. 1983).

In another study in Wyoming, 96 soil samples were collected from eight stockpiles which had been stored from 0.5 to 6.0 years (Miller 1984). The stockpiles were located within a two kilometre radius; their average volume was 1400 m^3, with heights varying from 4 to 5 m. Soil cores were collected from each stockpile to a depth of 2.0 m. For each stockpile, bioassays were carried out on three subsamples from each of the four depth increments. The results are shown in Table 13.

Assuming that, initially, VAM fungal infectivity was similar for all stockpiles, Miller (1984) estimated that after 12 years of storage, infectivity within the stockpile would approach zero using regression techniques. From the data presented, it appears that MIP for 0.5 to 2.0 years is significantly higher than for 3 to 6 years. No information was presented to indicate if stockpiled soils were constructed of similar soil materials however.

Table 13. Mycorrhizal Infectivity Potential for Stockpiled Soils at 0.5 to 2 m Depth, in Wyoming (Miller 1984).

Age of Stockpile (Years)	Mean Infection Potential % ± Standard Error
0.5	45.6 ± 3.7a**
0.8	51.5 ± 3.3a
1.0	44.6 ± 3.5a
2.0	52.5 ± 1.9a
3.0	18.4 ± 2.1b
5.0	28.9 ± 4.5b
5.5	24.6 ± 4.5b
6.0	26.4 ± 2.9b

** Values followed by the same letter are not significantly different from each other as determined by Duncan's new multiple range test (P=0.01).

Miller (1984) also attempted to correlate soil physical properties, particularly those associated with soil water, chemical properties, and MIP. It was concluded that survival was primarily related to the soil water potential under which soils were stored. Soil chemical factors were not significantly correlated.

Abdul-Kareem and McRae (1984) in the UK found that storage of a sandy soil reduced VAM infectivity. A bioassay was conducted on soil from 1.8 m and 2.0 m depths of a 7 year old stockpile (pH 7.1) and from the surface of an adjacent undisturbed soil (pH 6.8). VAM infectivity was up to ten times greater in the undisturbed site than in the stockpile. However, the stockpiled soil still produced 67% infection in host roots.

Jasper et al. (1987) measured the effects of soil storage on infectivity of VAM fungal propagules in topsoil from several regions of Australia. The sites differed in climate (from Mediterranean to tropical/monsoonal); rainfall (from 530 mm/year to 2083 mm/year); storage method (shallow stored i.e., stripped and re-spread immediately but not seeded for several months, to stockpiled for 1 to 4 years); pH (3.5 to 4.8); soil type (podsolized sand dunes to loam); chemical characteristics and vegetation. Results varied considerably. Several trends were evident:

1. Viable propagules of VAM fungi were present in undisturbed soils at all sites.
2. At all sites, infectivity of VAM fungi in disturbed soils was less than that of similar undisturbed forest soils.
3. Topsoil that had been stored in deep stockpiles for 4 years had no VAM fungal spores, and few other infective propagules. This may have been due to high moisture levels in the stockpiles (Miller 1984), or because of dilution of the most infective (surface) soil with deeper soil during stripping. Soil mixing may also have damaged propagules or exposed them to an unfavourable micro-environment.
4. At one of the sites, VAM formation was not reduced but it was delayed (Visser et al. 1984b). This may have indicated a reduced number of viable propagules.
5. At the two "shallow stored" sites, there were also substantial reductions in VAM infectivity.

Thompson and Jehne (1988) continued this study, comparing VAM fungal spore numbers and mycorrhizal infectivity in fresh and stored topsoils, with those in soils from adjacent undisturbed areas. Topsoils from four of the previous sites were used. For each site, types and numbers of spores from 0 to 10 cm samples were compared for: (1) freshly spread topsoil; (2) stored topsoil; and (3) undisturbed soils. Bioassays (using several hosts) were conducted and MIP was rated. They concluded that at least two species of VAM fungi were present at each site, and most sites had three to five species, but there was no consistent relationship between spore types or numbers and MIP. Storage of topsoil resulted in fewer spores and a lower MIP than for freshly collected and spread topsoil or undisturbed soil.

Harris and Birch (1988) sampled a 3 month and a 4 year old stockpile in Derbyshire, UK. They found that, in both stockpiles, the number of root fragments, weight of fragments, and percentage of the fragments that were mycorrhizal all decreased with decreasing depth. This was likely due to degradation of the roots after root death following soil disturbance. A bioassay showed that overall infectivity was generally lower in the 4 year old stockpile than in the 3 month old stockpile.

To summarize, there appears to be a general consensus that disturbance and storage reduces the MIP of topsoil within 3 years for temperate soils. Infectivity decreased with time in most studies, along with a decrease in the number of spores and mycorrhizal fragments capable of propagation. Species composition of the VAM fungal population may change during soil storage, depending upon species present, soil conditions in the stockpile and duration of storage. The only study carried out in Alberta however, found that 3 year storage of topsoil caused a delay in infection and a change in infective species, but no overall decrease in MIP. It was speculated that this could seriously affect seedling viability during revegetation, particularly under drought stress.

2.3.3.2.2 Effect of depth of storage on MIP. Viability of VAM inoculum at depth within a topsoil stockpile is an important consideration when planning optimal size and configuration of stockpiles, and re-spreading methods.

Stark and Redente (1987) reported that initially, levels of VAM inoculum were higher in deep layers than in surface soil of a stockpile 23.5 m long, 5 m wide, and 3 m deep. This was possibly due to stockpile construction methods where the upper layer of the native soil which has the highest inoculum potential, is stripped first and placed at the bottom of the pile. By 1984, however, inoculum levels in this same stockpile were similar at all depths sampled. In the deeper parts of the stockpile of a Colorado loam, mycorrhizal inoculum evidently decreased after 5 years in storage (Stark and Redente 1987).

Persson and Funke (1976) sampled a stockpile located on the Baukol-Noonan Mine near Center, North Dakota. The pile was constructed in July 1983 and vegetative cover was established. Soil cores were collected and VAM infectivity measured in 0 to 7.6 cm and 114 to 122 cm subsamples. The approach was that, if the stockpile was homogeneous when constructed, surface samples would show the effects of revegetation and depth samples would show the effects of storage. VAM infectivity was measured using a corn bioassay. The results indicated that, over time, VAM infectivity decreased with storage at the lower depths samples, but increased at the surface due to the effects of vegetation. Reeves et al. (1984, cited by Stark and Redente 1987) also reported that vegetated portions of a stockpile had higher mycorrhizal inoculum potentials than nonvegetated portions of the same stockpile.

Harris and Birch (1988), working on 3 month old and 4 year old stockpiles in the UK, found that MIP decreased with depth in both stockpiles. Below 1 m there was no infectivity in either stockpile. This reduction in infectivity below 1 m likely results from a combination of dilution of propagules, or soil "inversion", damage to propagules during stockpile construction, and anaerobic conditions.

To summarize, it appears that there is a general decrease in MIP with depth of storage in a stockpile. Anaerobic conditions appeared to have totally reduced infectivity within 3 months in one temperate area.

2.3.3.2.3 Effect of moisture content and temperature on MIP. Although soil moisture and temperature are important parameters for reclamation, very few studies attempted to characterize either. Soil moisture conditions appear to be a critical factor in determining the MIP of stored topsoil. Soil moisture is influenced by soil texture, organic matter content, bulk density, temperature, precipitation, and storage conditions like depth and presence of surface vegetation. Where moisture is limiting, inoculation of re-spread soils with VAM may be required to re-establish preferred vegetation. Miller (1984) working eight stockpiles of various ages in a dry area of Wyoming, found a good correlation between soil physical parameters related to soil water, and MIP. The results suggested that if soils are to be stored, stockpiling should be limited to time periods when soil water potentials are below (more negative than) - 2 MPa to ensure adequate propagule survival. Miller (1984) recommended that the size of stockpiles should be varied according to the moisture regime of the ecosystem. In arid environs, large stockpiles should be made during periods when the soil is dry, while in more mesic ecosystems, shallow stockpiles should be the rule, because these stockpiles would have a tendency to be influenced by water recharge due to evapotranspiration. Another important consideration in stockpiling of topsoil is establishment of host plants on the stockpile surface. In arid ecosystems, host establishment appears to be initially difficult unless supplemental moisture is available, whereas in mesic environs, good host seedling establishment is less of a problem. Thus, in ecosystems where moisture is not limiting, the establishment of hosts and associated propagule production through root colonization can compensate for propagule losses associated with increased soil moisture during storage (Miller 1984).

Miller also examined the effect of high temperature on MIP. Soil subsamples were stored in pots in a glasshouse for 92 days, without watering, under temperatures up to 46° C. The result was complete loss of VAM infectivity, likely due to high temperatures. This temperature effect may occur in surface layers of stockpiles or in shallow-stored topsoil, in certain areas. For example, at one site in this study, mean daily maximum temperatures for October was 35°C. This temperature effect may result in death of both spores and mycorrhizal fragments.

2.3.3.2.4 Effect of soil type on MIP. Only one study examined the effect of different soils on MIP. Thompson and Jehne (1988), working at a number of reclaimed and stockpiled sites throughout Australia, found that the distribution of two species in VAM (*Glomus* sp. and *Scutellospora* sp.) were tolerant of a wide range of soil conditions. It was noted that different strains of these may be associated with different soils.

2.3.3.3 Mycorrhizal development after re-spreading of stockpiled topsoil. Studies conducted in arid and semi-arid range areas of the US indicated that the reduction in VAM fungal infectivity in stored soil may profoundly influence plant species composition after the soil is re-spread (Allen and Allen 1980; Loree and Williams 1984; Reeves et al. 1979; Stark and Redente 1987; Trappe 1981). Reeves et al. (1979) reported that non-mycorrhizal species became established more quickly than mycorrhizal species in disturbed rangeland areas of Colorado. They also noted that, on a world wide basis, many of the most successful weedy colonizers are non-mycorrhizal species. In Canada, Mulligan (1965, cited by Reeves et al. 1979) listed the most common weedy invaders; more than half of these were potentially non-mycorrhizal genera.

Reeves et al. (1979) have proposed that disturbance of soil leads to reduction and possibly elimination of propagules of mycorrhizal fungi. The reduced numbers of propagules leads to a lower potential for infection of new host plants. Non-mycorrhizal species become established because normally mycorrhizal plants die in the seedling stage due to lack of mycorrhizal fungi. The success of non-mycorrhizal species further reduces the propagules of mycorrhizal fungi since the fungi are obligate symbionts. Total elimination of mycorrhizal fungi obviates competition by mycorrhizal higher plants. Succession is slowed because of the lack of potential mycorrhizal fungi which may be slow invaders. Finally, the harsher the site the greater the potential for elimination of mycorrhizal propagules and, therefore, a longer time is required for re-establishment of mycorrhizal vegetation.

Trappe (1981) indicated that inoculation of VAM fungi may be required for some areas if rapid establishment of vegetation is required. This could be done by direct placement of topsoil stripped from suitably vegetated sites, or by using a commercial inoculum, if available.

Warner (1983) monitored the re-establishment of VAM fungi after topsoil re-spreading from a 12 year old stockpile in the UK. Soil was re-spread over a period of 20 months as successive reclamation took place. The first area restored was seeded to barley, the second to rapeseed, and the third left fallow, although it soon had a dense weed and grass cover. From this study it appeared that the reduction in VAM infectivity in the topsoil was temporary; after re-spreading it reached levels similar to those for a neighbouring field within 17 to 20 months. This differed from the studies already cited and carried out in the arid regions of the US, where drought stress plays a major role in plant establishment. It appears, then, that where water is not limiting, inoculation of re-spread topsoil with VAM fungi would be of little benefit.

Jasper et al. (1987) found comparable VAM infectivity between undisturbed soil and a 5 year old revegetated soil at one site; and undisturbed and a 4 year old revegetated soil at another site in Australia. However, infectivity was highly variable, indicating that a uniform inoculum level had not yet been established after stockpiled soil was re-spread.

Gardner and Malajczuk (1988), also working in Australia, examined VAM and ectomycorrhizal fungal recolonization of restored bauxite mine sites. Infectivity, species distribution, and abundance of spores were compared between reclaimed areas (1 to 7 years old) and undisturbed eucalyptus forest. They found that diversity and abundance of both types of mycorrhizal fungi increased with time. For VAM fungi, the number of species, abundance of spores, and percentage of root infectivity (determined by bioassay) in the 7 year old stand were similar to those for the native forest site. However, the number of ectomycorrhizal fungi species present was less than half of that in the native forest site; only a few species were common to both habitats. There did appear to be a fungal succession progression, however. This was expected to continue as the leaf litter on the forest floor increased.

Thompson and Jehne (1988) compared VAM fungal spore numbers and infectivity in stored and re-spread topsoils in adjacent undisturbed sites in Australia. Results were variable, but at one site, spore numbers were still noticeably reduced 2 years after revegetation. At this site the soil was sandy with a pH 4.0 and precipitation was 4000 mm per year.

To summarize, restoration of VAM fungal activity to predisturbance levels after re-spreading of stored topsoil may take place within as little as 1.5 years, or it may require many years (seven or more). Where moisture is not limiting, inoculation of soil with VAM mycorrhizae is likely unnecessary. As host plants re-establish, numbers of VAM fungal propagules increase.

However, in very dry soils in arid or semi-arid regions, additional water and/or inoculation with VAM fungi may be required for best re-establishment of host species. If this is not done, non-mycorrhizal plant species will likely dominate the vegetation for the first few years of reclamation. The following conclusions may be drawn:

1. For most of the soils studied, VAM MIP declined during storage. This occurred in both stockpiled and shallow-stored soil. The extent of this decline depended upon soil conditions and duration of storage. The species composition of the VAM fungal population may change during soil storage, depending upon (a) species present; (b) soil conditions in the stockpile; and (c) duration of storage. MIP declines significantly within 3 years of storage for temperate and arid soils.
2. MIP in stored soil is enhanced by the presence of vegetation, particularly if the cover includes host species.
3. Changes in species composition of the VAM fungal population during storage may result in a delay in mycorrhizal development after re-spreading, depending mainly on the host species used for revegetation and moisture availability during the initial stages of revegetation.
4. Soil moisture conditions are the most critical in determining the MIP of stored soil. Where moisture is limiting, inoculation of re-spread soils with VAM fungi may be required to re-establish the preferred vegetation.
5. Within stockpiles, MIP declines with depth. At 1 m below the surface, infectivity may be eliminated in as little as 3 months in temperate zones. This is likely related to anaerobiosis within the stockpile.

2.3.4 Effects of Storage on Other Micro-organisms in Topsoil

The soil biomass is the total mass of all living organisms, within the soil; in most soils 90% of the biomass is made up of micro-organisms: bacteria, actinomycetes, fungi, algae and protozoa. Several methods have been developed to estimate the microbial biomass in soils, including; (1) the chloroform fumigation/incubation technique described by Jenkinson and Powlson (1976, cited by Johnson et al. 1988); (2) measuring certain soil enzyme activities or adenosine triphosphate levels in soil; and (3) by measuring microbial respiration in soil (Visser et al. 1984). These techniques are usually used in conjunction with other methods of estimating microbial populations, such as plate counts, direct counts, or the Most Probable Number procedure.

Ross and Cairns (1981) measured soil biomass in stockpiles at two sites in New Zealand using the chloroform fumigation/incubation technique. Stockpiles were 50 m long, 10 m wide and 2 to 3 m high, and were 10 to 12 years old. Both were silt loam in texture.

The results were highly variable, but generally indicated that biomass was lower at the bottom of stockpiles than in adjacent undisturbed soil. However, surface samples from the stockpiles had biomass values similar to those of undisturbed soil, particularly for a stockpile which was being grazed. A greenhouse experiment was carried out to determine the influence of plant growth on microbial biomass of samples from the bottom of the stockpiles. After plant growth was established, mineral N production increased from that of the unplanted soil. However, levels were still very low, suggesting that the recovery of microbial biomass in soil from the bottom of stockpiles could be slow after re-spreading. This might be significant in soil organic matter turnover and the release of nutrients for plant growth in re-spread soils.

Visser et al. (1983), in a southern Alberta study, monitored changes in microbial respiration and biomass in topsoil that had been stockpiled for 3 years. The stockpile was composed of a Brown Chernozemic soil and was 6 m by 12 m by 2.5 m high. An experimental plot was established on the top of the pile, and two control sites were established as a cultivated check plot and as an undisturbed prairie grassland plot. Soil samples were collected at 0.5 months after stockpile construction, and again at 4, 12, 17, 25, 29 and 36 months. Stockpile soil was sampled at 0 to 15 cm, 100 to 150 cm, and 150 to 200 cm. The control plots were sampled at 0 to 15 cm. For each sample, microbial respiration was determined and biomass estimated by measuring substrate induced respiration. Organic C was also determined for all samples.

The results showed that immediately after stockpile construction, soil organic C levels were reduced, particularly in the surface layer of the stockpile. This was likely due to dilution of the topsoil or the "inversion" effect noted in other sections of this report. After 0.5 months, microbial activity was consistently higher deep within the stockpile than in the surface layer. This may have been due to low organic C levels in the surface soil, and also due to temperature/moisture factors at the surface such as freezing, thawing, high temperatures, drying, etc.

Microbial biomass C in the surface soil was lower than that in the undisturbed soil throughout the study, whereas microbial biomass in soil from the bottom of the stockpile was never significantly different from that of undisturbed soil. To summarize this study, stockpiling topsoil in the dry climate of southern Alberta appeared to have very little effect on soil respiratory activity, but reduced microbial biomass levels in the outer surface of the stockpile and reduced the rate at which this biomass responded to glucose. However the reduction in biomass after storage for 1 year did not have any detrimental effects on decomposition or primary production potential of the stored soil (Visser et al. 1984a).

Abdul-Kareem and McRae (1984) determined soil microbial biomass changes in 18 stockpiles of different textures, ages, sizes and storage conditions in the UK. Their paper presented microbial biomass data for three stored soils of sandy, loamy, and clayey-textures. For each stockpile, an adjacent undisturbed site was also sampled. The stockpiles ranged from 1.5 years to 7 years and heights ranged from 3 to 7 m. Microbial biomass was determined by the chloroform/fumigation technique. Microbial biomass was lower in the stockpiles than in the adjacent undisturbed site for all three stockpiles. The statistical significance of these results is questionable however.

Persson and Funke (1976) used measurements of alkaline phosphatase and dehydrogenase enzyme activity to estimate microbial activity of stockpiled soil in North Dakota. After 1 and 2 years of storage, activity of both enzymes decreased with depth and time. However, no statistical analysis of the results was presented.

Harris and Birch (1987) sampled stockpiles of different ages, depths and soil types on an opencast mine in Great Britain. Microbial biomass was estimated using an adenosine triphosphate (ATP) assay. The results showed an initial decrease in biomass after stockpile construction and a further steady decline over time. This immediate decrease may be due to a decline in fungal numbers.

Johnson et al. (1988) estimated microbial biomass in stockpiles at six sites in the Midlands region of Great Britain. Using chloroform fumigation and substrate induced respiration techniques, the results frequently showed no significant effects of depth on biomass carbon levels, although values were sometimes higher deep within the stockpile than at the surface. The authors point out that the chloroform fumigation/incubation technique may be invalid in some situations. They reported a delay in glucose-induced respiration at depth; however the eventual large CO_2 release indicated that microbiological activity was present.

To summarize the results of these studies, the effect of storage on microbial biomass is often inconclusive. Some of the research indicates that microbial biomass decreases with stockpile depth and increasing storage time, while other studies report higher microbial biomass values deep within the stockpile than in surface samples. This may indicate problems with analytical methods, the inherent heterogeneity of stockpiles, or that specific soil conditions such as soil moisture, temperature or texture may be influencing the results. Unfortunately, few of the studies reviewed gave detailed information on the soils being studied. Soil conditions may be more critical than is generally acknowledged in these research papers. Several different analytical techniques may have to be employed to give a comprehensive picture of change in different types of organisms in the soil.

2.3.4.1 The effect of storage on bacterial and actinomycete populations in topsoil. Bacteria are the most abundant micro-organisms in the soil, usually present in higher numbers than the other four groups combined (Alexander

1967). Although bacterial numbers are generally higher, their biomass in soil is usually lower than, for example, that of the larger fungi. Bacteria decompose a wide variety of substrates and multiply very rapidly by cell division when conditions are favourable. A highly fertile topsoil may attain numbers from 10^8 to 10^9 bacteria cells per gram of soil. Bacterial polysaccharides play a key role in aggregation of soil particles.

Several methods are used to determine bacterial numbers in soil, including: (1) plate counts, in which a diluted soil extract is incubated in a sterile agar medium; (2) direct counts, in which a soil suspension is stained and cells are counted under the microscope; and (3) Most Probable Number procedures, where dilution extinction is measured. Selective media or use of antibiotics or fungicides can be used to differentiate relative numbers and activities of bacteria and fungi. The plate count method is the one most frequently used to estimate bacterial populations. Soil factors which affect bacteria and fungi are given in Table 14.

Actinomycetes are, in effect, bacteria which produce fungus-like filaments or mycelium; a "transition group" between bacteria and fungi. They are the second most numerous group of micro-organisms in soil. Most are saprophytic, living on dead organic material. Actinomycete numbers in soil vary considerably, ranging from 10^5 to 10^8 per gram of soil in temperate zones. In waterlogged soils actinomycete numbers tend to be lower. They are more numerous in alkaline than in acidic ($pH<5.0$) soils; in dry than in wet soils; in warm than in cold soils; in pasture and grassland than cultivated soils; and in soils with higher organic matter content. Actinomycetes produce asexual spores which are resistant to desiccation and can persist for many years. Optimum temperature range for growth is 28°C to 37°C. These organisms are most numerous in surface soil, but they also make up a large part of the microbial population deep within the soil profile (Alexander 1967). Counts in the C horizon may range from 10^3 to 10^5 per gram.

Table 14. Soil Factors Affecting Bacteria and Fungi (after Alexander 1977).

Soil Factor	Bacteria	Fungi
Soil Moisture	For most aerobic bacteria, optimum soil moisture levels are 50 to 70% of field capacity. Anaerobic bacterial populations increase where moisture is excessive, due to low O_2 levels; aerobic bacteria levels decrease.	Numbers are usually highest when soils are near field capacity. Some species favour moist soils, but all fungi are aerobic. Some species can function in very dry (desert) soil.
Aeration	Poor aeration favours growth of anaerobic bacteria.	All fungi are aerobic; numbers decline as oxygen availability declines. A few hyphae in anaerobic regions of the soil may survive, but only if a large part of the fungus material is in the aerobic zone. Some spores may survive anaerobiosis (mainly chlamydospores, or resting spores).
Temperature	Most bacteria are mesophiles (optimum range 25° to 35°C); some are thermophiles (range 45° to 65°C); a few are psychrophiles (optimum temperatures <20°C). In temperate regions, a warming trend favours increased growth of most bacteria.	Species vary in temperature response, but most are mesophiles. A few (e.g., those predominant in compost piles) are thermophiles.
Organic Matter	Addition of organic matter promotes an increase in bacterial numbers until nutrients (especially N) become limiting.	As organic matter increases, fungal populations increase until nutrients or moisture become limiting.

continued . . .

Table 14. Continued

Soil Factor	Bacteria	Fungi
Inorganic Fertilizer	Bacterial numbers may be suppressed by addition of ammonium-containing fertilizers.	Ammonium fertilizers tend to increase fungal population.
Cultivation and Type of Vegetation	Variable effects, depending on the presence of plant residues and moisture availability.	Species present may change with changes in vegetation; some fungi are more specific than others in their requirements, particularly plant pathogens. Some fungi may respond to specific root secretions or particular components of the plant debris.
Position in Undisturbed Soil	Numbers are generally highest in the upper metre of soil; generally the most active populations are in the top few centimetres.	Most numerous in surface layers, but under sod, populations can maintain high numbers to more than 1 m depth. Species generally change with profile depth, possibly because of selection due to CO_2 levels.
Season	Bacterial numbers are usually highest in spring and fall due to the presence of plant residues, favourable moisture status and temperatures. Numbers are lower in the summer, especially when soil is dry; in winter the population decreases but remains viable.	Highest numbers usually in the spring and fall, because of high amounts of plant residue present. Activity decreases, in summer, especially when soil is dry. Low activity in winter.

continued . . .

Table 14. Concluded

Soil Factor	Bacteria	Fungi
pH	Optimum conditions are neutral, but can exist as low as 3.0.	Most species tolerate a fairly wide pH range. Fungal numbers are often higher in acid (low pH) soils because of reduced competition for nutrients from bacteria and actinomycetes, which require a higher pH.

Hunter and Currie (1956) reported that topsoil stockpiles gave off a characteristic anaerobic smell when opened up. O'Flanagan et al. (1963, cited by Abdul-Kareem and McRae 1984) found that nitrification rates and aerobic bacterial counts decreased during storage; however, recovery was rapid after soils were re-spread.

Barkworth and Bateson (1964) sampled soil from 32 stockpiles from January to March 1959, in Great Britain. Construction of the stockpiles had taken place from 6 months to 14 years before sampling.

Total numbers were determined for aerobic and anaerobic bacteria using the Plate Count Method; the presence of nitrifying and cellulose-decomposing bacteria was detected using specialized media.

Total aerobic colony counts for surface samples were similar to those made for normal field soil, approximately $5x10^7$ colony forming units per gram of soil; for deeper samples they were often one-tenth of this figure ($5x10^6$ colony forming units per gram of dry soil). A substantial reduction in numbers often occurred at 3 m depth. The total colony counts for anaerobic bacteria, usually about $1x10^5$ colonies per gram of dry soil in normal field samples, ranged from $3x10^5$ colonies per gram of dry soil in the clay-textured stockpiles to 1000 or fewer colonies per gram of soil in the lighter textured stockpiles. Generally speaking, a count of 10^3 colony forming units per gram of soil is considered the minimum number of any significance in the soil.

Nitrifying bacterial numbers were similar to those of normal field soils. The authors point out that soil from the surface of vegetated topsoil dumps should be regarded as a "functioning topsoil" and as such it differs from the remainder of the stockpile.

Conclusions from this study were: (1) there was a reasonably high bacterial population in all the dumps sampled, even when soil had been stockpiled for 14 years; (2) there was a decrease in bacterial numbers with depth, but even at 5 m there were enough bacteria to act as an inoculum after re-spreading; and (3) the anaerobic population was higher than in field samples, suggesting that anaerobic activity increased within the stockpile. This study suffers from lack of documentation on homogeneity and composition of stockpiles studied. Applicability of controls to stockpiles is questionable in some cases. Results may be confounded by these factors.

In a 1982 study, Fresquez et al. (1982) compared fungal, bacterial and Streptomyces (an actinomycete) populations in soils from four locations at the San Juan coal mine in New Mexico. The sample sites were: (1) a nonvegetated spoil bank (clay loam pH 7.6); (2) a topsoil stockpile at least 1 year old (sandy loam, pH 8.0); (3) a vegetated reclaimed site where stockpiled topsoil had been re-spread 3 years previously; and (4) an adjacent undisturbed site. No textures or pH values were given in this paper for sites (3) or (4). Bacterial populations were estimated by soil dilution and plating on selective media. Numbers of ammonium oxidizing bacteria were estimated by the most probable number method. Fungal propagules were estimated by the plate count method using rose bengal-streptomycin agar. Results showed that: no Azotobacter colonies (a free-living nitrogen fixing bacterium) were present at any of the sites. For all other bacteria and Streptomyces, numbers were greater for both the undisturbed and reclaimed sites than for the stockpiled topsoil, with the nonvegetated spoil having the lowest numbers.

Since population estimates have been criticized as being inaccurate measures of the biological status of soil, dehydrogenase activity was also measured for each of the above sites. Again, the results indicated that microbial activity in the spoil and stockpiled topsoil was low: although there was an indigenous microbial population, the population was relatively inactive (Fresquez and Lindemann 1982). The results are shown on Table 15.

Harris and Birch (1987) compared microbial populations in stockpiles of different ages, depths and soil types on an opencast coal mine site in Great Britain. A more detailed investigation was carried out at another site; soils were sampled before stripping and then monitored during storage. Selective media were used to obtain colony counts for aerobic and anaerobic bacteria and other micro-organisms.

Bacterial groups in all depth zones increased immediately after storage, but declined after a few months. Aerobic bacteria declined with increasing stockpile depth. For example, in a 4 year old stockpile, the deepest zone contained only 18% as many bacteria as the surface soil.

From their studies, Harris and Birch (1988) summarized the effects of storage on bacterial populations thus: (1) numbers of most bacterial groups increased on stripping and storage - an initial "flush"; (2) bacterial numbers then declined, especially below 1 m; (3) viable bacterial spore numbers decreased with increased storage time; (4) anaerobic bacteria decreased during construction of the stockpile, probably due to exposure to oxygen during earth-moving; and (5) deep within the stockpile, numbers of anaerobes recovered to pre-storage levels and gradually surpassed them. However, at the very deepest levels, numbers of anaerobes did not increase.

Johnson et al. (1988) used several techniques to determine the effects of storage on microbial populations. In this study, microbiological analyses of stockpiled soils were carried out at six sites within British Coal's West Midlands and North West areas. Selective media were used to determine numbers of total bacterial aerobes and anaerobes, and actinomycetes; cellulolytic aerobes and anaerobes were also counted. Direct counts were also conducted. Unfortunately, little information was presented on soil characteristics. Stockpiles of various ages within the six sites were examined to obtain an overall picture of microbiological changes from pre-stripping to stockpiling and then re-spreading.

Table 15. Numbers of Microbial Types and Dehydrogenase Activity Measurements, for Stored Topsoil in New Mexico. (Fresquez and Lindemann 1982).

Organisms	Undisturbed Soil	Reclaimed Spoil	Stockpiled Topsoil	Nonvegetated Spoil
Heterotrophic aerobic bacteria x 10^6/g	95.8 a[1/]	48.0 a	1.0 b	0.1 b
Fungal propagules x 10^3/g	19.8 b	39.7 a	5.7 b	4.2 b
Streptomyces propagules x 10^6/g	6.4 a	6.7 a	0.5 a	0.2 a
Aerobic asymbiotic nitrogen fixers x 10^3/g	0	0	0	0
Ammonium oxidizers x 10^3/g	0.1 a	9.1 a	0.02 a	0.1 a
Total micro-organisms x 10^6/g	102.2	54.7	1.5	0.3
Activity				
Dehydrogenase mg Formazan/g/day	0.30 a	0.09 b	0.04 b	0.03 b

1/ Means in the same horizontal row followed by a common letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Results showed that for the first few weeks after stripping, only minor changes occurred in bacterial populations; in some cases numbers increased due to the increased availability of organic matter. By approximately six months after stockpile construction, definite changes were apparent: bacterial numbers declined with depth, but not as markedly as numbers of fungi and actinomycetes, both obligate aerobe, populations. Fungal and actinomycete numbers reached base levels approximately 2 m below the surface, the usual depth where anaerobiosis developed, but bacterial base levels were attained much deeper in the stockpile. This infers that some bacterial species were facultative anaerobes. Anaerobic bacterial populations did not increase with soil depth, and were often as numerous in the aerated surface soils as in the anaerobic deep soils.

Direct counts showed that there was a high ratio of total to plateable bacteria in deep soil compared with surface soil, indicating that most bacterial cells within the mound were dead. This was also reported for fungal hyphae. A high proportion of the bacteria present at depth were Bacillus spp. which form endospores. The ability to produce endospores ensures survival under adverse conditions. An increase in numbers of spore-forming bacteria usually indicates the population is under stress (Johnson et al. 1988). Nitrifying bacteria (Nitrosomonas and Nitrobacter, spp.), obligate aerobes, survived in the anaerobic zones, confirming the results of Persson and Funke (1976).

Monitoring of topsoil after re-spreading indicated that initially, bacterial numbers increased substantially, while actinomycete numbers declined. The decline in actinomycete numbers may be a reflection of their lower numbers deep within the stockpile. Within a year, bacterial numbers had subsided while actinomycete populations were increasing. In addition, within 13 days the ratio of total: plateable bacteria decreased, as did the number of Bacillus isolates relative to the total counts. After a year, the numbers and proportions of aerobic micro-organisms had stabilized on restored sites. Numbers of anaerobes had increased significantly ($P<0.05$) by 13 days after re-spreading, and continued to increase over the next 3 years. Nitrifying bacteria returned to previous levels within 4 days, probably due to the quantities of accumulated ammonium-N within the stockpile.

To summarize the preceding subsection:

1. When a stockpile is constructed, soil bacterial and actinomycete populations increase for a short time (a few weeks), due to the incorporation of plant debris and other organic material throughout the stockpile.
2. After about six months, bacterial and actinomycete populations subside, probably because readily decomposable organic matter has been depleted.
3. Populations of aerobic bacteria and actinomycetes are highest in soil near the stockpile surface (the aerobic zone) and lowest deep within the stockpile.
4. Facultative anaerobes, anaerobes, and spore-forming bacteria tend to be predominant deep within the stockpile.
5. Numbers of anaerobic bacteria tend to decrease immediately after stockpile construction and then gradually increase, but remain below predisturbance levels.
6. When stockpiled soil is re-spread, populations of aerobic bacteria increase very quickly. Actinomycete populations increase as well, but at a much slower rate. Aerobic populations are generally stable by 1 year after re-spreading.
7. When stockpiled topsoil is re-spread, numbers of anaerobic bacteria increase rapidly; this tapers off, but a gradual increase in numbers may continue from 1 to 3 years.
8. Even after prolonged storage (up to 14 years) enough viable inoculum remains at all depths in the stockpile to allow restoration of bacterial and actinomycete populations to predisturbance levels. This recovery will generally occur within a year of re-spreading.

2.3.5 The Effect of Storage on Fungal Populations in Topsoil

2.3.5.1 Introduction. Although bacteria are numerically the largest microbial group, fungi have the largest biomass in most aerated soils. Bacterial cells are generally very small rods and spheres, whereas fungi also form an extensive network of filaments (mycelium) generally of significantly larger diameter than bacterial cells. In acidic environments, particularly in the organic layer of forest soils, fungi are the main agents of decay. Fertile land may contain 10 to 100 m of active fungus filaments per gram of soil.

Fungi play an important role in decomposition of organic plant materials such as cellulose, hemicelluloses, pectins, starch and lignin, as well as animal protein. They are important in aggregation of soil particles, since hyphae physically bind particles together.

Fungi propagate vegetatively (from hyphae or asexual spores); or sexually (sexual spores). Several methods have been developed to estimate fungal populations, including plate counts; buried slides, in which microscope slides are buried in soil for a specific length of time, then stained and examined microscopically; and the immersion tube method, in which an agar-filled tube with openings in the side is incubated in soil for a few days, then stained and examined microscopically. The plate counting methods are used to estimate colony forming units. Since each piece of the fungal mycelium and each spore could theoretically produce a fungal colony on the agar, numbers of some species may be deceptively high using this procedure, but it does give an indication of the relative numbers and diversity types of fungi present.

Table 14 summarizes the effect of various soil and environmental conditions on the survival and growth of fungi.

2.3.5.2 Fungal populations during storage. Miller (1984), working in a Wyoming desert location, compared fungal species distribution on three undisturbed sites, a 5 year old topsoil stockpile, a disturbed plot in which 20 cm of soil from a vegetated site was applied over spoil, a disturbed plot in which 20 cm of topsoil from a 2 year old stockpile was applied over spoil, and disturbed plots where topsoil had been directly replaced. A plate count method was used.

Species diversity was reduced on the stockpile, but increased when re-spread. Species composition differed between the predisturbed and re-spread soil. An increase in seed rotting fungi suggested that a reduction in the viability of native plant seeds stored in the stored topsoil could occur.

Miller (1984) also reported the possibility that mycotoxins may be present in stockpiled soil, after conducting a bioassay and finding some evidence of a toxic water soluble carbon compound limiting root growth.

Fresquez and Lindemann (1982), also working in New Mexico, reported that stockpiled topsoil had fewer fungal species than an adjacent undisturbed site. They concluded that the more narrow fungal genera distribution of stockpiled topsoil may reduce its enzymatic capabilities, especially if the bacterial population also has a narrow genera diversity. Reduced enzymatic capabilities may hinder normal nutrient cycling and decomposition processes. If microbial processes are slowed in stored topsoil, plant establishment may likewise be slowed down during reclamation.

At the same site, Fresquez and Aldon (1984) compared fungal populations in 0 to 13 cm samples from: (1) a 3 to 4 year topsoil stockpile (sandy loam pH 7.7); and (2) an undisturbed site (loamy sand, pH 7.8). A modified plate count method was used. The number of fungal propagules isolated was not significantly different between the undisturbed and stockpiled soil (Table 16). However, the undisturbed soil had a higher diversity of fungal genera and higher evenness (distribution of genera among samples) than the stockpiled soil. A higher diversity of genera generally indicates a more stable soil ecosystem.

In a study reported by Harris and Birch (1987), stockpiles of different ages, depths and soil types were sampled. Total fungal colony counts declined with increasing depth, even in a 3 month old stockpile. In a more detailed study at another site, soil was sampled before stripping and throughout the storage period. Total counts of fungal groups declined immediately after stockpile construction; biomass also decreased after

Table 16. Distribution of Fungal Genera in Undisturbed and Stockpiled Soils, New Mexico. (Fresquez and Aldon 1984).

Fungal Groups	Undisturbed Soil	Stockpiled Topsoil
Acremonium	1	0
Alternaria	1	0
Annellophorella	1	0
Aspergillus	5	13
Chaetomium	2	10
Chrysosporium	0	0
Cladosporium	0	1
Curvularia	15	3
Dreshlera	1	1
Fusarium	7	10
Humicola	5	0
Microascus	0	2
Myrothecium	1	0
Mortiorella	1	0
Mycelia sterilia	0	1
Penicillium	15	44
Phoma	5	0
Rhizopus	5	0
Sepedomium	0	1

continued . . .

Table 16. Concluded.

Fungal Groups	Undisturbed Soil	Stockpiled Topsoil
Stachybotrys	3	1
Thielavia	1	0
Trichoderma	3	0
Unidentified		
Isolate #1	15	0
Isolate #2	3	0
Total no. of isolates	90	87
Total no. of genera	19	11
Fungal genera diversity	1.091	0.689
Evenness	0.853	0.662

construction and steadily afterwards. In contrast, as previously noted, bacterial numbers increased immediately after construction and declined after a few months.

In a study examining microbial populations of topsoil stockpile materials from British opencast coal operations, Johnson et al. (1988) took many samples from the anaerobic zones of 2 and 3 year old stockpiles. They found that for plateable fungi, populations decreased with depth from surface to 2 m. Below 2 m (where soils were anaerobic), numbers declined to a base level of probably inactive propagules. A dual-staining technique revealedthat although there were many fungal hyphae present at 3 m depth, 99% of this material was dead, compared with 90% dead material at the surface.

2.3.5.3 Fungal populations after re-spreading of stored topsoil. The rate of recovery of fungal populations after re-spreading of topsoil depends largely on how rapidly the soil is revegetated. Fresquez et al. (1984) reported that when re-spread topsoil was mulched, fertilized, reseeded, and irrigated, in the arid southwest US, fungal populations rapidly surpassed predisturbance levels. When irrigation was stopped, the fungal diversity and numbers were comparable to that of an adjacent undisturbed site four years after re-spreading.

In the same study, Johnson et al. (1988) also monitored fungal populations after re-spreading of topsoil. They found that 2 weeks after re-spreading the number of fungal propagules had declined, unlike bacterial numbers which initially increased. After 1 year, however, fungal numbers had increased, while bacterial numbers had declined. Biomass calculations confirmed the plate counts: the hyphal biomass proportion of total biomass also increased during the first year.

2.3.5.4 Summary. There is little information available on the effect of storage on fungal populations. However, the limited work done in arid regions of the US indicates that diversity and numbers of fungal propagules are reduced during storage, but both increase rapidly upon re-spreading and are similar to undisturbed soils within a few years. Some changes in species may occur during storage and re-spreading, however. Counts of propagules and diversity also decreased with depth very soon after stockpiling, to very low levels in the anaerobic areas of the topsoil pile.

2.3.6 The Effect of Storage on the Mesobiota in Topsoil

The soil Mesobiota, or "middle life" includes nematodes, earthworms, springtails, beetles, flies and other insects which spend part or all of their life cycle in topsoil. Very little information is available on the effects of topsoil storage for most of these groups. The best-documented group is the earthworms, although they are not generally present in high numbers in Alberta soils.

2.3.6.1 The effect of storage on earthworm populations in topsoil. The importance of earthworms in soils has been evident for many years. Hopp and Slater (1949) reviewed studies indicating that earthworm activity, such as burrowing and channelling, improves soil structure, increases soil aeration and infiltration, and incorporates organic material from the surface into the inorganic soil fraction.

The importance of earthworms in maintaining plant productivity has been discussed by Martin et al. (1988). Work has also been carried out to determine the effect of topsoil manipulation and storage on earthworm populations, mostly in the Midlands coal mining region of Great Britain.

Earthworm numbers and species distribution vary from region to region; some are deep burrowers while others live in the upper regions (0 to 30 cm) of the soil. In general, earthworm populations benefit from high organic matter levels, good drainage, and non-acidic soils (pH>4.5) (Alexander 1977). Populations can be extremely variable (both numbers and species distribution), not only between adjacent fields but within the same field (Martin et al. 1988). They are sensitive to environmental changes in general (Alexander 1977); land use and farm practices are more important in determining earthworm populations and activity than is soil type (Martin et al. 1988). The highest densities of earthworms are usually associated with productive permanent pasture; the lowest with arable land.

In fields under continuous cultivation, earthworm numbers are often very low, particularly for the larger species such as *Lumbricus terrestris*. Where soil moisture is very low in the summer, populations are low due to desiccation (Standen et al. 1982).

Earthworm populations are measured either by hand picking, or by using the formaldehyde method (Armstrong and Bragg 1984). The latter method was used for most of the work reviewed here; it involves pouring a dilute formaldehyde solution over a specific area of soil and collecting the earthworms as they emerge over a specified time, usually one hour.

Hunter and Currie (1956) reported that earthworm activity in soils recently returned to agricultural use after storage was negligible. However, Standen et al. (1982) compared earthworm populations on ten reclaimed storage sites and one topsoil stockpile associated with a coal mine site in County Durham, UK. They found that earthworm numbers in the stockpile were higher than those found on any of the other sites. The authors concluded that the stripping and stockpiling process was probably less hazardous to earthworms than ploughing, cultivating and reseeding. Both shallow- and deep-burrowing types were present in the stockpile.

Abdul-Kareem and McRae (1984) determined earthworm populations in UK stockpiles representing each of three soil textures: (1) sandy (pH 5.3 to 6.4); (2) loamy (pH 6.8 to 7.1); and (3) clayey (pH 6.4 to 6.5). Stockpile ages were from 1.5 years to over 7 years. Pile heights ranged from 3 to 7 m. Anaerobiosis was detected at 1.5 m depth in the sandy soil, at 0.3 to 0.4 m depth in the clay soil, while for the loamy soil the depth at which anaerobiosis occurred was inconsistent. The latter stockpile was likely more heterogeneous than was thought before the experiment began due to incorporation of subsoil and burial of vegetation along with the soil.

At all three sites, earthworm populations were significantly lower for stockpiled soils than for the adjacent undisturbed land.

In a less comprehensive earlier study, O'Flanagan et al. (1963, cited in Scullion et al. 1988) suggested that populations would likely be confined to superficial layers (<50 cm depth). They also reported that worms were not present in the top of a stockpile under study because of severe compaction, but were only present in the stockpile sides. Armstrong and Bragg (1984) suggested that earthworm species colonizing re-spread soils may originate from low numbers surviving in stockpiles in the UK. Allabophora chlorotica, a species associated with wet conditions, may survive within the pile while other species, particularly deep-burrowing earthworms, are less likely to survive such conditions.

Scullion et al. (1988) sampled earthworms at four randomly distributed points along each side and the top of a 3 year old stockpile in Wales. The topsoil was clay loam with pH 7.1. Earthworms were extracted using formaldehyde. Results indicated no significant difference in numbers between the top and sides of the pile, although numbers were generally highest on the south facing side. Few deep-burrowing species were found. Earthworm numbers and weights per unit area in the surface of the pile were 20% to 50% of values in adjacent pastures. Since few worms would have survived below 50 cm from the surface, earthworm numbers in the stockpile may have been reduced to 4% to 10% of their original population. This, however, would likely provide a sufficient inoculum for earthworm re-establishment after re-spreading topsoil.

Martin et al. (1988) assessed the effects of soil stripping and stockpile construction in the UK on earthworm populations, using both the formaldehyde and hand-sorting techniques. Results indicated that both topsoil stripping and placement in the stockpiles caused a reduction of total numbers of earthworms to 20% and total biomass to 2% of the field populations. This equalled a mortality rate of more than 90% on a volume basis. The greater reduction in biomass was partly due to the greater proportion of adults lost compared to immature worms. (Before stripping, 37% of the population were adults, while in the stockpile only 6% were adults). In addition, the large biomass decrease was due to a change in species composition; before stripping, 20% of the population was Lumbricus terrestris, a large bodied species; after stockpile construction no L. terrestris adults were found. More than 90% of the surviving worms were in the sides of the stockpile. Earthworm biomass showed some recovery during storage.

Over the first winter, the total number of earthworms increased to 51% of predisturbance levels and earthworm biomass to 27% of the original though, on a volumetric basis, actual recovery was much less owing to the small surface area to volume ratio. Almost all of the recovery was on the sides of the pile; 15% of the population were adults. Some L. terrestris immatures were present, having emerged from cocoons within 20 cm of the surface. There were no live individuals or viable cocoons below 30 cm depth; however, cocoons in the surface layers remained viable for up to a year.

It is likely that, although earthworms in all stages would be distributed throughout the stockpile during construction, they can only survive in the aerobic zone. There may be some worm movement between the transition and aerobic zones, depending on oxygen availability. This might be largely dependent on soil moisture, texture, and temperature. Shallow and wide stockpiles would maximize earthworm survival, since surface area would be increased.

Impact of soil handling techniques on earthworm populations were studied by Martin et al. (1988) in the UK. Topsoil was stripped from a field with a known population of earthworms in May, using conventional equipment and stored in a conventional mound. The remainder of the field was stripped without compacting the topsoil, using a front loading shovel. The soil was transported by dump trucks and tipped to form a shallow mound, 1 m deep. A low ground pressure bulldozer was used to level the mound following completion of tipping. Both soil mounds were seeded to grass and were managed according to current practices of cutting and applying fertilizer. The two mounds were sampled in September of the same year and 3 years later.

Populations in the normal strip and mound treatment were notably lower than in the low compaction and shallow mound treatment. Populations in the shallow mound was similar in density to populations on the uncompacted sides of the conventional mound. Dominant species were Allabophora caliginosa, Allabophora chlorotica and Allabophora longa in both mounds. For both mounds, numbers for L. terrestris were low.

Martin et al. (1988) concluded that the less disruptive method of stripping and stockpiling enhanced the recovery of earthworm populations. Construction of conventional mounds without heavy trafficking or compaction would also be beneficial. If appropriate methods were also used during soil re-spreading, the population would likely reach original levels more quickly.

Scullion et al. (1988) surveyed earthworm populations in surface soil from a clay loam stockpile after re-spreading. They also compared the effects of subsequent cultivations on earthworm numbers. Soil spreading and levelling caused a further reduction in earthworm numbers from previous stockpile levels, and later site cultivations virtually eliminated surviving earthworms. Thus, cocoons may have hatched immediately after re-spreading, and the immature worms would not have reached reproductive maturity before cultivation disrupted them again. The authors recommended that: (1) direct spreading of topsoil would be preferable to storage; and (2) where storage is necessary, placement of soil from the surface of storage heaps at appropriate spacing throughout the restored area would reduce the distance required for recolonization, so long as cultivation of this "inoculum" is avoided. This would likely allow complete colonization within 5 years.

Martin et al. (1988) also studied the effects of spreading stockpiled soil in the UK. The initial population in the soil mound was determined in March and August 1984; the re-spread soil was sampled in November 1984, March 1985 and May 1986.

In the stockpile, the population was dominated by Allabophora caliginosa, A. chlorotica and A. longa. Most of the individuals (85%) were immatures. Following re-spreading on a unit area basis, the total population was <10% of the previous (stockpile) level. During the winter, the population fell to only 5% of the stockpile level. The authors concluded that soil handling methods caused severe reductions of earthworm populations, particularly L. terrestris. The primary causes were: (1) physical disruptions; (2) compaction; and (3) burial. Thus, although after 2 years in the stockpile earthworm numbers had begun to increase, they decreased again during re-spreading. The authors recommended that either direct placement of topsoil be used and/or surface layers where earthworm numbers are highest be removed separately with minimum compaction. Alternatively, inoculation of newly restored sites should be undertaken after re-spreading and initial cultivation.

Scullion et al. (1988) noted the sensitivity of earthworms to agrochemicals, both fertilizers and pesticides. Earthworm populations, soil granulation and hydraulic conductivity in the top 15 cm of soil were significantly reduced where fertilizer had been topdressed, for example.

To summarize the preceding subsection:

1. Earthworms are beneficial in topsoil, particularly where compaction may be a problem.
2. Earthworm numbers and species composition are reduced during topsoil stripping and stockpile construction, although it appears they may recover slowly if the stockpile is not disturbed.
3. Earthworm activity is limited to the surface layers of the stockpile, likely within 30 cm of the top and sides.

4. Vegetation cover is beneficial for earthworm survival in the stockpile, since it provides nutrition, conserves moisture, and provides shade.
5. Compaction of the top of the stockpile may further reduce earthworm survival.
6. Soil handling procedures during and after re-spreading are critical in earthworm survival after storage. Cultivation, ploughing and other mechanical disturbances, particularly during the first 2 years after re-spreading, significantly reduce earthworm numbers.

2.4 SOIL ZONE

Virtually no information is available on the effect of soil storage on soils of different soil zones or Orders in Alberta or elsewhere. No studies focused specifically on changes in stored topsoil from different soil zones. From available information on soils in Alberta, some comments can be made. Organic matter in topsoils from the Black and Dark Grey soil zones, or of the Black or Dark Grey Chernozemic or Solonetzic Great Groups, may be more resistant to change during long term storage. They tend to have a larger component of humified and partly humified materials which are resistant to decomposition (Dormaar 1975). Topsoils of the Brown soil zone on the other hand have less humified and partly humified organic matter, and may be more readily decomposed during storage.

It is more difficult to speculate on differences between soil zones, in terms of the reaction of the biological soil component to topsoil storage. However, the more strongly structured Chernozemic Ah may be less susceptible to loss of structure and aggregation during storage than A materials of other soil Orders, such as Luvisol or Gleysol.

3. TOPSOIL STORAGE IN ALBERTA

Very little published information exists on the situation under which topsoil is generally stored in Alberta, and the changes taking place during storage. A brief survey was undertaken of both the public and private sectors, of people actively involved in the storage of topsoil. A cross-section of representatives of mining, oil and gas, and other industries was included. None of the information is based on formal experimental or monitoring studies. Rather, it is based on more subjective evaluations of topsoil storage and re-spreading situations by those closely involved in these operations.

3.1 MINING INDUSTRY

Very different procedures are used for strip and open pit mine topsoil handling and storage in different regions within Alberta. Each will be dealt with separately.

3.1.1 Plains Region

Slightly different procedures are currently in use, depending on the specific operations and companies involved. Generally, an attempt is made to re-spread topsoil onto successively reclaimed areas as soon as it is stripped. This minimizes topsoil handling operations considerably, and there is no need for large areas of land to be made available for storage facilities. Possible degradation of topsoil during storage is then avoided. Direct spreading is the preferred method of topsoil handling, from both economic and reclamation viewpoints.

Topsoil must be stored in a number of situations however. Topsoil stripped from the first area to be mined must be stored, since no reclaimed areas are available for direct replacement. Depending on the mine plan, these materials may be stored for the life of the mine, and used to reclaim the last area to be disturbed. Alternatively, it may be stored for two or more years until an area adjacent to the storage area is ready for reclamation. In some operations topsoil stockpiles are used for sight and sound barriers.

Stockpiles vary in size with each situation, and range from 2500 to 50 000 m^3 of material. They are generally constructed using scrapers. Once constructed, they are contoured to allow upkeep, and seeded to a grass-legume mixture. Total amounts of material in storage appear to vary from about 5% of topsoil stripped, to 25%. Most topsoil handling operations are carried out under moist to dry soil conditions. Anaerobic soil conditions in piles at the time of re-spreading were reported in some places. Topsoil is seldom stripped while frozen.

Not all mining operations have re-spread topsoil which has been stored for an extended period of time. Where this has occurred, no differences in crop production following reclamation with stored topsoil were noted, compared to areas reclaimed with direct spread materials. In one case, organic matter levels appeared to be slightly lower than freshly stripped topsoil, but the pH was more favourable to crop production in the stored topsoil. In another case, crop growth on re-spread topsoil stored for 3 to 4 years appeared to be better than on direct placed topsoil. No differences in weed diversity or quantity were noted. No formal monitoring studies were undertaken in either case.

Topsoil stripped from mining roads on the mine site is also stored, usually in smaller stockpiles of 1000 to 5000 m^3, or bermed beside the road itself. In some operations, this is the only situation in which topsoil is stored, the rest being direct placed. It is re-spread when the road is reclaimed, usually in 3 to 5 years. No loss of productivity was reported where roads have been reclaimed with stored topsoil, although compaction of subsoil has caused problems in some places. A relatively small proportion of the mine area is affected in this way.

3.1.2 Foothills Region

Mines in the foothills region use slightly different topsoil handling procedures. Much more of the topsoil is stockpiled compared to operations in the Plains regions. One mine reported that up to 85% of topsoil stripped was stockpiled for 3 to 10 years or more. Stockpiles were reported to vary in size from 10 000 m^3 to 200 000 m^3, depending on individual site characteristics, mine plans and space available for storage. Scrapers, trucks and loaders were used to construct topsoil storage piles.

Topsoil materials are most often moist when stripped and stockpiled, although they can vary from dry to wet depending on season, and recent rainfall events. Occasionally, storage takes place while materials are frozen. None of the mines surveyed had replaced any of the frozen materials, but one operation reported that frozen topsoil materials below the surface of a stockpile had remained frozen 5 years after construction.

One of the mines reported a better grass catch on stored, replaced topsoil, than on direct replaced materials, if the materials had not been stored longer than 2 or 3 years. It was much harder to establish a good grass cover on topsoils which had been stored for 8 to 10 years. Invasion of native species was much better on direct replaced topsoiled areas than on areas with stored topsoil. Similarly, on another mine, very good grass catch was reported on topsoil materials which had been stored for up to 3 years. Some native species were present. When materials which had been stored for longer periods of time were used, revegetation to grasses was much more difficult, often requiring re-seeding two seasons in a row. Fewer native species developed on these areas.

3.1.3 Sub-alpine Region

Because sub-alpine regions have very little actual topsoil coupled with steeply sloping terrain, materials handling procedures are quite different than in either Foothills or Plains regions. One operation for example, limits topsoil salvage operations to slopes of less than 22°, and to materials with less than 25% rock content. Because topsoil usually occurs in relatively small pockets, smaller dozers and trucks are often used to strip, haul, and pile topsoil. Storage is generally necessary. Stockpile sizes varying from 5000 to 100 000 m^3 were reported. They are contoured and seeded to permanent vegetation cover to prevent erosion. Topsoil may be stored for 1 to 20 years. Size and length of time in storage depends on mining plans, area available for storage, and amounts of material to be stockpiled in any given area. Stored materials are often wet, since natural topsoil pockets are most commonly found in low-lying areas. Stripping and stockpiling can also occur when soils are frozen.

Where stored topsoil has been re-spread, no difference in revegetation response was noted by one operation, compared to direct replaced areas. Anaerobic conditions were apparent in stored materials during re-spreading operations. At another mine, materials which had been stored for 2 to 3 years were replaced. Invasion of fewer native species was noted on this area compared to areas which had been direct seeded. No differences in revegetation success between frozen and non-frozen stored materials were noted. No other special reclamation problems occurred on the stored materials.

3.1.4 Northern Forest Region

Large scale mining operations in the northern forest region are restricted to oil sands operations. Very little actual topsoil, defined as A horizon materials, exists in many of these areas. Organic peat layers are salvaged, along with some of the underlying mineral soil, and mixed for use as a top-dressing on reclaimed areas. Direct replacement is the preferred topsoil handling procedure, but it is possible for no more than 25% of the 'topsoil' materials stripped. Most stripping and storage operations are carried out in the winter, under frozen soil conditions, and stored materials often remain frozen below the surface layer of stockpiles. Diesel and electric shovels, dozers, and trucks are used for stripping and stockpiling operations.

Materials may remain in storage for up to 25 years. Little has been re-spread to date. Where it has occurred, no special revegetation problems were noted. Good regrowth of native species occurred even on materials which had been stockpiled for 10 years.

3.2 OIL AND GAS INDUSTRY

Topsoil salvage and replacement on land disturbances has been a requirement in Alberta's oil and gas industry for more than a decade. A very large number of operators are involved in construction and reclamation operations, many of them relatively small companies. As a consequence, a large number of different methods are in common use. Some are much more effective than others.

Information in the following sections has been derived from conversations with workers directly involved in field operations. Representatives of both industry and governmental monitoring agencies were included. All information is of a subjective nature. None is based on formal monitoring or experimental studies.

3.2.1 Conventional Oil and Gas Wellsites

Two methods of topsoil handling and storage are commonly used on conventional oil and gas wellsites in the province. In cultivated areas, only the well centre and vehicle turn-around area remain uncultivated, once the well is in production. Topsoil stripped from the well centre and turn-around, usually less than one third of the lease, is feathered out over the rest of the restored lease area, and returned to the landowner for normal cultivation or seeding to pasture. This situation is illustrated in Figure 1.

This method of storage is probably optimal for limiting degradation of topsoil quality during storage. Since materials are not stockpiled, anaerobic conditions and possible changes in soil quality associated with it are unlikely to occur for extended periods of time. Normal farming practices or seeding to forages will keep nutrient and organic matter cycling systems in the topsoil operational. Erosion will be no different than on adjacent lands. Soil biota, seeds and plant propagules will remain at normal levels.

Problems were reported when final reclamation of the lease occurs once the well is abandoned, as long as 20 years later. If the adjacent lease area upon which topsoil has been stored has been revegetated, companies are often hesitant to disturb it in order to replace topsoil on the lease and turn-around area. Landowners often do not want topsoil stripped from what has

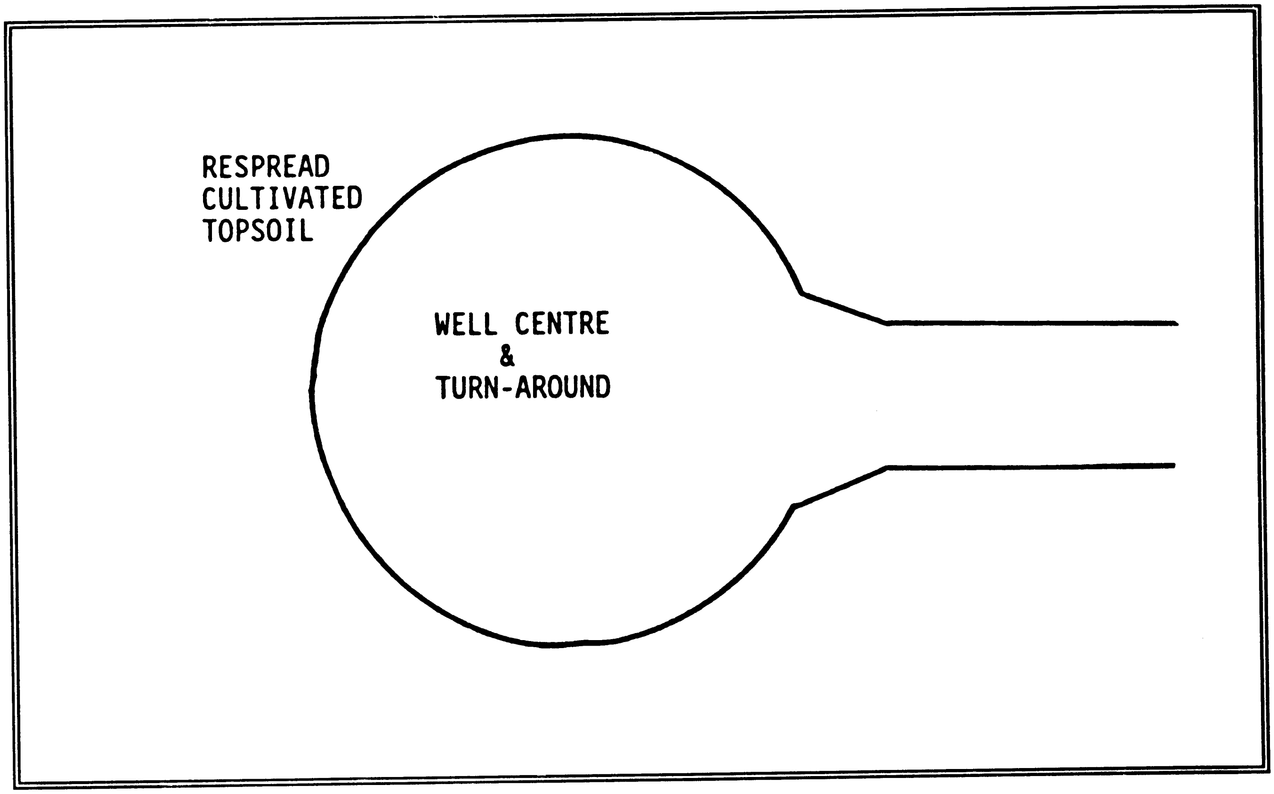


Figure 1. Topsoil from Well Centre and Turn-around Feathered Out Over the Lease Area.

become their normal field. Well centres can end up with thin or no topsoil-cover as a result, and final restoration must be carried out using topsoil from another source, or with other soil amendments. For this reason, topsoil storage in an easily identifiable, designated area is often preferred.

A second method is commonly used when well lease areas are to be fenced, or otherwise to remain uncultivated for the lifetime of the well. In this case, stripped topsoil is stored in low berms 1 to 2 m high, on the outside edges of the lease area (Figure 2). Depending on the amount of material to be stored and physical characteristics of each site, berms may be built on one or more sides, and will vary considerably in size. Usually they are constructed outside any barriers or ditches built to contain oil or

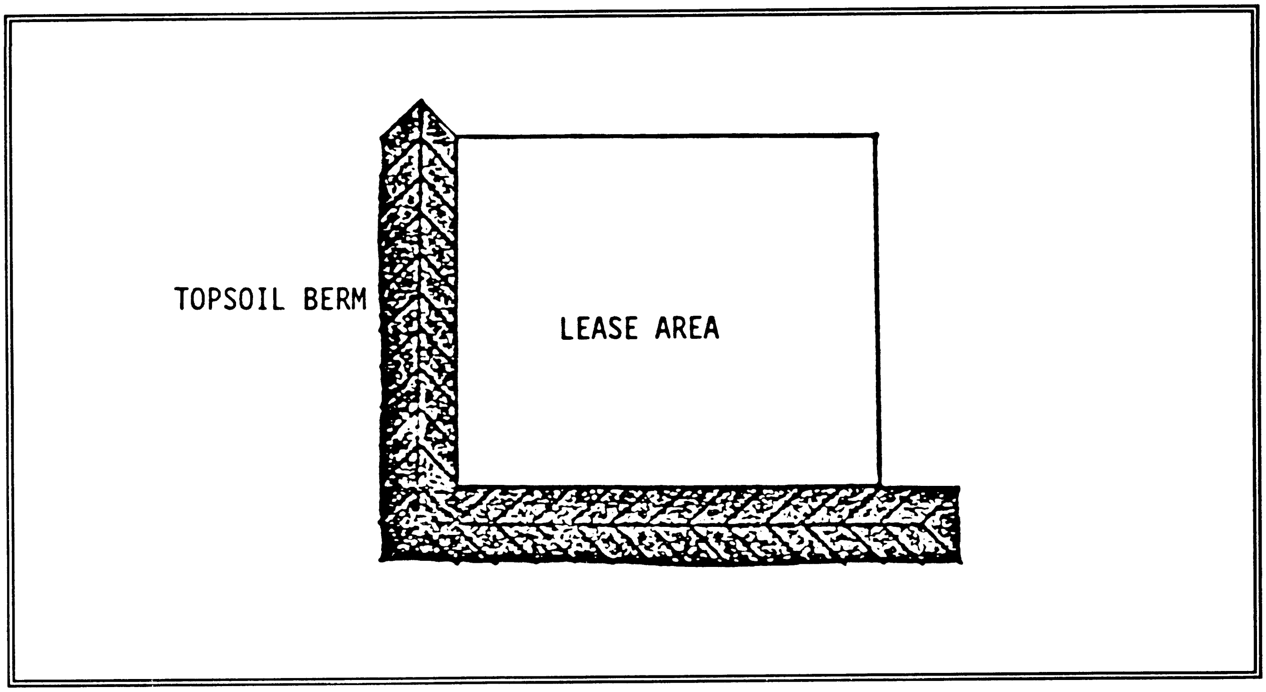


Figure 2. Topsoil Bermed Around Leased Area

chemical spills, so that potential damage from these causes are minimized. A few cases of topsoil being used as containment berms, and resulting contamination were reported however.

Berms are normally contoured and seeded to a grass mixture. Sometimes the landowner is able to farm up to the top of the berm, as illustrated in Figure 3. This method avoids problems of stripping topsoil from the adjacent restored lease area, since the location of stored topsoil is obvious. Soil biota and organic matter cycling systems in the berms are disrupted to a greater degree however.

On some of the larger leases, berms are occasionally designed to control runoff and are situated so that water will pond against them. In this case waterlogging could create anaerobic conditions within the berm, resulting in possible topsoil degradation if stored for periods longer than a few years.

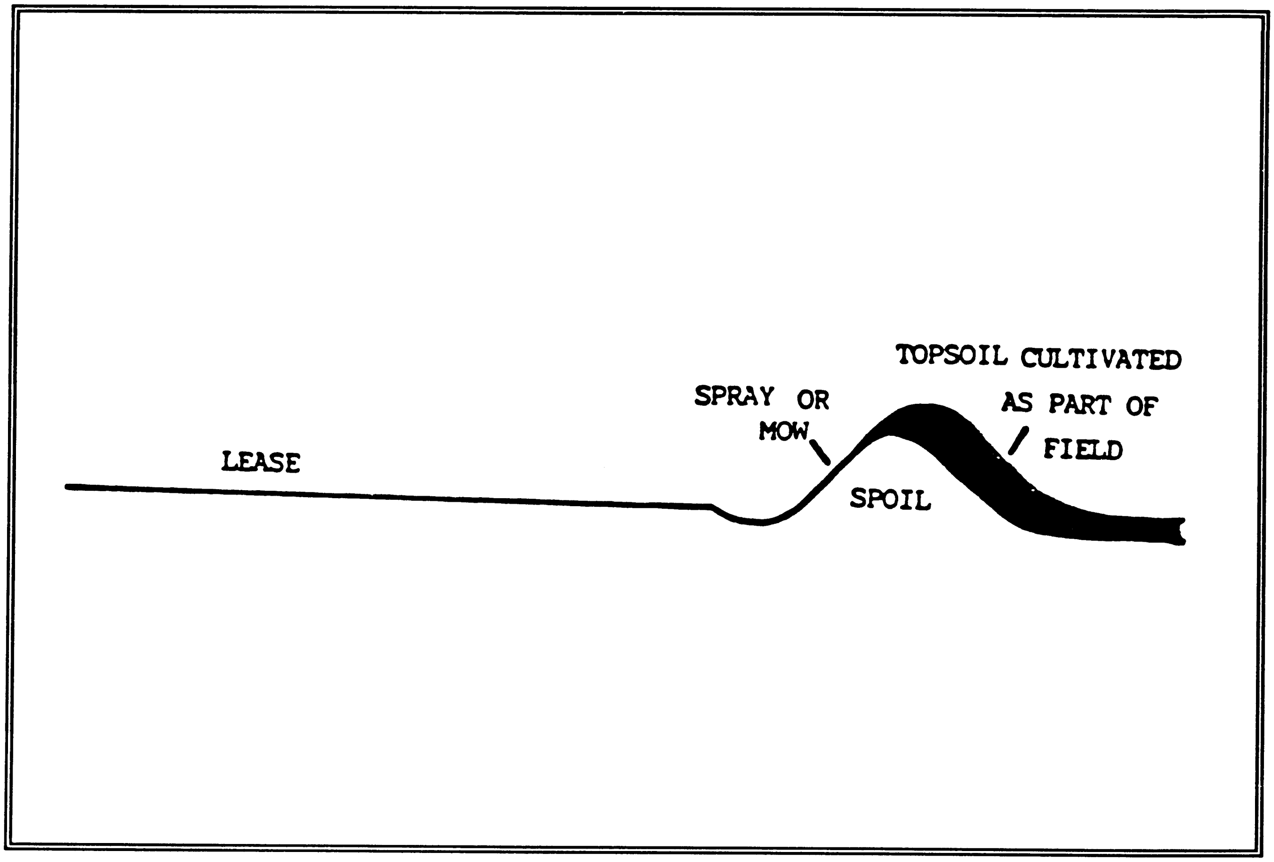
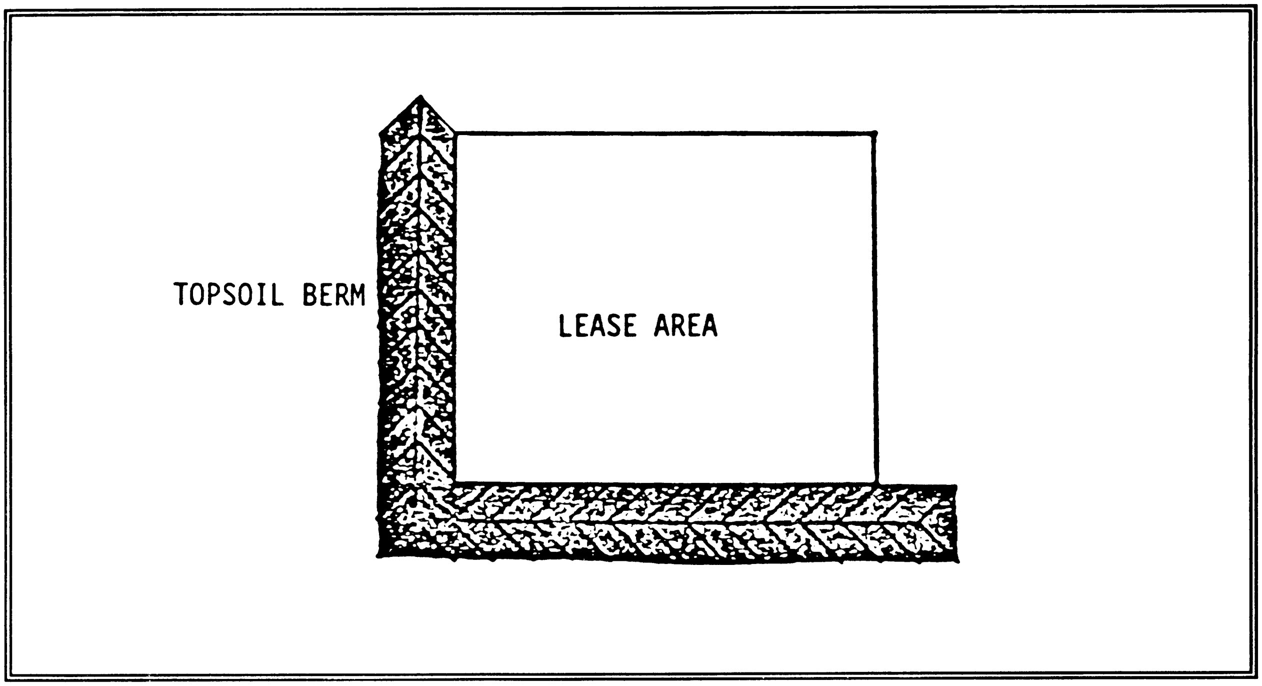


Figure 3. Berm Cultivated as Part of Field

Very few sites with bermed topsoil storage have been restored to date. Where restoration had taken place, no reclamation or revegetation problems were reported, although material had been stored for a few years only.

Other, more controversial methods of storage have been used as well. Burial of topsoil in pits on site has occurred. Generally, if pits are not below the seasonally high water table or its capillary fringe, and if soils surrounding buried topsoil are not saline or sodic, degradation of stored materials may be restricted to physical changes. Locating the topsoil when the site is to be reclaimed, some years later, may pose a major problem, unless storage pits are surveyed in, and located on plans of the lease.



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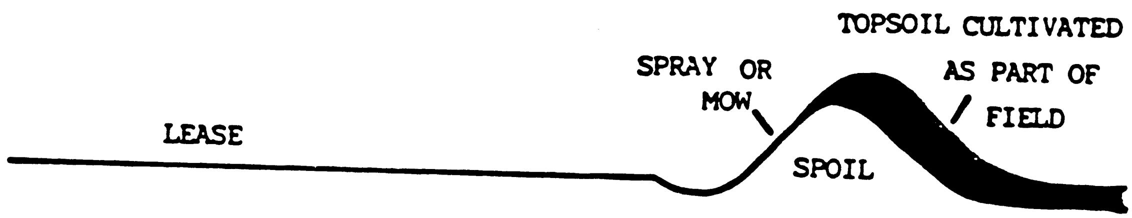

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Occasionally, topsoil is spread over adjacent non-leased lands with the permission of the landowner. Without legal access to these areas, chances of topsoil being replaced after abandonment are not good. On older sites constructed before there was a legal requirement for topsoil salvage, original topsoil may have been lost be mixing with subsoil or by burial.

3.2.2 In Situ Heavy Oil Leases and Plant Sites

In situ heavy oil operations are similar to standard wellsites, but leases are far larger in area. On some, topsoil is stripped and stockpiled as in a mine situation, but on a smaller scale. On others, it is bermed as on a standard wellsite. In at least one case, sight and sound barriers have been constructed from stored topsoil materials. Storage periods may be 25 years or more. Berms and storage piles are seeded to permanent grass cover. Larger lease areas have been obtained in some cases to allow the re-spreading of stripped topsoil directly onto an adjacent leased but farmed area. Because the extra area is retained for the life of the lease, it is hoped that problems of salvaging topsoil from a cultivated storage area will be avoided when restoration is required. None of these sites have been reclaimed yet, so no information is available on soil quality after re-spreading of stored materials.

3.2.3 Plant, Battery and Compressor Sites

Plant, battery, compressor, and other similar sites are similar to in situ heavy oil leases in that topsoil is usually stored either in stockpiles or as berms. Occasionally, stripped topsoil is feathered over unused portions of the site and farmed. Berms and stockpiles are often seeded to forage mixtures and mowed. Sometimes they are allowed to revert to weeds. Topsoil burial in pits, as on wellsites, has occurred also.

Most of the sites which have been restored were constructed before topsoil salvage and replacement were a requirement. Consequently, few observations have been made concerning loss of topsoil quality due to length of time and methods of storage.

3.2.4 Access Roads

Access roads are required into most oil and gas leases and many plant, battery, and similar sites. Usually the right of way is leased from landowners. Topsoil salvage and storage for use in reclamation of the road once the site is abandoned, are required by law. Materials must be kept in storage for the lifetime of the site, which can range from several to 20 or 30 years.

Topsoil stripped from access roads is stored in a number of ways. It can be stripped, bermed and revegetated on one side of the right of way. Occasionally, it is farmed through, with subsequent lowering of the pile every time a tillage operation takes place. Alternatively, it may be used to construct ramps and fill ditches (Figure 4). This procedure has the disadvantage that the exact location of topsoil may not be apparent many years later when the road is abandoned. Topsoils are subject to erosion, and contamination with runoff from leases or fields. Materials used for ramps are subject to severe degradation of soil physical properties.

Roads may also be constructed directly on the topsoil, with the addition of gravel to the surface. Resulting compaction, loss of soil structure, changes to water holding characteristics, and other physical properties will cause a loss of topsoil quality when the material must be restored and revegetated. Removal of added gravels from topsoil is virtually impossible once the road is subject to regular traffic.

3.3 SAND AND GRAVEL OPERATIONS

Methods of topsoil handling and storage in the sand and gravel industry vary with the size of operation, its location, and the amount of topsoil available for stripping. On larger, regulated pits, topsoil is generally stored in stockpiles, as in mining operations. Direct placement is sometimes used when suitable sites are available for re-spreading. Piles are routinely contoured and reseeded to a grass mixture. Once stored, materials may remain in storage for the life of the pit, up to 20 years. In some situations, there is insufficient topsoil to warrant salvage. No information was available on soil quality or revegetation success of stockpiled topsoil materials compared to freshly stripped materials.

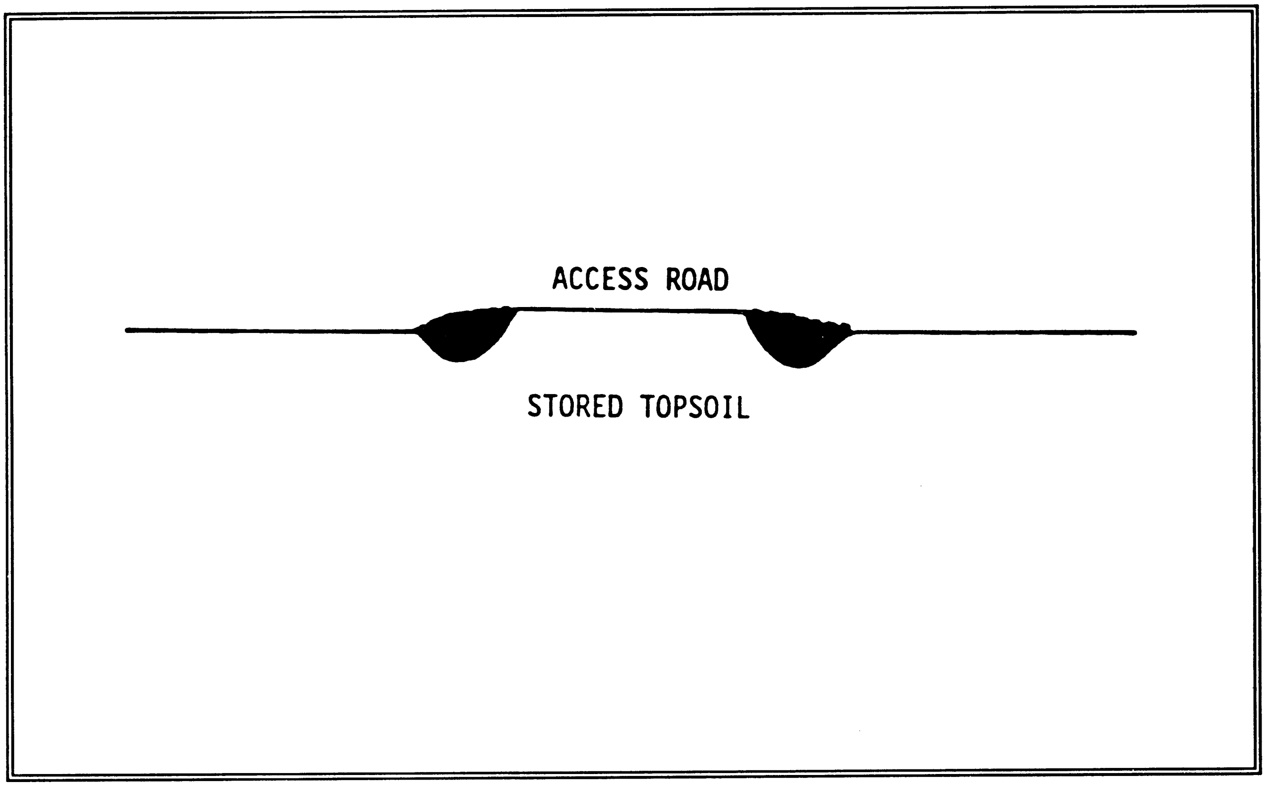

Figure 4. Topsoil Stripped from Access Road, Stored in Ditches.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Information on the effects of storage on topsoil has been derived from a large number of studies, carried out in areas of diverse climate, soils, vegetation and soil biota. Many studies were carried out under climatic and environmental conditions which are very dissimilar to those in Alberta. At times, results of similar studies are apparently contradictory. Problems inherent in the methodologies for studying such a diverse population as soil flora and fauna often result in lack of comparable data. Many studies suffered from a lack of good controls which prevented a true comparison between undisturbed and disturbed conditions.

Very little experimental or monitoring information is available, specifically for Alberta. Studies which have taken place in the province relate to very specific climatic, soil and vegetation conditions. Therefore, most of the information on Alberta conditions included in this report is of a very subjective nature.

Despite the relatively disappointing representation in the literature, conclusions for the storage of topsoil can be drawn. Generally speaking, topsoil storage, specifically in stockpiles, does not appear to have any severe and long term effects on topsoil quality. Chemical changes such as possible loss of nitrogen, other nutrients or organic matter can be rectified in most cases with the judicious use of fertilizers or manure following re-spreading. Changes in the physical properties of topsoil during storage in stockpiles appear to be potentially less serious than changes which can take place during stripping and re-spreading operations, particularly if these are carried out under sub-optimal conditions resulting in undesirable compaction or mixing.

Changes to the biological component are more complex and potentially more serious. Even here, however, it appears that soil biota revert to pre-disturbance levels of activity within a few years. The presence of mycorrhizal fungi in replaced topsoil may be important in the rapid and effective re-establishment of native vegetation in the drier areas of the province. As viability of these organisms decreases with time in storage, areas reclaimed with stored topsoil may require inoculation with freshly stripped materials or from topsoil stripped from the surface of the stockpile.

Viability of native seeds and other plant propagules in stored topsoil, important where native vegetation is to be re-established, appears to decrease quickly if materials have been stored longer than 2 or 3 years. This conclusion, drawn in several studies from different parts of the world, appears to hold true in Alberta as well, based on subjective observations of several mining operations in the province. An exception may be where stripped materials remain frozen for the entire storage period, although this conclusion must be backed up with scientific data before being accepted as fact.

No rigorous studies have been carried out on the effects of topsoil quality when it is thinly spread and cultivated; or stored in small berms. Both these methods are in common use in the oil and gas industry in Alberta. The literature suggests, however, that both have low potential for soil degradation, since anaerobic conditions are avoided, and nutrient and organic cycling systems are retained. The topsoil storage problem with these methods may relate more to other factors such as ease of locating materials when required, and possible contamination with oil or other chemicals, than with changes which may occur due to storage per se. This is more of a loss of quantity than a loss of quality concern.

4.2 RECOMMENDATIONS

A number of recommendations for topsoil storage in Alberta have resulted from this review. These are:

1. **Wherever possible, topsoil should be directly re-spread after stripping, using successive reclamation.** Some microbial populations like bacteria and fungi appear to increase in size to undisturbed levels very quickly after re-spreading. A lag of several years for other micro-organisms and mesobiota populations to return to normal levels seems common. As soil organisms are closely tied to organic matter degradation, nutrient cycling

systems and soil structure development, initial revegetation efforts can be affected by changes to the biological component of the soil during storage and re-spreading. Subjective information from operations in Alberta would indicate that this does not constitute a major reclamation problem.

2. **Storage time of stockpiled materials should be kept to a minimum, particularly where survival of native species is a priority.** The shorter the time in storage, the better the chances that seeds and rhizomes in the soil will survive. In dry areas of Alberta, topsoil should not be stored longer than 2 years if Mycorrhizal Infectivity Potential (MIP) is to be maintained. In some situations, such as where it is critical that particular plant species be established quickly after reclamation, direct placement of 5 cm of freshly stripped topsoil over re-spread, stored topsoil may act as a mycorrhizal inoculum. Alternatively, separate storage of the upper topsoil layer (0 to 10 cm), will avoid dilution of mycorrhizal populations.
3. **Topsoil handling and disturbance of topsoil in stockpiles should be kept to a minimum.** These operations should not be undertaken under wet soil conditions. Mycorrhizal infectivity and mesobiota such as earthworms are particularly susceptible to mechanical disturbance, including such minor disturbances as discing or regrading sides of stockpiles. Changes to the physical properties due to compaction, mixing with subsoil, loss of structure, and changes to soil water holding characteristics before and after storage may cause more topsoil degradation than the actual storage in stockpiles. It is likely that other soil animals would be sensitive to stockpiling though lack of data does not allow us to say if such changes might be significant in the long term.

4. **Stockpiles should be seeded and a vegetative cover maintained at all times.** Vegetation should include species known to be mycorrhizal. This not only provides protection against erosion, but also promotes biological activity and encourages nutrient cycling.
5. **In areas to be restored to native vegetation, particularly in the drier areas of the province, agro-chemicals should be used with extreme caution on stored topsoil, and their use should be recorded.** Low to moderate levels of fertility, particularly phosphorus, are optimal for mycorrhizal development. High levels of fertilizer application appear to inhibit earthworm activity. Pesticides and herbicides will adversely affect soil biota, particularly mycorrhizal fungi and mesobiota.
6. **In native pasture, gravel pits, mining areas, and forested areas, a wide, shallow storage configuration appears to be best for seed and rhizome survival, bacterial, fungal and mesobiota activity and propagation, and access for seeding and weed control.** In general, anaerobic conditions common to the centre of large piles should be avoided because of adverse effects to soil biota, seed viability and nutrient availability. Figure 5 shows a schematic cross section through a topsoil store (after Harris and Birch 1988). The depths of the three zones - aerobic, transition and anaerobic - will depend on the size of the pile, soil texture, structure, bulk density, moisture content at the time of storage, and climate. In dry areas, if topsoils are stored when dry, piles can be much larger than in more humid areas, or if soils are stored when wet.
7. **In cultivated agricultural areas, if topsoil stockpiles will exceed a duration of 1 year, it is preferable to re-spread topsoil over an adjacent farmed area for storage.** This appears to have more potential for maintaining quality during storage than stockpiling. This method also benefits weed control mechanics. Restoration must be worked on a site by site basis, provided

there is no chance stored topsoil materials can be contaminated with oil, sterilants or other chemicals. However, all such stockpiles should be surveyed and recorded so that quantities thus stored can be effectively recovered.

8. **In industrial plant sites where stockpile duration is long term, re-spreading topsoil for farming use or developing wide, shallow stockpiles for site landscaping appear to be the most applicable storage systems.** Careful records of topsoil storage locations should be generated and kept on file to facilitate its recovery for reclamation.

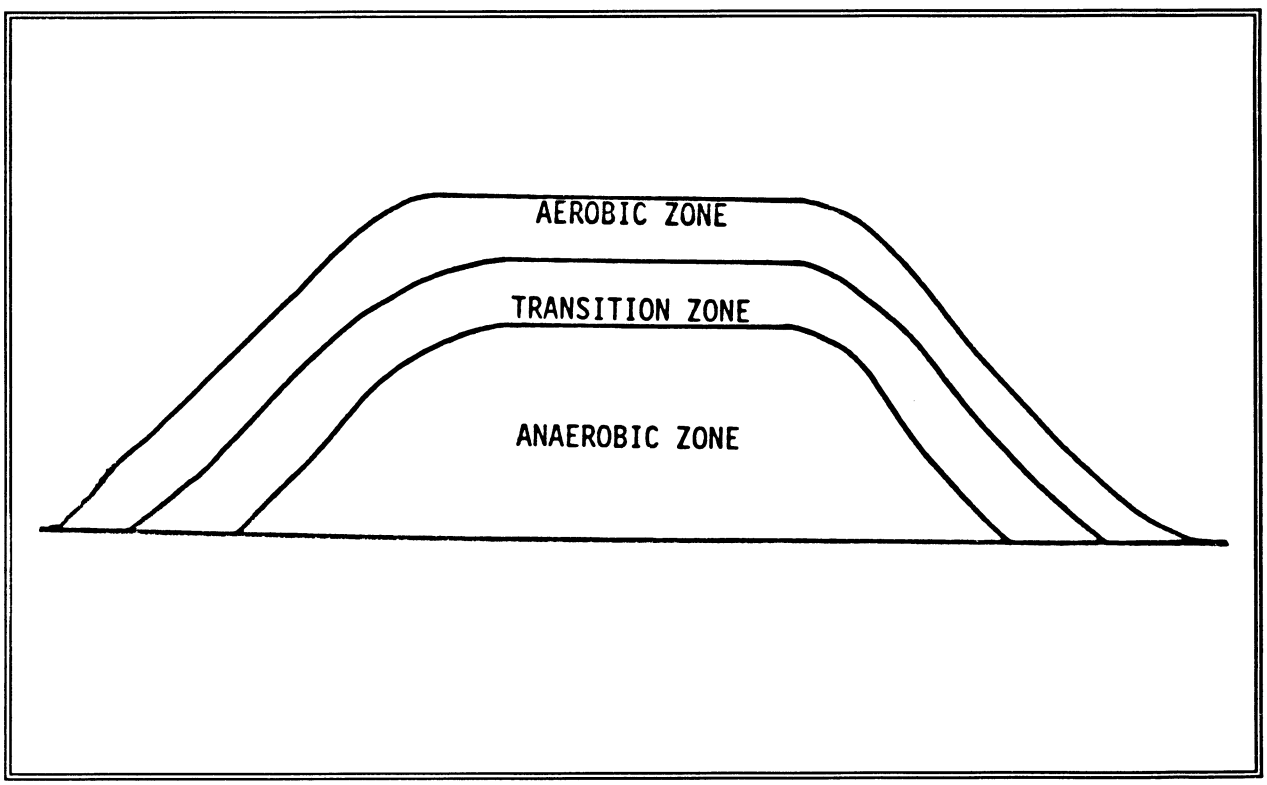

Figure 5. Topsoil Stockpile Schematic Cross-Section (after Harris and Birch 1988).

9. Berms left for more than a few weeks should be given a grass/legume cover to prevent erosion and to encourage organic matter build up and nutrient cycling.

10. For large stockpiles where, through time and lack of aeration, mycorrhizal populations have been virtually eliminated, consideration should be given to reinoculation with strains of mycorrhizae after topsoil spreading. This may significantly improve plant growth.

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6. RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes (one at Caw Creek Ridge and two at Cadomin). Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. $10.00**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

4. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

5. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

6. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

7. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

8. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

9. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

10. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

11. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

12. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

13. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

14. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

15. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

16. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

17. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

18. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. $10.00**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

19. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

20. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

21. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

22. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

23. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

24. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

25. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

26. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

27. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

28. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

29. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

30. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. $10.00**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

31. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

32. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

33. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

34. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

36. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

37. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

38. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

39. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

40. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. $10.00**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

41. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

42. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

43. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. $10.00**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

44. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

45. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

46. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. $10.00**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

47. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

48. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

49. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

50. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. $10.00**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

51. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. $5.00**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

52. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

53. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

54. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

55. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. $10.00**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

56. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

57. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. $10.00**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

58. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. $10.00**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

59. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. $10.00**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

60. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

61. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. $5.00**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

62. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

63. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

64. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. Moran, S.R., T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.