Use of Crop Selection and Cattle Manure to Bioremediate a Heavy Oil-Polluted Loamy Sand for Grain Production*

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ABSTRACT

The study reported here is an offspring from a 6-year field study near Maidstone, SK that was originally designed to assess the feasibility of utilizing a heavy oil production waste to improve erodible, sandy cropland through oil-induced stable soil aggregation and microbial conversion of hydrocarbons into humus. In one of our two plot experiments on a Meota loamy sand initial soil oil contents in the top 10 cm were much higher than anticipated, i.e. 7.0% and 3.0% instead of the targeted 1 and 2%, inadvertently rendering that experiment into an 'oil spill remediation' study. Early attempts to remediate the 'overoiled' soil with more tillage and greatly increased N + P + S fertilization failed to improve soil conditions enough to allow any crop growth. Thus we focused on screening for crops with higher tolerance to oily residues and on amending the polluted soil with an application of 63 tonnes (t) dry wt/ha of old cattle manure, containing 20 t OM/ha with a C/N ratio of 10.5. The main objectives of our study were (i) to assess the restorative ability of manure for soil properties critical to plant growth, and (ii) to measure manuring benefits for grain production by more oil-tolerant crops. Greenhouse and field tests indicated that cereals, as a group, are less sensitive than pulses, forages and oilseeds toward oily residues in soil. Among the cereals, oat was by far the most tolerant crop with wheat a distant second but well ahead of barley and rye. Within 4 months of manure incorporation there were marked improvements in soil properties that are indicative of soil quality and productivity. In unfertilized plots manuring effected a 20% reduction of the erodible fraction (<0.84 mm), 30% increase in waterstable aggregates, 20% decrease in bulk density, 56% increase in hydraulic conductivity and a 131% increase in viable bacteria. The effectiveness of manure in improving soil conditions was found to decrease with increasing rates of previous fertilizations. One year later, the overoiled plots were seeded to oat and wheat but due to extensive damage by grasshoppers only manure effects on emergence and vegetative growth up to flowering could be

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measured. In unfertilized plots manuring increased oat plant density by 53% and DM production by 150% relative to the unmanured check. Corresponding increases with wheat were 55% for stand density and 65% for biomass production. Stand densities and vegetative growth in overoiled, but manured, plots were very similar to those of unoiled controls emphasizing the effectiveness of a single manure application in restoring crop productivity to a heavy oil-polluted soil. Two years after soil incorporation of manure all plots were seeded to oats that were grown to maturity. When averaged across fertilizer treatments, manuring resulted in a 55% increase in plant density, 70% increase in crop biomass and an 82% increase in grain yield. There was also a significant positive interaction between manuring and earlier fertilizations in enhancing oat growth and particularly grain yield. On manured, but unfertilized plots the grain yield was 32% greater than on the corresponding unoiled and unmanured plots which attests to the restorative ability of decomposed cattle manure for cereal production. Manuring was also found to improve grain quality by maintaining protein levels and by markedly increasing kernel size and test weight of the oats. Thus we can conclude from this field study that a single application of old manure can be very effective in improving critical soil properties and, in turn, restoring the oil-polluted topsoil to full productivity in terms of grain yield and quality within one to two years.

INTRODUCTION

When oil spills happen in the Prairie region they frequently occur in or near fields of annual crops such as cereals, oilseeds and pulses. When a spill is rated as ‘medium’ (i.e. >4% oil in topsoil) or ‘heavy’ (i.e. >8.5% oil in soil) the affected area must be treated or it will remain unproductive for years (Toogood and McGill 1977). Spill studies in Alberta demonstrated that crop yields can be restored but only if microbial activity in the polluted soil is stimulated by frequent tillage and massive applications of fertilizer nutrients (Toogood 1977; McGill et al., 1981). However, there are instances, including the present study, when tillage and fertilization have failed to remediate polluted cropland in a timely fashion.

The study reported here is an offspring from a 6-year field study by Agriculture and Environment Canada with P.E.R.D. funding to assess the feasibility of utilizing heavy oil production wastes for protection and potential improvement of erodible, sandy cropland in northwestern Saskatchewan. Originally this research was focused on improving marginally-productive, arable land through oil-induced stable soil aggregation and microbial conversion of hydrocarbons into humus rather than to emphasize industrial disposal goals.

We found that a single application of a heavy oil sludge and incorporation into Meota loamy sand, at 1 to 2% initial soil oil contents, effected large increases in size and stability of aggregates (Rasiah et al., 1997) and eventually resulted in an average gain of 35 tonnes (t) of humus per hectare (ha) without any residual oil in soil or migration of organic pollutants into the groundwater (Biederbeck et al., 1993). It seems that many of the >3 million ha of cultivated sandy soils on the Prairies could benefit from improvements in soil structure and humus content that can be realized by incorporation of organic, including petro-type, wastes (Biederbeck et al., 1997). However, in one of our two plot experiments initial oil contents in the top 10 cm of soil were much higher than anticipated, i.e. 7.0% and 3.0% instead of the targeted 1 and 2%, inadvertently rendering that experiment into an 'oil spill remediation' study. At first we attempted to remediate the 'overoiled' soil with more frequent tillage and greatly increased N + P + S fertilization but these practices failed to improve soil conditions enough to allow any crop growth. Thus we focused subsequent reclamation efforts on screening for crops with greater tolerance to oily residues and on amending the polluted soil with a massive application of old cattle manure, because livestock manures had already been shown to be more effective than chemical fertilizers in restoring productivity to artificially eroded soils in western Canada (Dormaar et al., 1988; Larney and Janzen 1996). The main objective of our spill remediation study was, therefore, to assess the restorative ability of manure for those soil properties that are critical to plant growth and for grain production by more tolerant crops on an oily waste-polluted loamy sand.

MATERIALS AND METHODS

Details of experimental design, research methodology and sampling techniques were as described previously by Biederbeck et al. (1993). In June and September 1986, two plot experiments were established on 2 ha of Meota loamy sand (Black Chernozemic soil) 10 km southeast of Maidstone, SK. The topsoil (0-10 cm) at the site had the following main properties: 80% sand, 9% silt and 11% clay; pH=5.8, EC=0.54 dS/m, BD=1.31 g/cm^3, CEC=5 meq/100g; 2.20% organic C, 0.184% total N and a C/N ratio=12.0 prior to oily waste sludge application. In both experiments, the same 3 sludge (00=none, 01=300 and 02=600 tonnes/ha) and fertilizer rates (F0=none, F1=150 kg N + 15 kg P + 24 kg S, and F2=300 kg N + 30 kg P + 48 kg S/ha) were applied to reach targeted waste loadings of 1.0 and 2.0% oil in soil (wt/wt), respectively. The EOR sludge was hauled from Husky's Fireflood Plant #4 near Maidstone. All 9 sludge x fertilizer combinations were replicated 3 times on 27 plots (4 x 14 m) per experiment. Fertilizer was broadcast and then sludge was applied and incorporated to 10 cm depth with a modified rotovator connected through its Bowie pump to a tank truck running alongside. Soils in all plots were sampled hydraulically to 120 cm depth just before sludge application in 1986 and then each spring and fall for routine physical and chemical analyses. The surface 10 cm were sampled manually for soil structural, biochemical, microbiological and hydrocarbon analyses.

In the first experiment, initial oil contents averaged 1.0 and 1.5% of soil in 01 and 02 plots, respectively. However, in the second experiment, initial oil contents were much higher averaging 7.0% in 01 and 3.0% in 02 plots due to extreme variability in oil content of EOR sludge from one truckload to another. In the plots with 7% oil content, and where no plants could grow in 1987, the soil was rototilled more often (fall and spring) and the fertilizer rate was increased in April 1988 to F4=600 kg N + 60 kg P + 96 kg S/ha to attempt remediation of the polluted soil.

During the winter of 1987/88, greenhouse tests were conducted to assess the response of various agricultural crops to soil-incorporated EOR sludge using bulk samples collected from 00, 01 and 02 plots of the second experiment in October 1987. Average oil contents of samples from 01 and

02 plots were 5.0 and 2.2%, respectively. Test plants included forage grasses and legumes, cereals, oilseeds and pulse crops. On May 17, 1988, each plot in the second experiment was divided along the length into 5 subplots (2.8 m x 4 m) and seeded to the following 5 annual crops, that had shown promising results during the earlier emergence tests in the greenhouse:

1) spring wheat, cv. Katepwa, at 82 kg/ha
2) oats, cv. Calibre, at 57 kg/ha
3) barley, cv. Leduc, at 68 kg/ha
4) spring rye, cv. Gazelle, at 61 kg/ha
5) field peas, cv. Trapper, at 178 kg/ha.

At maturity a 1.0 m^2 area was hand cut in each subplot for subsequent threshing and yield measurements.

In 1989, all plots were summerfallowed, receiving a total of 4 tillages: rototilling in spring and fall and cultivating twice in summer for weed control. On May 17, 1989, a mixture of well rotted barnyard manure and sand from a nearby farm was applied with a manure spreader to half the width of each of the nine 'overoiled ' 01 plots in the second experiment and was incorporated to 10 cm soil depth with the rotovator. A total of three loads of manure were used and subsequent sampling of the surface-spread material on all plots, prior to rototilling, indicated an average application of 97 tonnes wet weight or 63 tonnes dry weight or 20 tonnes of organic matter/ha. This well aged (>3 yr) cattle manure had an average C/N ratio of 10.5, indicating that it had undergone extensive decomposition. On May 18, 1990, half the length of each plot in the second experiment was seeded to wheat, cv. Katepwa, at 86 kg/ha and the other half to oats, cv. Calibre, at a rate of 88 kg/ha. A very severe grasshopper infestation after mid-June caused progressive crop damage, despite repeated spraying with deltamethrin. Thus plant dry matter of both cereals, when sampled at flowering, was markedly reduced and there was not enough grain left to harvest any plot at maturity. In spring 1991, all plots were seeded to oats and, with frequent and timely applications of various insecticides and border planting of deterrent crops, reasonable grasshopper control was eventually achieved. In late August, m^2 samples of oats were collected from the manured and unmanured halves of each plot for determination of plant populations, dry matter production, grain yield and grain quality.

RESULTS AND DISCUSSION

The effects of oils on plant growth can range from kill on contact and other direct physical damage, such as inhibition of seed germination, to growth reductions from indirect effects due to changes in soil moisture retention, reduced nutrient availability and development of anaerobic conditions and on to stimulation of growth at very low concentrations of hydrocarbons (Deuel 1990). The degree of toxicity also depends on the chemical nature of the hydrocarbons and generally decreases with an increase in molecular size and viscosity (McGill et al., 1981). Thus fuel oils are more phytotoxic than unrefined oils or heavier sludges.

Crop Selection for Tolerance to Oily Residues

The response of various crops to the previously soil-incorporated EOR waste sludge was assessed in the greenhouse by placing bulk soils, collected from the top 10 cm of selected plots at 13 months after sludge application, in wooden trays and measuring the relative rate of emergence on test plants

Table 1. Emergence of ten test crops in Meota loamy sand containing an average of 2.2% (02F2) and 5.0% (01F2) oil, when removed from plots for plant assays in the greenhouse.

Plant type and cultivar	Relative Emergence (% of unoiled soil)†	
	02F2	01F2
Sweetclover, cv. Norgold	0	0
Alfalfa cv. Rambler	137	49
Crested Wheatgrass, cv. Parkway	88	15
Bromegrass, cv. Carlton	150	75
Red Clover, cv. Norlac	88	31
Canola, cv. Tobin	37	1
Wheat, cv. Katepwa	83	71
Pea, cv. Trapper	188	37
Oat, cv. Calibre	120	82
Barley, cv. Klages	120	85

† Each number is the mean of three replicates per treatment

seeded at recommended rates and at optimum depth and then maintained at optimum soil moisture (field capacity). The cultivars of forage and field crops tested were chosen according to published recommendations from Saskatchewan Agriculture for crop production in the Black soil zone. Final seedling counts, as a percentage of those in the unoiled control soil, are shown in Table 1. At the
2.2% soil oil content, the effects ranged from complete inhibition of germination (sweetclover) to stimulation (alfalfa, bromegrass, pea, oat and barley). At the high oil level (5.0%), germination of all crops, except pea, was reduced and among the cereals only oat and barley emerged at a rate greater than 80% of the control. At both oil contents, canola had the lowest tolerance of any annual crop (Table 1). In a second test fungicides were used to prevent soil-borne diseases and then oat was the only crop able to germinate and emerge at both soil oil contents while wheat emerged well at 2.2% oil and pea, which appeared so tolerant in the first test, was severely inhibited (data not shown).

To further explore the issue of plant tolerance to oily residues, five annual crops with promising results from the greenhouse tests were evaluated under field conditions on the overoiled plots near Maidstone, SK in 1998. Analyses of soil samples, taken from these plots in spring 1988, indicated that oil contents in the top 10 cm averaged 2.1% (range 1.7 to 2.5%) in 02 and 4.6% (range 2.8 to 6.1%) in 01 plots prior to seeding the five subplots per plot. All yield data for grain and straw were averaged across the three fertilizer rates and are expressed as a percentage of the corresponding yield in the unoiled control plots (Table 2). The main conclusion from these results is that under field

Table 2. Yield of five annual crops grown on 'overoiled' plots of Meota loamy sand in the drought of 1988 (i.e. 2 yrs after heavy oil sludge application).

Avg. topsoil oil content in April 1988 (%)	Relative yield (% of unoiled treatment)†		
	Total biomass	Grain	Straw
	Barley		
2.1	8	8	8
4.6	0	0	0
	Oat		
2.1	150	171	142
4.6	4	6	3
	Pea		
2.1	0	0	0
4.6	0	0	0
	Rye		
2.1	2	2	2
4.6	0	0	0
	Wheat		
2.1	28	28	28
4.6	0	0	0

† Each number is the mean of three replicates per treatment.

conditions, oat was much more tolerant of oily residues than any of the other crops tested. At the lower oil content oat grain yield was actually increased by 71% over the control, but at 4.6% oil the yield was still 94% below the control. The only other crop that exhibited any reasonable tolerance of oily-residues was wheat. The failure of barley to tolerate these oily residues (Table 2) was disappointing as the well known salt tolerance of this crop would enable it to cope well with the high salt concentrations found in soils following EOR sludge applications. Except for the remarkably greater oil tolerance by oat, the results from our greenhouse and field tests are generally consistent with previous studies in central Alberta showing canola to be very sensitive to oil, barley as quite sensitive and wheat as moderately tolerant (Toogood and McGill 1977). However, our findings strongly disagree with the oil tolerance ratings for selected crops reported from the southern US (Deuel 1990) which assign a higher level of tolerance to peas, clover and perennial grasses than to wheat and oat.

Effect of Manure on Soil Properties

To be effective in restoring crop productivity to an oil-polluted soil, the application of manure must not only stimulate the microbial decomposition of oily residues but it must also improve the soil's structure and render conditions more favorable for plant growth by reducing soil compaction,

increasing aeration and tilth and by optimizing soil water and nutrient dynamics. The size distribution of aggregates is commonly used to assess soil structure and is recognized as a critical indicator of soil quality (Rasiah et al., 1997). In the overoiled Meota loamy sand, major soil physical properties such as stability of dry and wet aggregates, bulk density and hydraulic conductivity were markedly improved within four months and soil microbial population within three months of incorporating the well rotted manure (Table 3). In the unfertilized plots, manuring effected a 20% reduction of the erodible soil fraction, a 30% increase in mean size of waterstable aggregates, a 20% decrease in bulk density, 56% increase in potential rate of water movement and a 131% increase in the number of live bacteria.

Our results tend to agree with studies on artificially eroded soils in that plots receiving manure have more waterstable aggregates than in check plots (Dormaar et al., 1988) and that the beneficial effects of manure in restoring soil productivity are much larger than those achieved with inorganic fertilizers (Larney and Janzen 1996). However, our soil analyses (Table 3) also indicate that the effectiveness of manure in improving soil conditions for plant growth generally decreased with increasing rates of previous fertilizations. This decrease can be attributed to the large total amounts of inorganic nutrients applied in two consecutive fertilizations (i.e. 900 kg N + 206 kg P_2O_5 + 144 kg S/ha in all F4 plots and half that in F2 plots) and to the length of time by which the fertilizations preceded the manure application (i.e. 31 and 13 months). Evidently these fertilizations provided sufficient nutrients to stimulate soil microbial growth and accelerate oil decomposition and and they also allowed plenty of time and created favorable conditions for the bioconversion of hydrocarbons into stable, soil structure-improving, humus.

When manure is applied to unfertilized, oil-contaminated soil it will not only improve soil structure but will serve as a slow release source of various macro-and micronutrients for oil decomposing microbes and for crop growth. Thus the extent of reclamation effected with manure following an oil spill on farmland depends not only on the amount but also the type of manure being applied. In

Table 3. Effect of manure application in spring 1989 on selected surface soil properties in a heavy oil-polluted Meota loamy sand when sampled 4 months later.

Oil (O) and Fertilizer (F) treatment	Erodible Fraction†, %		Size of Waterstable Aggregates, GMD, mm‡		Bulk Density, g/cm^3		Hydraulic Conductivity, cmH_2O/hr		Bacterial Population, no. x 10^6/g soil§	
	unmanured	manured	unmanured	manured	unmanured	manured	unmanured	manured	unmanured	manured
01F0	59.1	48.1	3.62	4.69	1.25	1.01	6.87	10.75	268	618
01F2	65.8	55.2	3.98	4.69	1.23	1.08	8.57	12.55	191	536
01F4	59.4	59.5	4.71	4.87	1.16	0.98	5.08	15.52	277	438
Average	61.4	54.3	4.10	4.75	1.21	1.02	6.84	12.94	245	531

† The fraction of soil susceptible to erosion by wind, i.e. aggregates <0.84 mm in size, was determined by rotary dry sieving.

‡ Waterstable aggregates were determined by wet sieving and aggregate size distribution was expressed as the geometric mean diameter (GMD)

§ Bacteria enumerated by dilution plating on Soil Extract Agar of samples collected August 9, 1989; while physical properties were determined on samples collected September 19 and 20, 1989.

reclamation studies at the University of Alberta (Toogood 1977) application of 9 t/ha of a cattle manure with low nutrient content failed to increase the yield of oats growing on oil-polluted soil in the greenhouse while addition of 12 t/ha of a N-rich chicken manure to soil from a spill site significantly increased microbial CO_2 production when incubated in the laboratory. In our field study at Maidstone, SK a single manure application was very effective in improving soil structure and productivity (Tables 3, 4 and 5) because well rotted manure was used at a rate of 20 t organic matter/ha which is similar to the manuring rates used by Dormaar et al. (1988) and by Larney and Janzen (1996) to successfully restore productivity in artificially eroded soils.

Effect of Manure on Cereal Production

Based on the results from our earlier greenhouse and field tests for the tolerance of various crops to residual oil we decided to plant the two most tolerant cereals, viz. oat and wheat, into the 'overoiled' plots in spring 1990, i.e. one year after the manure application. Unfortunately, all plants had already suffered significant damage from predation by grasshoppers when both cereals were sampled at flowering stage, in late July. Yet the beneficial influence of manuring on emergence and vegetative growth could still be measured and was very evident according to the data in Table 4. In the unfertilized plots the manure treatment effected a 53% increase in plant density and a 150% increase in DM production of oats; the corresponding increases by wheat were 55% for stand density and 65% for biomass production. The effectiveness of the manure in improving cereal growth tended to decrease with increasing rates of previous fertilization (Table 4), i.e. the same trend as observed earlier for manure effects on soil properties that are critical for plant development (cf. Table 3). However, even in fertilized plots the benefits of manuring were still strong. When averaged across all fertilizer treatments oats in overoiled, but manured plots had essentially the same plant density as in unoiled plots (218 vs 214) and produced only 29% less biomass (146 g/m^2 vs 206 g/m^2). For wheat too plant density in manured plots was very similar to that in unoiled soil (177 vs 185) while DM production was only 12% less (98 g/m^2 vs 112 g/m^2). These comparisons with unoiled controls emphasize how effective a single manure application can be in restoring full crop productivity to a severely oil-polluted soil. Chemical analyses of the plant material indicated similar N contents on manured and unmanured plots, but P contents were consistently greater in cereal biomass from manured plots (data not shown). These increased plant P contents are corroborated by studies with eroded soil which have attributed part of the restorative ability of manures to improvements in the soil's P-supplying power (Dormaar et al., 1988; Larney and Janzen 1996).

In 1991, when oats were grown to maturity, the influence from the single manure application, two years earlier, on crop production in the oil-polluted soil was again highly beneficial. When averaged across fertilizer treatments manuring resulted in a 55% increase in plant density, a 70% increase in crop biomass and an 82% increase in grain yield relative to the unmanured plots (Table 5). However, in contrast to the results obtained in 1990, there was a significant positive interaction between manuring and earlier fertilizations in enhancing crop growth and particularly grain yield. It may be that the initial crop response to manuring of oil-polluted soil is affected primarily by the improvement in soil physical properties while subsequent crops will depend increasingly on fertilization to produce optimum yields under the improved soil conditions. This corroborates the suggestion made by McGill during earlier oil spill studies (cf. Toogood 1977) that manure should

always be used in conjunction with other fertilizers. On the manured, unfertilized plots plant density

Table 4. Effect of amendment with manure on plant density and dry matter production of two cereals at flowering (July 26) in 1990 on heavy oil-polluted Meota loamy sand.

Cereal type	Oil (O) and Fertilizer (F) treatment	Plant Density, plants/m^2		Aboveground Dry Matter, g/m^2	
		unmanured	manured	unmanured	manured
Oat	01F0†	179	273	60	150
Oat	01F2	148	169	93	117
Oat	01F4	137	211	77	172
Oat	Average	155	218	77	146
Wheat	01F0†	132	204	66	109
Wheat	01F2	164	181	76	99
Wheat	01F4	123	146	41	85
Wheat	Average	140	177	61	98

§ Average plant density and DM on corresponding unoiled, unfertilized and unmanured, i.e. 00F0, plots was 214 plants/m^2 and 206 g/m^2 for oats; and 185 plants/m^2 and 112 g/m^2 for wheat.

was identical, biomass production was 8% more and grain yield was 32% higher than on the corresponding unoiled and unmanured plots (Table 5). This comparison proves that a single manure application was able to fully restore, within two years of soil amendment, the productivity for cereal grains on the oil-polluted Meota loamy sand. In a study of organic amendments to restore soil productivity of oil well sites in central Alberta (Akinremi et al., 1999) composted cattle manure was superior to alfalfa hay, fresh cattle manure and wheat straw and was able to restore wheat yields within two years of soil incorporation. Our results also agree with studies on artificially eroded soils in southern Alberta which found that treatment with manures or manure plus fertilizer combinations

Table 5. Effect of amendment with manure on plant density and production of oats at maturity (August 26) in 1991 on heavy oil-polluted Meota loamy sand.

Oil (O) and Fertilizer (F)	Plant Density, plants/m^2	Aboveground Plant Dry Matter, kg/ha	Grain Yield, kg/ha

	unmanured	manured	unmanured	manured	unmanured	manured
01F0†	178	240	5571	7428	2524	3715
01F2	98	229	3753	8487	1642	3961
01F4	126	156	4870	8135	2206	3925
Average	134	208	4731	8017	2124	3867

† Average plant density and production of oats on the corresponding unoiled, unfertilized and unmanured, i.e. 00F0, plots was 240 plants/m^2, 6865 kg DM/ha and 2824 kg Grain/ha.

essentially restored productivity within one or two years as measured by wheat yields (Dormaar et al., 1988; Larney and Janzen 1996). The effect of these soil amendments on grain quality had not been examined in the Alberta studies thus we analyzed the harvested oat grain for several quality characteristics. On previously fertilized plots there was no significant difference in protein content, kernel size and test weight between grain from manured and from unmanured treatments (data not shown). However on unfertilized plots manuring lowered the protein content by 9%, although the total quantity of grain protein harvested per unit area was still markedly increased with the 47% increase in grain yield (cf. Table 5), and manuring did increase the kernel mass by a remarkable 59% and the test weight by 86% over that of grain from the unmanured check (data not shown).

These field study results lead us to conclude that amendment of the oil-polluted soil with a single application of old manure was highly effective in improving critical soil properties and in restoring soil productivity not only in terms of grain yield but also with regard to grain quality.

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1:45 – 3:25	**Concurrent Sessions**	
Session C:	**Native Plants and Revegetation** – Saskatchewan Room 'A' Session Chair: Anne Naeth – Department of Renewable Resources, University of Alberta	
1:45 - 2:05	Relative performance of native prairie grasses and forbs for revegetation of a pipeline disturbance on native prairie. David Walker, Walker and Associates	126
2:05 – 2:25	Revegetation of wellsite disturbances on Fescue Prairie in east-central Alberta. Jay Woosaree, Alberta Research Council	118
2:25 – 2:45	The evolving native plant industry in Saskatchewan. Nora Stewart and Andy Hammermeister, Native Plant Society of Saskatchewan	115
2:45 – 3:05	Cameco, Key Lake regreening project, in harmony with nature - (1978-1999 & beyond). Lotfi Haji, Cameco	n/a
3:05 – 3:25	Rare Plant Rescue During Pipeline Construction *(Erigeron compositus* Pursh. var. *glabratus* Macoun, Fern-leaf Fleabane on the 1998 Foothills Pipe Lines Expansion Project.) David Walker, Walker and Associates	n/a
Session D:	**Soils and Restoration**– Saskatchewan Room 'C' Session Chair: Mike Solohub – Department of Soil Science, University of Saskatchewan	
1:45 - 2:05	Soil information resources for the prairies. Alvin Anderson and Glenn Padbury, Agriculture and Agri-Food Canada	n/a
2:05 – 2:25	Setting reclamation standards: When is soil decompacted? Richard Johnson, Alberta Research Council	175
2:25 – 2:45	Using oily waste to restore productivity in a severely eroded loamy sand. M.C.P. Jarvis[1,3], V.O. Biederbeck[2], K.G. Hanson[2], T.A. Fonstad[3] ;[1] Imperial Oil Resources, [2] Semiarid Prairie Agricultural Center, and [3], University of Saskatchewan	68
2:45 – 3:05	Remediation of potash slime tails through use of cross-linked polyacrylamide hydrogel. Kathleen Cameron, University of Saskatchewan	169
3:05 – 3:25	Fifteen years of subsoil/mine spoil development on a	