Using Oil Industry Waste Effectively to Improve an Eroded Loamy Sand

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Introduction

As depletion of the easily recoverable oil reserves in western Canada accelerates, the volumes of waste generated during heavy oil production and processing are steadily increasing. The 600 million litres of heavy oil produced in 1998 accounted for 40% of total oil production, i.e. all across Canada plus offshore. The safe disposal of heavy oil wastes became an environmental issue when the conventional practice of 'road oiling' for dust suppression on rural roads could no longer accommodate the growing waste volumes (Biederbeck et al. 1993). We propose that agriculture may provide effective solutions for some oily waste disposal problems by utilizing such organic C-rich wastes to amend nearby areas of marginally productive cropland. Cultivated land on the Prairies includes >3 million ha of sandy soils (>50% sand) that are highly susceptible to degradation by wind and water erosion and are low in organic matter and productivity. Much of this marginal cropland could benefit from improvements in soil structure and humus content that can be realized through incorporation of organic, including petro-type, wastes (Biederbeck et al. 1997). Consequently, we conducted, with support from AFIF, a field experiment on a windy ridge at Richmound, SK to:

(i) assess the impact of soil incorporation of a heavy oil processing sludge on soil and groundwater quality and on crop production, and
(ii) generate benchmark data needed by regulatory agencies to develop guidelines for future use of suitable hydrocarbon wastes in an environmentally safe and agronomically beneficial manner on sandy cropland in Saskatchewan and Alberta.

Materials and Methods

The soils at the field research site, located 7 km southeast of Richmound, SK, are Orthic and mixed Rego and Calcareous profiles of Brown Chernozems all belonging to the Hatton Soil Association. Average texture near the surface is 84% sand, 9% silt and 7% clay. These loamy sands contain only 0.4% organic C and few plant nutrients and have a low moisture retention capacity (<6%). The many small stones on the surface and frequent occurrence of shallow carbonates in Orthic profiles attest to a long history of severe wind erosion.

The study consists of a 96 plot experiment with two cropping systems (i.e. fallow and cropped), two cereal crops (i.e. oats and wheat), three oily waste application levels (i.e., none, 1%, 2% soil oil content, wt/wt), two fertilizer treatments (i.e., none and best management practice), and four replications of all treatment combinations. The oily waste was applied and incorporated on November 5, 1997 by rototilling into the top 10 cm of the 2m x 12m plots. It originated from the Heavy Oil Upgrader of Consumers' Co-operative Refineries Ltd. in Regina, SK and has a gross composition of 61% water, 31% hydrocarbons and 8% solids (clay). This sludge contains a total of 5,000 ppm of polynuclear aromatic hydrocarbons (PAH) but only few total volatiles (420 ppm) and salts (280 ppm) or nutrients (70 ppm N, 20 ppm P), except for sulfur (6000 ppm S). Heavy metal contents (<2 ppm) were very low.

Fertilization of plots was oily waste related and was intended to minimize the release of waste-C as CO_2 (a 'greenhouse gas') to the atmosphere and to enhance C sequestration by gradual humification in the soil. Consequently, our 'best management practice' was based on the amount of waste oil applied and the average C:N:P ratio of stable soil organic matter (80:7:1) so as to optimize the microbial conversion of oil to humus, assuming that as much as 3/4 of the soil incorporated oil-C may be involved in the humification process. Thus, sludge application to an initial 1% soil oil content called for 700 kg N and 105 kg P/ha and, accordingly, twice as much fertilizer for plots receiving the higher sludge application. Urea (46-0-0) was used as N fertilizer and the P source was superphosphate (0-45-0). To reduce nutrient losses and minimize osmotic stress within the seeding depth the oil-related, massive fertilization was split into equal applications at three different times, viz. initial third on November 4, 1997 and the remainder on April 7 and April 15, 1998.

Soil samples for physical, chemical and microbial analyses were collected in all plots within 24 h of the November 5, 1997 oily waste incorporation, then from selected plots three weeks later, and from all plots in spring and fall 1998 and again in spring and fall 1999. On February 12, 1998 the drill crew from the Geotechnical Division of PFRA installed six groundwater monitoring wells at strategic locations within and around the experimental area as identified by an earlier topographical survey.

Results and Discussion

For this severely eroded Hatton loamy sand, that originally contained only 0.7% organic matter, the applied oily waste served initially as an effective 'glue' for binding and holding the sand grains together. Thus, by early spring 1998, the surface of the oiled plots showed no signs of topsoil loss to wind erosion while the unoiled control plots were littered with many stones and pebbles that became exposed as the surrounding topsoil had been swept away by strong Chinook winds. Rotary dry sieving of soils sampled that spring showed a decrease in the wind erodible soil fraction (i.e., aggregates < 0.84 mm) of 10 % where 1% oil was applied five months earlier and a 13% decrease where 2% oil was applied (Figure 1a). These reductions of the wind erodible fraction were maintained relatively unchanged, while the waste oil underwent biodegradation, at least until fall 1999, i.e. 23 months after sludge application. The resistance to erosion by water was boosted much more than dry aggregate stability as wet sieving analysis of the spring 1998 soil samples indicated increases of 58% and 68% in water stable aggregates where sludge was previously applied to a 1% and 2% soil oil content, respectively (Figure 1b). The marked improvement in structure of this sandy soil was rather persistent and by fall 1999 the corresponding gains in water stable aggregates were 42 and 67% due to waste oil incorporation two years earlier. Large and persistent increases in stable aggregation were also found by Giddens (1976) in a field experiment with waste oil on a loamy sand in Georgia. Considering the long-term nature of oil-induced aggregation benefits, we suggest that a single sludge application, every four to six years, should provide adequate protection against topsoil degradation by wind and water, even on very erosion-prone light land.

Microbial numbers and activity are known to increase whenever oily wastes are tilled into aerobic topsoil (Bossert and Bartha 1984) and the Hatton loamy sand at Richmound was no exception. As reported elsewhere at this Soils & Crops Workshop (Hanson and Biederbeck 2000), incorporation of the upgrader sludge boosted not only the proportion of oil degraders within the bacterial flora from <5% to >40% in only three weeks but it also stimulated other types of organisms within the microbial community. Relative to the microflora in control soil, oil-induced population responses during the first year were greater for bacteria than actinomycetes and greater for yeasts than filamentous fungi. The enhancements were not short-lived because two years after sludge application bacterial populations in oiled soils were still severalfold greater than in controls particularly in those plots that were heavily fertilized at the start. These oil-related fertilizations caused a marked reduction in microbia respiration rates during the first year and after two years CO_2-C evolution by fertilized soil was still lower per microbial unit than in unfertilized soil indicating that nutrient supplementation tends to improve the efficiency of bioconverting hydrocarbons to soil humus.

Fertilization generally enhances the biodegradation of oil in soils (Riser-Roberts 1998) and addition of nitrogen and phosphorus is reported to stimulate microbial degradation of saturated hydrocarbons more than that of aromatic hydrocarbons (Fedorak and Westlake 1981). Rapid immobilization of indigenous soil nutrients after applying oily waste to the Hatton loamy sand and benefits of N supplementation for subsequent cereal production were demonstrated in a growth chamber experiment with four rates of sludge application and urea vs hog manure as N source (Abujnah et al. 1999). Although our heavy N & P fertilization of the oiled field plots was split into three separate applications, within six months of sludge incorporation, the resultant concentration of both nutrients near the surface was much greater than what could be consumed or immobilized by oil-degrading microbes, suffering under severe drought stress in spring and summer of 1998, or what could be physico-chemically absorbed and retained within the 10 cm deep, sludge-treated layer of loamy sand. Consequently, by late fall 1998 about 700 kg N/ha, i.e. half of the total fertilizer N applied to the 2% oil containing fallow plots, was found as nitrate between 10 cm and 120 cm soil depth (Figure 2). Another 130 kg N/ha between 10 and 120 cm was still in the ammonium form (NH_4-N data not shown) while only 13 kg NH_4-N plus 15 kg NO_3-N remained within the treated 10 cm of topsoil, suggesting that there was considerable leaching of fertilizer N even deeper than 120 cm in this sand. It seems that much of the applied N had moved below the treated layer, at least initially, as unhydrolyzed urea rather than as nitrate because we still found urea near the surface by late May and then massive leaching occurred on 26 and 27 June as the plots received >80 mm of rain in less than 26 hours. By fall 1999, after producing a good cereal crop in a moist spring and summer, the 10 to 120 cm depth of fertilized 2% oil plots still contained 240 kg/ha more NO_3-N than was found under check plots (Figure 2), but NH_4-N contents were no longer different. Since the cereals, grown in 1999, would have assimilated less than half of the decrease in nitrate to 120 cm depth, that was observed between fall 1998 and 1999, we assume that most of the original fertilizer N was leached through the sand to much greater depth. To confirm the deep leaching and to measure the magnitude and extent of downward movement of nutrients it is imperative to conduct some deep coring in selected plots in early spring 2000.

Much of the P applied with the three early superphosphate fertilizations was also transported downward in the loamy sand and by fall 1998 about 150 kg/ha more PO_4-P was found between 10 and 120 cm in 2% soil-oiled plots than in unfertilized checks (Figure 3). Thus >2/3 of the total 210 kg fertilizer

P applied was moved well below the sludge-treated topsoil, primarily by mass flow due to the lack of P-absorbing colloids (only 7% clay content) and P-precipitating carbonates, but some P may also have been chelated or complexed with metabolites from oil biodegradation and thus rendered more mobile. By fall 1999, the oiled and fertilized plots contained between 10 and 120 cm depth only 15 kg/ha more P than was under the check (Figure 3) indicating that, analogous to the aforementioned decrease in nitrates, most of the observed loss of phosphates between fall 1998 and fall 1999 should be attributed to increased leaching during the wet spring and summer rather than to root uptake by either cereal crop.

In 1998 the 48 plots on chemfallow were seeded on April 15 to cereals, 24 plots to oats, cv. Calibre, and 24 plots to durum wheat, cv. Kyle. Due to poor emergence, probably caused by excessive moisture deficiency after the 1997 late fall rototilling and the lack of overwinter snowcover, all plots had to be reseeded on May 27, 1998. As a result of this late seeding and considerable early drought stress, crop growth and production was generally poor on most plots. Harvest sampling showed invariably a strong negative interaction between the oily waste-related fertilizer treatments and grain yields by both cereals. On oiled but unfertilized plots, the grain yield of oats was significantly increased by 1% soil oil content and at 2% oil it was equal to the check yield. Thus the yield depression on heavily fertilized plots was not caused by incorporation of waste oil but rather by temporary physico-chemical plant stress exerted by fertilizer salts and aggravated by severe drought conditions. The amounts of weathered waste oil remaining in the loamy sand as the first crop grew were apparently within the range that is considered to be safe for cereals when properly managed and in the absence of salt-induced osmotic stress (Deuel 1990). On May 4, 1999, the previously fallowed 48 plots were seeded to oats and durum wheat and subsequent crop establishment was good with no adverse weather conditions. Plant emergence counts indicated there were no residual phytotoxic effects from the waste oil application on plant density or early development of either cereal. Manual sampling of the crop biomass at flowering, in mid-July, showed a two- to three-fold increase in durum production with 1% oil and a doubling of the check dry matter with 2% initial oil application. At maturity (2 September) grain yield was measured by harvesting a 10 m long strip down the middle of each plot with a small combine (1.5 m cutting width). Even without the earlier oily waste-related massive fertilization durum yields were significantly increased by sludge incorporation to Hatton loamy sand, exceeding check yields by 40% at the 1% initial soil oil content and by 80% at the 2% oil content (Figure 4a). Residual benefits from that fertilization were still reflected as yield increases, particularly the 160% higher yield at 1% soil oil content. Despite these yield increases protein contents of the durum on oiled plots were generally above the 14.5% level of check plots as they averaged 15.0% on unfertilized oiled and 15.9% on fertilized oiled treatments, thus indicating high grain quality. For corresponding treatments the oat crop generally yielded better than durum on this sandy soil (Figure 4a & b). As noted for durum, oat yields were also significantly increased where only sludge had been applied thus corroborating the beneficial effects from oil-induced soil improvements for crop production on marginal land. Oat yields were further enhanced by residual effects from initial heavy fertilization resulting in about 50% and 70% more grain harvested from 1% and 2% waste oiled soils than from check plots.

To date, repeated sampling of the six on-site groundwater monitoring wells and subsequent analysis have not detected the appearance of any PAHs or other waste oil-contained organics.

Conclusions

From the results analyzed to date we can conclude that a single application of oily waste sludge to an eroded loamy sand:

1. Effected large and persistent improvements in aggregation, thus 'erosion proofing' the topsoil.
2. Should be accompanied by N & P supplementation, but fertilizer rates must be much lower, than used here, and must be spread over longer intervals to prevent excessive leaching losses.
3. Greatly increased the yield of durum and oats after a year of fallow, even without initial extra fertilization.
4. Did not cause any pollution of groundwater with organics.

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Acknowledgements

Financial support by the Agri-Food Innovation Fund is gratefully acknowledged. Thanks also to Dean James, Mike Jarvis, Doug Judiesch, Dean Klassen, Rod Ljunggren and Tricia Thomas for their technical assistance.

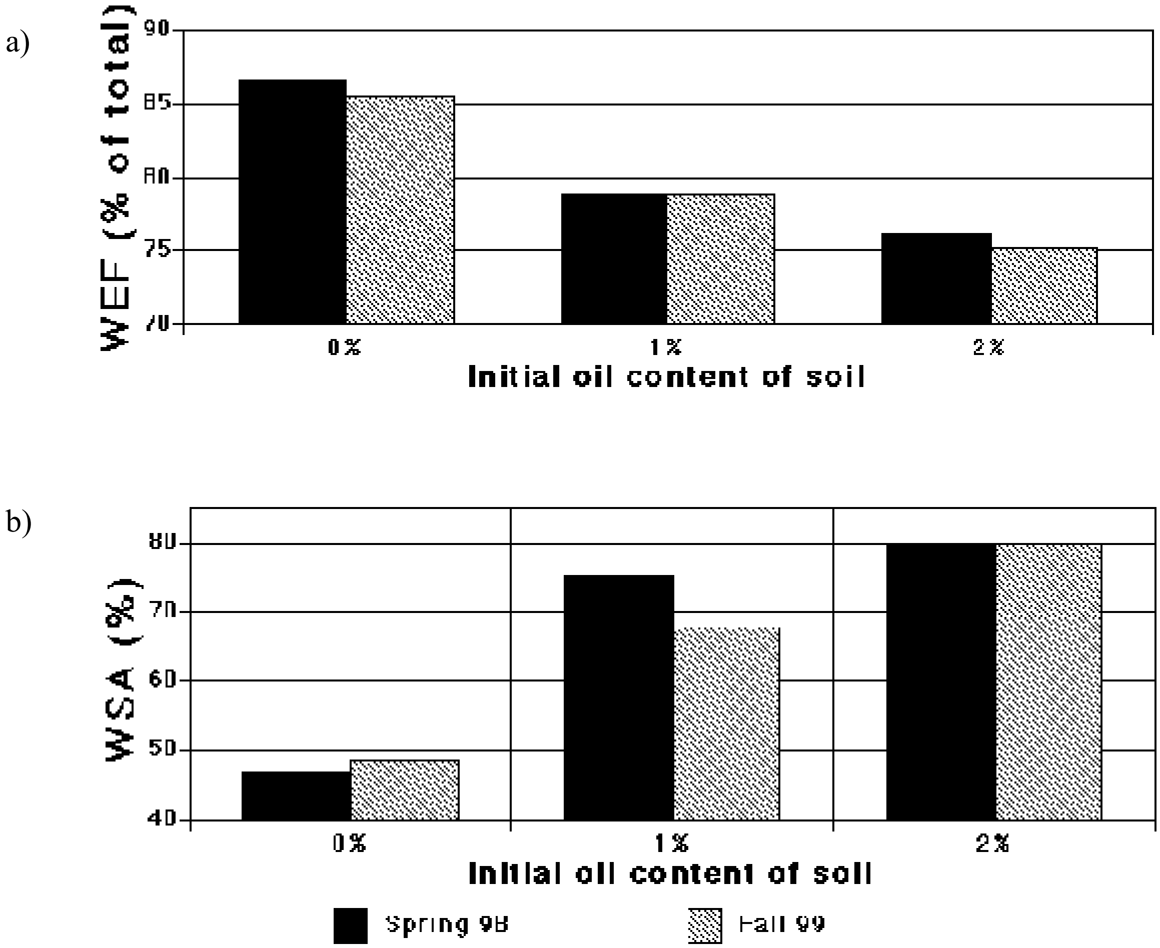

Figure 1. Effect of oily waste sludge incorporation on a) wind erodible fraction (WEF) and b) waterstable aggregates (WSA) in top 10 cm of Hatton loamy sand at 5 and 23 months after treatment.

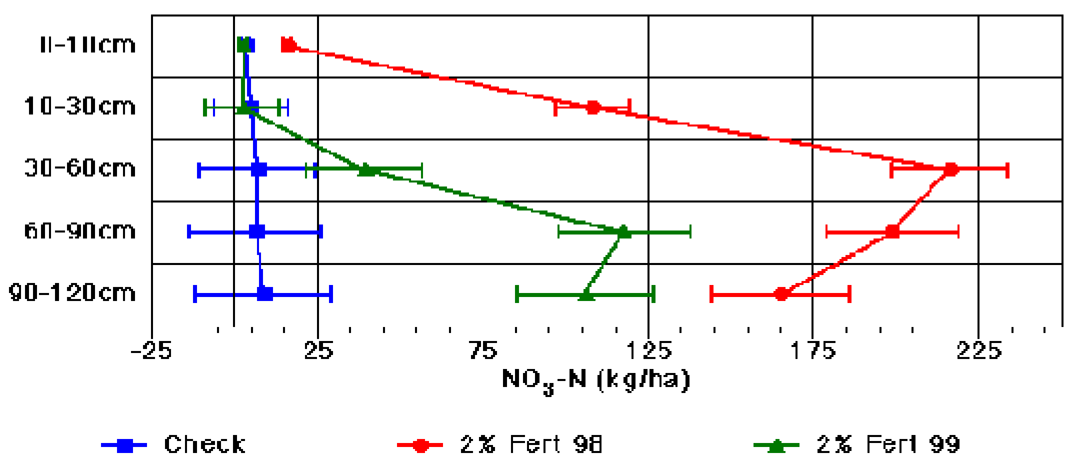

Figure 2. Nitrate distribution to 1.2 m depth in Hatton loamy sand at one and two years after oily waste application and heavy fertilization.

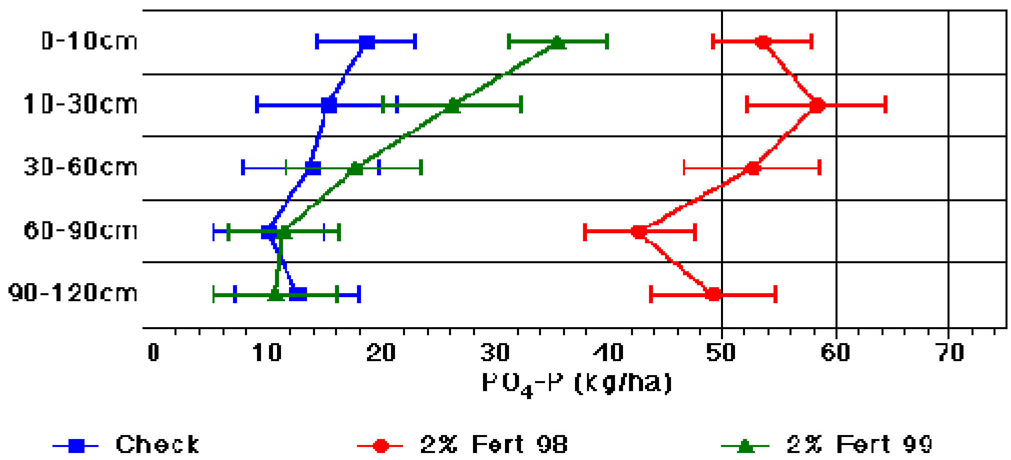

Figure 3. Phosphate distribution to 1.2 m depth in Hatton loamy sand at one and two years after oily waste application and heavy fertilization.

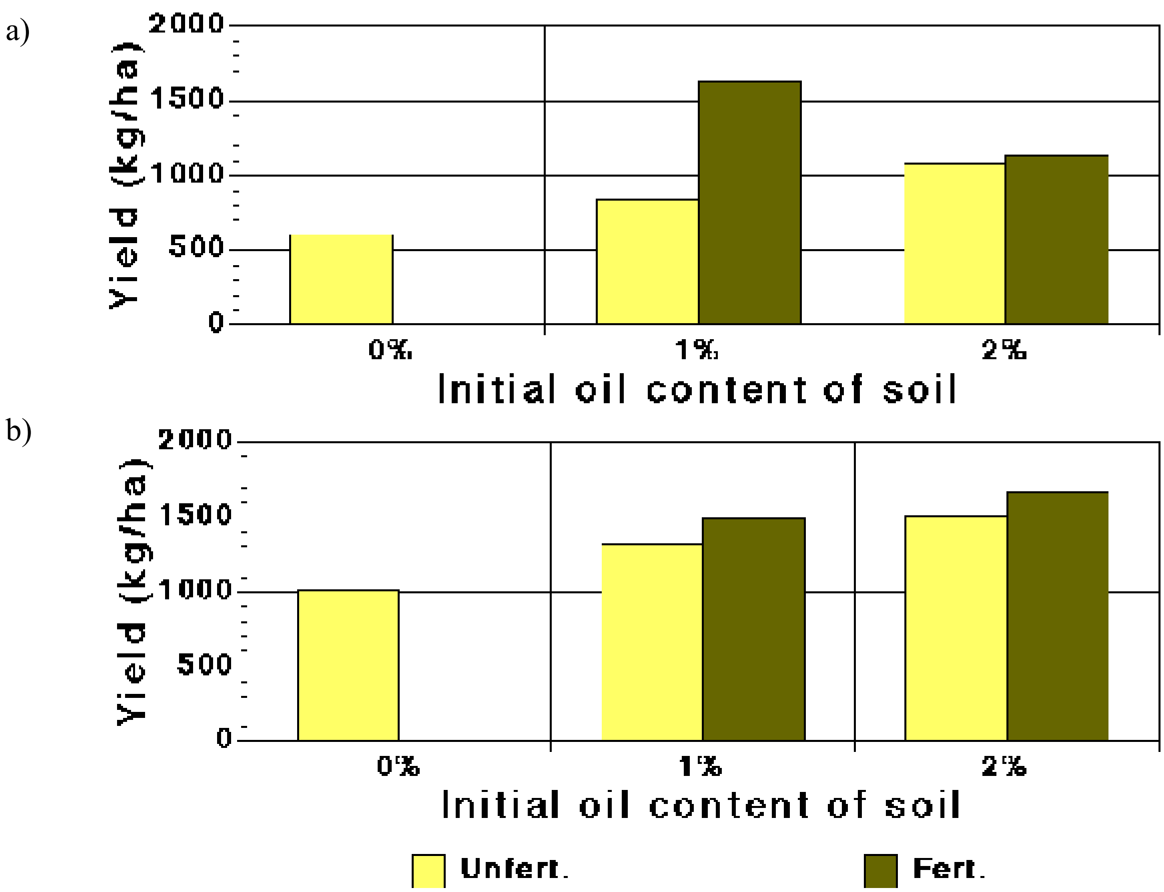

Figure 4. Effect of oily waste application and related fertilization on 1999 grain yields of a) durum wheat, cv. Kyle, and b) oats, cv. Calibre.

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Keywords: oiling sandy soil; wind erodible fraction; water stable aggregates; nutrient leaching; cereal production.