TRABAJO 2. TOMO 1

CHANGES IN SOIL CHARACTERISTICS AND VEGETATION BY LANDFARMING OF PETROLEUM WASTES IN A COLD DRY CLIMATE

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Abstract

The effect of adding organic oily wastes on plant cover and on soil water was studied in a soil covered by a community of low forage value in Tierra del Fuego (Argentina). Oily wastes was mixed with the top 3 cm of the soil in May 1993 at rates of 1.51 and 3.03 % w/w. In December 1993, half of each plot was fertilized with N and P, and changes in species abundance and total cover, were evaluated in December of 1994 and 1995. Soil samples at a range of 0-9 cm depth were taken in December of 1993-1995, and analysed for pH, water content, and total petroleum hydrocarbon (TPH).

The oily wastes increased water content and pH in the soil. Fertilization increased plant growth but both fertilization and oily waste increased plant cover. TPH in soil decreased from 3 % to 0.18 % during the experimental period, but fertilization did not affect the decrease in TPH with time. The results, combined with the annual rainfall and the water table elevation at the site, suggests that the risk of contaminating the water table is relatively low. It is concluded that landfarming could be applied as a remedial action in soils of Tierra del Fuego. In addition, amending the soil with oily waste in dry heath ecosystems increased water conservation and this effect promoted plant growth.

Introduction

Northern Tierra del Fuego is one of the most productive areas of petroleum and of wool in Argentina. Thus, the petroleum industry and wool production must be compatible. The climate is characterized by low temperature, low rainfall, and strong winds during the most part of the year. In this region, as a consequence of intensive sheep-grazing during the last 100 years, prostrate evergreen shrub have formed extensive heathlands of low forage production that intermingle with the grassland steppe of good forage production (Collantes et al., 1989).

The old exploring technology used for oil prospecting consisted of pumping liquid residues into a pool excavated near the wells. The liquid residues were petroleum floating on runoff rain water. Remedial action has consisted of pumping and recovering the free petroleum. Nevertheless, a considerable amount of contaminant residues remains on the surface which must be eliminated.

Landfarming is one of the technologies to bioremediate petroleum-contaminated soils, or to eliminate the accumulated petroleum residues in undesirable sites (Preslo et al, 1989). This is because of the capacity of soils to decompose the applied waste (Lynch and Genes, 1989). Soil temperature and soil moisture are important factors controlling the oily degradation process. In laboratory, soil temperature has been shown to increase 1.5 °C when oily wastes were applied in soils from Tierra del Fuego (Mendoza et al, 1995a). Temperature influences oil biodegradation by altering the composition of microbial community, the rate of hydrocarbons metabolism by microorganisms, and the physical nature of the oil (Atlas, 1981). At field plots, oily waste increased soil moisture and this in turn increased potato yield (Mendoza et al, 1995a). Low moisture and low nutrient availability in soil have been identified as a potential factors limiting both plant growth in Tierra del Fuego (Collantes et al, 1989; Mendoza et al, 1995b), and the rate of biodegradation of petroleum hydrocarbons in cold climate of Alaska (Gould et al, 1997).

The amount of residue to dilute with the top soil depends of the ability of the soil to degrade the residue, as well as of the structure and the texture of the soil involved (Hillel, 1989). This, together with rainfall and depth of the water table, determines the time and the space for the retention and degradation of the contaminant prior to its probable penetration into the aquifer. Annual rainfall in Tierra del Fuego over a ten year period ranged from 250 to 350 mm being deficient for maximum pasture growth. In addition, frequent strong winds from the west increased evapotranspiration of the ecosystem (Fuerza Aérea Argentina, 1986). Previous work has demonstrated that 4.2 % of total petroleum hydrocarbons in soil declined by 55 % at 6 °C during 6 months (Mendoza and Rodriguez, 1996). In soil columns, the concentration of total petroleum hydrocarbons in leachates collected from a soil amended with 1 % oily waste did not increase significantly from the unamended soil (Mendoza, 1998).

In the present study, oily wastes were collected from undesirable sites and applied to a soil covered by a heath community of low forage production. The purpose of the present field experiment was to evaluate the effect of adding petroleum residues to the soil on some soil characteristics which in turn may affect plant growth. In addition, the decline of petroleum hydrocarbons with time was evaluated in order to know the impact of large applications of oily waste residues at full-scale.

Materials and methods

Site Description and Soil Characterization

The study was located in Northern Tierra del Fuego (Argentina), where the climate is cold, dry and windy during most of the year. The average maximum temperature in July (winter) is about 0 °C, and in January (summer) it reaches 15 °C (Fig. 1). The mean annual rainfall over a 10-year period (Fig. 2), ranged from 250 to

350 mm (Fuerza Aérea Argentina, 1986). At the field site, the water table elevation varies from 12 m (summer) to 8 m (winter) below ground surface..

The experimental site was on an acid heath soil mostly covered (77 %) by a prostrate evergreen shrub (*Empetrum rubrum*), and other shrubs such as *Discaria chacaye* and *Baccharis magellanica.* The total soil cover was 87%, with only 7% of grasses comprising *Festuca magellanica* (5%) and *Deschampsia flexuosa* (2%). The soil was a loam classified as a Crioumbrept characterized by high acidity, high organic matter, low base saturation and is nutrient deficient for plant growth (Table 1). The criteria used to select field site was based on:

1. The community is characteristic of the extreme conditions of the area having low forage production (Mendoza et al, 1995b). Thus, sheep grazing is uncommon in this area.

2. Low moisture and low nutrient availability in the soil have been identified as a potential factors limiting plant growth (Collantes et al, 1989; Mendoza et al, 1995b). Adding oily waste and fertilizers may increase plant growth by increasing moisture and nutrient availability in soil.

3. Previous studies in laboratory have demonstrated both, the capacity of the soil to decrease and to retain petroleum hydrocarbons decreasing the risk to contaminate groundwater (Mendoza and Rodriguez, 1996; Mendoza, 1998) .

The experiment

The topsoil (10 cm) was ploughed and oily wastes were distributed surfacely and mixed homogeneously into the top 3 cm with a hackle at rates of 0, 0.5 and 1 kg/m^2. As the soil density was 1.1 g/ml, this corresponds to rates of 0, 1.51 and 3.03 % of oily waste. As a consequence of ploughing, a high proportion of the native prostrate evergreen shrubs were cut and then partially removed from the experimental site. Plots of 5 x 3 m were replicated three times. The oily waste was a viscous petroleum residue collected in May 1993 from a lagoon near an abandoned petroleum well. The residue was characterized by gas chromatography with a flame-ionization detector (GC/FID) to determine the proportions of different hydrocarbons present. For the retention time used, the chromatogram showed that nearly 90 % of the residue contained hydrocarbons in a range of C_{13} to C_{33} (Fig. 3). The chromatogram also showed the presence of a small proportion of hydrocarbons lighter than C_{13}, presumably because residue was exposed to the atmosphere long enough before sampling to allow the light hydrocarbons to evaporate. The experiment was initiated in May 1993, when the oily waste was applied. At each plot, a composed soil sample (six sub-samples) was taken from 0-3, 3-6 and 6-9 cm depth in December of 1993, 1994 and 1995, and were analyzed for pH, soil water content and total petroleum hydrocarbon (TPH) concentration. TPH was measured by the infrared (IF) spectrometer EPA test method No. 418.1 (Kopp and Mc Kee, 1983). In December 1993, half of each plot was fertilized with 200 kg/ha of urea and 200 kg/ha of triple superphosphate, and *Dactylis glomerata* (orchard grass) was sown at a rate of 5 kg/ha. At that time, the total cover of vegetation was sparse because the effect of ploughing nine months earlier and permitted an appropriate preparation of the soil surface for sowing. Species abundance and total cover were evaluated in December of 1994 and 1995 by the method of Braun-Blanquet using a scale proposed by Westhoff and Van der Maarel (1978).

Statistical Analysis

Differences referred to as significant were at $P < 0.05$ as determined by Analysis of Variance (ANOVA) Type III Sums of Squares. For soil moisture content, a separate analysis was performed to provide an LSD applicable to each soil depth. The same method was performed to evaluate differences for percentage cover of each plant specie.

Results and discussion

Oily Waste and Soil Water Content

The moisture content of the soil reflects the interactions among recent rainfall, the effect of oily waste in decreasing evaporation and the effects of plant growth in increasing moisture losses. In 1993, there had been little rain in ten days prior to sampling (Fig. 4). Furthermore, the plant cover was sparse because of the ploughing nine months earlier and the slow plant growth in cold climate. At this time a visual observation indicated that vegetation was dominated by *Rumex acetosella* with a 10 % as a maximum value of total plant cover. The only observed effect was an increase in water content with increasing oily wastes for the samples between 6 and 9 cm depth (Fig. 5). On this occasion, the oily waste had not been effective in preserving water in the top layers. But had been effective for the lower 6-9 cm depth layer.

In 1994, 11 mm of rain fell on the day prior to sampling (Fig. 4). Consequently, the highest water content was in the surface layer, and there were no effects of fertilizer within this layer. For the deeper layers, water content decreased with depth and was lower for the fertilized plots (Fig. 5). For this sampling, the oily waste did not affect water content but there was a significant ($P < 0.05$) interaction between soil depth and fertilization on soil water content.

In 1995, the soil was sampled four days after 4.5 mm of rain and one day after 2 mm (Fig. 4). For this sampling in all layers, soil water increased with increasing levels of oily wastes added (Fig. 5). As in the previous year, there were small effects of fertilization in the surface layer. However, for the deeper layers, water content was lower for the fertilized plots (Fig. 5). This effect was independent of the amount of oily waste added, presumably as a consequence of a greater consumption of water by plant in fertilized plots. The plant roots in dry heath ecosystems do not normally absorb water from the superficial layers due to soil moisture is strictly confined to times when a recent rain occurs (Pate, 1994). Thus differences in water absorption by plants are expected to occur mostly below the first centimetres of the soil profile. The analysis of variance performed on all data sets indicated significant effects on soil water content by the three analyzed factors: the level of oily wastes added, the fertilization, and the soil depth (Table 2). In addition, there was a significant interaction between oily waste and soil depth (Table 2).

The results described here were consistent with the effect of oily waste in preserving moisture in soil reported in previous experiments. In glasshouse the addition of oily waste on the current soil increased water retention and soil temperature. At field, it was suggested that oily waste applications enhanced potato yield by increasing water conservation in soil (Mendoza et al., 1995a).

Oily Waste, Plant Cover, and Fertilization

The total plant cover of vegetation was increased both by addition of oily wastes and of fertilizers but these variables did not interact on plant cover (Fig. 6). Furthermore, the benefit from fertilization was greater in 1995 than in 1994 reflecting the slow development of plants in cold climate (Fig. 6). In 1994 and 1995, floristic observations of vegetation showed the presence of *Dactylis glomerata* and *Festuca magellanica* as predominant grasses, and of *Rumex acetosella* and *Senecio patagonicus* as predominant forbs. The percentage cover of *Festuca magellanica* (Fig. 7) and of *Senecio patagonicus* (Fig. 8) was low in 1994 and 1995, and was not significantly affected by oily waste or fertilizers additions. The percentage cover of *Dactylis glomerata* (Fig. 7) and of *Rumex acetosella* (Fig. 8) increased by fertilization and there was no significant effect of oily waste treatment on percentage cover. Once again, the benefit was greater in 1995 than in 1994 supporting the results observed for total plant cover (Fig. 6).

In fact, there were three effects that interacted among them but affected soil water content, and to determinate the amount of plant cover. They were: the level of oily waste added, the recent rainfall before sampling, and the fertilization. The increase in plant growth, increased the consumption of water specially below the first centimetres of the soil profile where the roots mass are generally concentrated. Thus, the differences in soil water content between fertilized and unfertilized plots tend to be higher with depth rather in the superficial layer (Fig. 5). This is the second field experiment we have found an increase in plant growth related to an effect of oily waste application in a cold dry climate. The result was ascribed to the capacity of oily waste has for conserving soil moisture when water supply is limiting for plant growth (Mendoza et al, 1995a).

Oily Waste and Soil pH

The soil pH of the plots that received oily wastes applications increased. This effect was mainly observed in the first two sampling, but the effect did not remain with time (Fig. 9). The increase in soil pH with oily waste has been previously reported (Mendoza and Rodriguez, 1996; Mendoza, 1998), probably due to the buffer capacity of the applied waste (Loehr et al, 1992). Initially, fertilization by urea and triplesuperphosphate decreased soil pH, but the effect disappeared with time (Fig. 9).

The soil pH also increased with time. This increase was independent of the level of oily wastes added but observed also in the control treatments (Fig. 9). An increase in the proportion of leaf litter of *E. rubrum* is related to a decrease in soil pH (Mendoza et al., 1995b). Further, changes in soil pH with time on these heath soils were ascribed to the different proportion of litter of *E. rubrum* or *D. glomerata*

(Mendoza and Collantes, 1998). In the present experiment, the native prostrate shrubs were partially removed after ploughing and then *D. glomerata* was sown. Thus, the amount and the type of litter present in soil changed with time. This effect may had caused the increase in soil pH with time.

TPH with Time

The TPH concentration in soil decreased consistently during the experimental period (Fig. 10). There was no effect of fertilization on the decrease of TPH in soil. At the end of the experiment in December 1995, the maximum values of TPH in soil were near to 0.2 %. The high content of organic matter (19.2 %) in the soil used may have caused interference with the method used (Gaglione and Johnston, 1995), and may have obscured differences among treatments. Nevertheless, the magnitude of the decrease of the initial rates of oily wastes added with time were sufficient to justify that TPH in soil decreased to an acceptable values for plant growth.

Previous studies showed that clay minerals and organic matter can adsorb organic pollutants thereby, decreasing hydrocarbons infiltration through the soil profile (Kowalska et al, 1992). The present soil has a high organic matter content, thus a greater proportion of hydrocarbons would be adsorbed, reducing the risk of groundwater contamination. Further, evidence of the low risk of hydrocarbon migration in these heath soils is a study in which a 8.5 % TPH w/w on the top 3 cm of the soil was applied, showed only 0.97 and 0.08 % TPH at 6 and 9 cm depth respectively (Mendoza et al, 1996).

During the 3-years experiment, with exception of the periods April-June 1993, and December 1994-March 1995, precipitation was higher than the mean period of ten years (Fig. 2). Further, the seasonal distribution of rainfall over a 30-years period indicated that 33 % of the annual rainfall takes place in summer when air temperature increases. This together with the air temperature measured close to the field site (Fig. 1), suggests that from September to March both soil moisture and soil temperature were suitable to promote oily waste degradation.

General discussion

The previous and the current results suggest that in a dry cold climate and in a nutrient deficient soil, as is the case for the heath soils in Tierra del Fuego, the addition of oily waste at appropriate levels is able to preserve losses of soil water and that effect increases plant growth. Increasing plant growth and soil moisture are important factors to promote oily waste degradation (Banks et al, 1997; Ferro et al, 1997; Gould et al., 1997).

The present work also shows that the addition of the oily wastes to these heath soils of low forage production is a cost-effective technique to eliminate the accumulated petroleum residues from undesirable sites. The effect of the rate of addition of oily waste on plant growth differs between laboratory and field experiments. In the laboratory, 1 % of oily waste was low enough to prevent water table contamination, but depressed plant growth (Mendoza, 1998). Under these conditions, water supply is not limiting for plant growth but the oily waste added even at low rate depressed plant growth. In contrast for field conditions where water supply is limiting, rates of oily waste near 3 % promoted plant growth by decreasing water losses. The elevation of the water table and the annual precipitation measured at the experimental site together with the low hydrocarbon migration in these heath soils suggest that the risk of groundwater contamination is relative low.

Even thought no much effort has been devoted to investigate degradation rates and organic components of the oily waste added, the magnitude of the decrease of TPH in soil during a 3-years period was sufficient to conclude that petroleum residues can be reduced low enough to restore the initial values of total cover of vegetation. The established plant community had a higher forage value relative to the native community at field site. Further research is needed to determine appropriate levels and kind of fertilizers to reach maximum plant growth and maximum rates of oily waste degradation.

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References

Aerts R. 1989. Aboveground Biomass and Nutrient Dynamics of Calluna vulgaris and Molinia caerulea in dry heathland. *Oikos* 56: 31-38.

Atlas R. M. 1981. Microbial Degradation of Petroleum Hydrocarbons: An Environmental Perspective. *Microbiological Re.*, 45: 180-209.

Banks M. K., S. Pekarek, K. Rathbone and P. Schwab. 1997. Phytoremediation of Petroleum Contaminated Soils: Field Assessment. *In Situ On-Site Bioremediation. The Fourth International Symposium.* Volume 3: 305-308. New Orleans 1997

Bower C. A. and W. Wilcox. 1965. Soluble Salts. In: *Methods of Soil Analysis, Agronomy N° 9*. Part 2, pp 933-940 (Black C. A., et al. Eds.). American Society of Agronomy. Madison. Wisconsin. USA.

Bray R. H. and L. T. Kurtz. 1945. Determination of Total, Organic and Available Form of Phosphorus in Soils. *Soil Sci*. 59: 39-45.

Bremmer J. M and C. S. Mulvaney. 1982. Nitrogen-total. In: *Methods of Soil Analysis, Agronomy N° 9*. Part 2, pp 610-616. (Page A. L., et al. Eds.). American Society of Agronomy. Madison. Wisconsin. USA.

Chapman H. D. 1965. Cation-exchange Capacity. In: *Methods of Soil Analysis, Agronomy Nº 9*. Part 2, pp 894-899. (Black C. A., et al. Ed.). American Society of Agronomy. Madison. Wisconsin. USA.

Chapman H. D. 1965. Total Exchangeable Bases. In: *Methods of Soil Analysis, Agronomy Nº 9*. Part 2, pp 902-904. (Black C. A., et al. Ed.). American Society of Agronomy. Madison. Wisconsin. USA.

Collantes M. B., J. Anchorena and G. Koremblit. 1989. A Soil Nutrient Gradient in Magellanic *Empetrum* Heathlands. *Vegetatio* 80: 183-193.

Collantes M. B., and J. Anchorena. 1993. Las Malezas Exóticas y Plantas Escapadas de Cultivo en la Región de Estepa de Tierra del Fuego. *Parodiana* 8: 213-217.

du Plessis C. A., C. B. Phaal and E. Senior. 1995. Bioremediation of Soil Contaminated with Hydrocarbons and Heavy Metals. In: *Applied Bioremediation of Petroleum Hydrocarbons*. pp. 107-113. (Hinchee E., Kittel J. and H. Reisinger. Eds). Battelle Press. Columbus. USA.

Ferro A., J. Kennedy and D. Knight. 1997. Greenhouse-scale Evaluation of Phytoremediation for Soils Contaminated with Wood Preservatives. *In Situ On-Site Bioremediation. The Fourth International Symposium*. Volume 3: 309-314. New Orleans 1997.

Fuerza Aérea Argentina. 1986. Estadísticas de Datos Meterológicos. *Servicio Meteorológico Nacional. Buenos Aires*.

Gaglione R. J., and R. S. Johnston. 1995. Use of Bioremediation to Resolve a Petroleum Hydrocarbons Contamination Lawsuit. In: *Applied Bioremediation of Petroleum Hydrocarbons*. pp. 89-95. (Hinchee E., Kittel J. and H. Reisinger. Eds). Battelle Press. Columbus. USA.

Gee G. W., and J. W. Bauder. 1986. Particle-size Analysis. In: *Methods of Soil Analysis, Agronomy Nº 9*. Part 1, 383-409. (Klute A., Ed.). American Society of Agronomy. Madison. Wisconsin. USA.

Gould T. F., M. J. Schmetzer, M. N. Wallace, and T. M. Deardorff. 1997. In Situ Aeration and Vadose Zone Moisture and Nutrient Conditioning Via Air Lift Pumping. *In Situ On-Site Bioremediation. The Fourth International Symposium*. Volume 1: 295. New Orleans 1997.

Hillel D. 1989. Movement and Retention of Organics in Soil: A Review and a Critique of Modelling. In, *Petroleum Contaminated Soils*, (1) pp. 81-86. (P. Kostecki and E. Calabrese. Eds.). Lewis Publishers, Chelsea, MI. USA.

Koremblit G., and J. Forte Lay. 1991. Contribution to the Agroclimatic Study from the North of Tierra del Fuego (Argentina). *Ans. Ins. Pat. Punta Arenas (Chile)*. 20: 125-134.

Kowalska M., Guler H., and D. Cocke. 1992. Interactions of Clay Minerals with Organic Pollutants. *The Science of the Total Environment*. 141: 223-240

Lawlor K., Sublette K., Duncan K., Levetin E., Buck P., Wells H., Jennings E., Hettenbach S., Bailey S., Berton Ficher J., and T. Todd. 1997. Long-Term Effect of Crude Oil Contamination and Bioremediation in a Soil Ecosystem. *Bioremediation Journal 1*(1): 41-51.

Loehr R. C., J.H. Martin and E. F. Neuhauser. 1992. Land Treatment of an Aged Oily Sludge-Organic Loss and Change in Soil Characteristics. *Water Reserarch* 26: 805-815.

Lynch J. and R. Genes. 1989. Land Treatment of Hydrocarbon Contaminated Soil. In: *Petroleum Contaminated Soils*, (1) pp. 163-174. (P. Kostecki and E. Calabrese. Eds.). Lewis Publishers, Chelsea, MI. USA.

Mendoza R. E. 1998. Hydrocarbons Leaching, Microbial Population and Plant yield in Soil Amended with Petroleum. *Bioremediation Journal*. Accepted for Publication.

Mendoza R. E. and R. Rodriguez. 1996. Empleo de Residuos Organicos de Petróleo (ROP) en Suelos Agrícolas. 3 Biodegradación del Residuo en Condiciones Controladas. In: *2das Jornadas, Preservación del Agua, Aire y Suelo en la Industria Petrolera*. pp. 47-56. Instituto Argentino del Petróleo. San Martín de los Andes. Argentina.

Mendoza R. E. and M. Collantes. 1998. Efecto del Aumento de la Fertilidad en un Murtillar Xerico de la Estepa Fueguina sobre la Vegetación Nativa y la Producción de Forraje. *Ciencia del Suelo*. Submitted for Publication.

Mendoza R., D. Caldiz, O. Caso, G. Vater, and R. Portal. 1996. Empleo de Residuos Orgánicos de Petróleo (ROP) en Suelos Agrícolas. 2 Efecto Sobre la Conservación de la Humedad del Suelo y la Producción de Papa para Semilla. *2das Jornadas, Preservación del Agua, Aires y Suelo en la Industria Petrolera*. pp. 31-45. Instituto Argentino del Petróleo. San Martín de los Andes. Argentina.

Mendoza R., M. Taboada, D. Rodriguez, O. Caso, and R. Portal. 1995a. Use of Oily Waste Organics as Amendment of Soils. In: *Applied Bioremediation of Petroleum Hydrocarbons*. pp. 319-328. (Hinchee E., Kittel J. and H. Reisinger. Eds). Battelle Press. Columbus. USA.

Mendoza R. E., M. Collantes, J. Anchorena, and S. Cainzos. 1995b. Effect of Liming and Fertilization on Forage Yield and Vegetation in Dry Heath Soil from Tierra del Fuego. *Journal of Plant Nutrition* 18: 401-420.

Pate J. S. 1994. The Mycorrhizal association: Just One of Many Nutrient Acquiring Specialization in Natural Ecosystems. In: *Management of Mycorrhizas in Agriculture, Horticulture and Forestry*. pp 1-10. (A. D. Robson, L. K. Abbott and N. Malajczuk. Eds). Kluwer Academic Publishers. Dordrecht. The Netherlands.

Peech M. 1965. Hydrogen-ion activity. In: *Methods of Soil Analysis, Agronomy N° 9*. Part 2, pp 914-926. (Black C. A., et al. Eds.). American Society of Agronomy. Madison. Wisconsin. USA.

Preslo L., M. Miller, W. Suyama, M. Mac Learn, P. Kostecki, and E. Fleischer. 1989. Available Remedial Technologies for Petroleum Contaminated Soils. In: *Petroleum Contaminated Soils*, (1) pp. 115-125 (P. Kostecki and E. Calabrese. Eds.). Lewis Publishers, Chelsea, MI. USA.

Richter M. and E. von Wistinghausen. 1981. Unterscheidbarkeit von Humusfraktionen in Boden bei Unterschiedlicher Bewirtschaftung. *Z Pflanzenernaehr Bodenk* 144: 395-406.

Sveum P., and S. Ramstad. 1995. Bioremediation of Oil on Shorelines with Organic and Inoganic Nutrients. In: *Applied Bioremediation of Petroleum Hydrocarbons*. pp. 201-217. (Hinchee E., Kittel J. and H. Reisinger. Eds). Battelle Press. Columbus. USA.

Westhoff V., and Van der Maare. 1978. The Barun-Blanquet Approach. In. *Classification of Plant Communities*, pp 287-399. (R. H. Whittaker. De). Junk, The Hague Switzerland.

Table 1. Some Physical and chemical Characteristics of the Top Soil Used.

Parameter. Method Used	Value
Texture: Gee and Bander (1986).	loam
Sand (%)	46.70
Loam (%)	33.70
Clay (%)	19.60
pH (1:2.5, water). Peech (1965)	4.9
pH (1:2.5, 1 *M* KCl). Peech (1965)	4.2
Electrical Conductivity (dS/m). Bower and Wilcox (1965)	0.4
Total Organic Carbon (%). Richter and Wistinghausen(1981)	9.60
Organic Matter (% estimated).	19.2
Nitrogen (%). Bremmer and Mulvaney (1982)	0.52
Phosphorus (ppm). Bray and Kurtz (1945)	2.40
Cation Exchange Capacity ($cmol_{(c)}/kg$). Chapman (1965)	23.24
Exchangeable Bases. Chapman (1965).	
Calcium ($cmol_{(c)}/kg$)	6.8
Magnesium ($cmol_{(c)}/kg$)	5.0
Sodium ($cmol_{(c)}/kg$)	1.1
Potassium ($cmol_{(c)}/kg$)	1.3

Table 2. Analysis of Variance of soil water content as described by a best fit model against level of oily wastes added, fertilization, and soil depth. *F* value test by the significance of the type III sum of squares of each term in the model.

Source of variation	d.f	*F* ratio	Sig. level
Main Effects			
Oily Waste	2	6.492	0.0039 **
Fertilization	1	10.817	0.0023 **
Soil Depth	2	20.740	0.0000 ***
Interactions			
Oily Waste x Fertilization	2	0.687	0.5098 ns
Oily Waste x Soil Depth	4	3.630	0.0139 *
Fertilization x Soil Depth	2	0.233	0.7936 ns
Oily Waste x Fertilization x Soil Depth	4	0.343	0.8470 ns
Residual	36		

* = significant at $P < 0.05$.

** = significant at $P < 0.01$.

*** = significant at $P < 0.001$.

ns = no significant at $P < 0.05$.

Legends of the figures

Figure 1. Maximum and minimum monthly average air temperature at the weather station close to the field site.
Figure 2. Mean monthly precipitation at the weather station close to the field site.
Figure 3. Straight and branched-chain hydrocarbons concentration as a function of carbon number for the oily waste used.
Figure 4. December daily precipitation at the field site for the 3-years experiment.
Figure 5. Effect of oily waste and fertilization on soil water content at the field site for the 3-years experiment. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.
Figure 6. Total plant cover of vegetation for 2-years sampling affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.
Figure 7. Percentage cover of predominat grasses (*D. glomerata* and *F. magellanica*) for 2-years sampling affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.
Figure 8. Percentage cover of predominat forbs (*R. acetosella* and *S. patagonicus*) for 2-years sampling affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments. Bars indicate LSD = 5 %.
Figure 9. Effect of oily waste and fertilization on soil pH after 3-years sampling. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments Bars indicate LSD = 5 %.
Figure 10. Effect of time on the decrease of TPH in soil affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

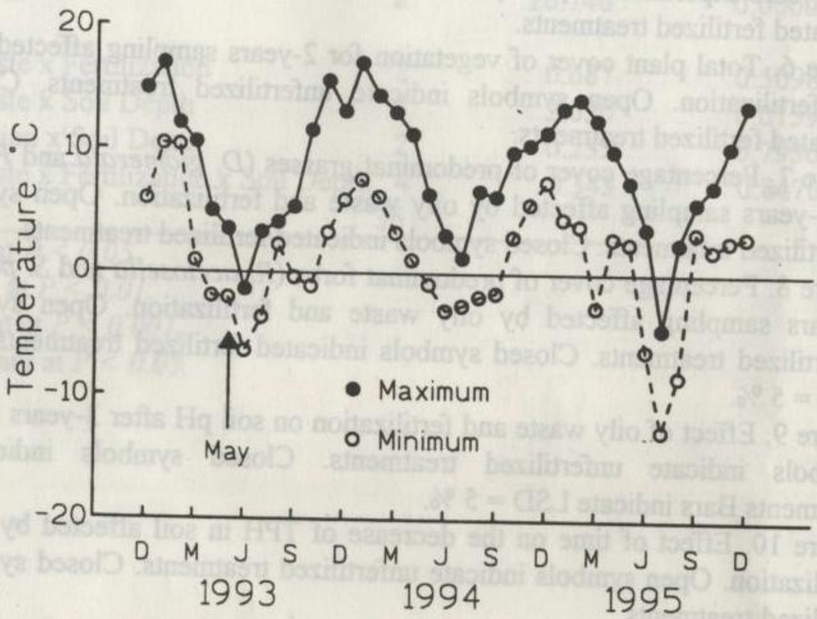

Figure 1. Maximum and minimum monthly average air temperature at the weather station close to the field site.

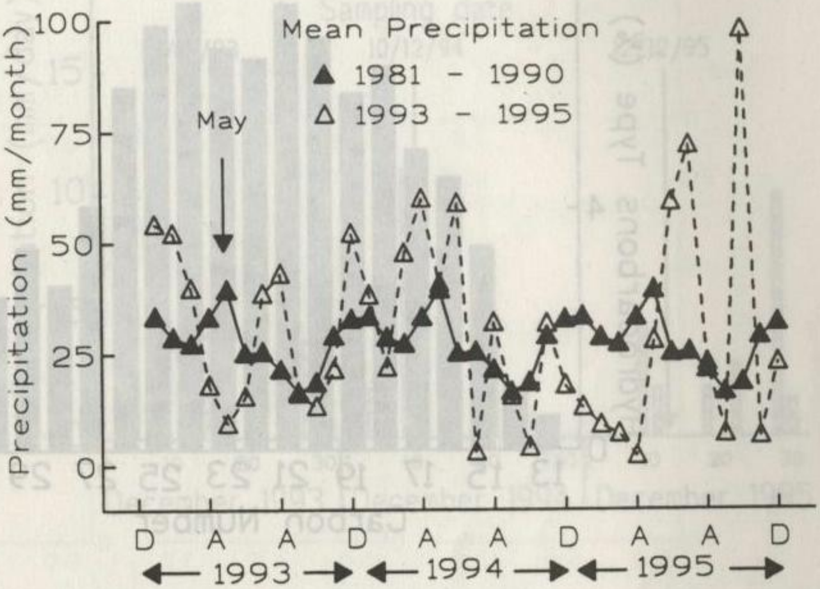

Figure 2. Mean monthly precipitation at the weather station close to the field site.

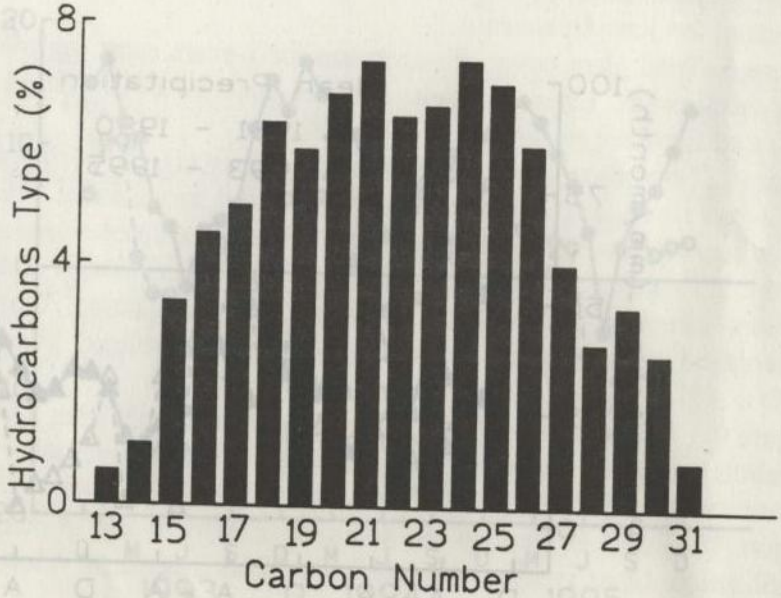

Figure 3. Straight and branched-chain hydrocarbons concentration as a function of carbon number for the oily waste used.

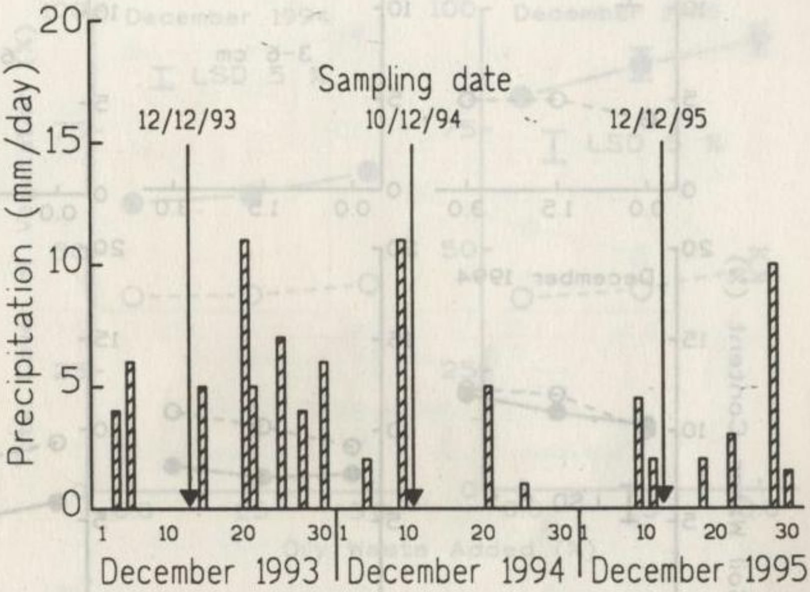

Figure 4. December daily precipitation at the field site for the 3-years experiment.

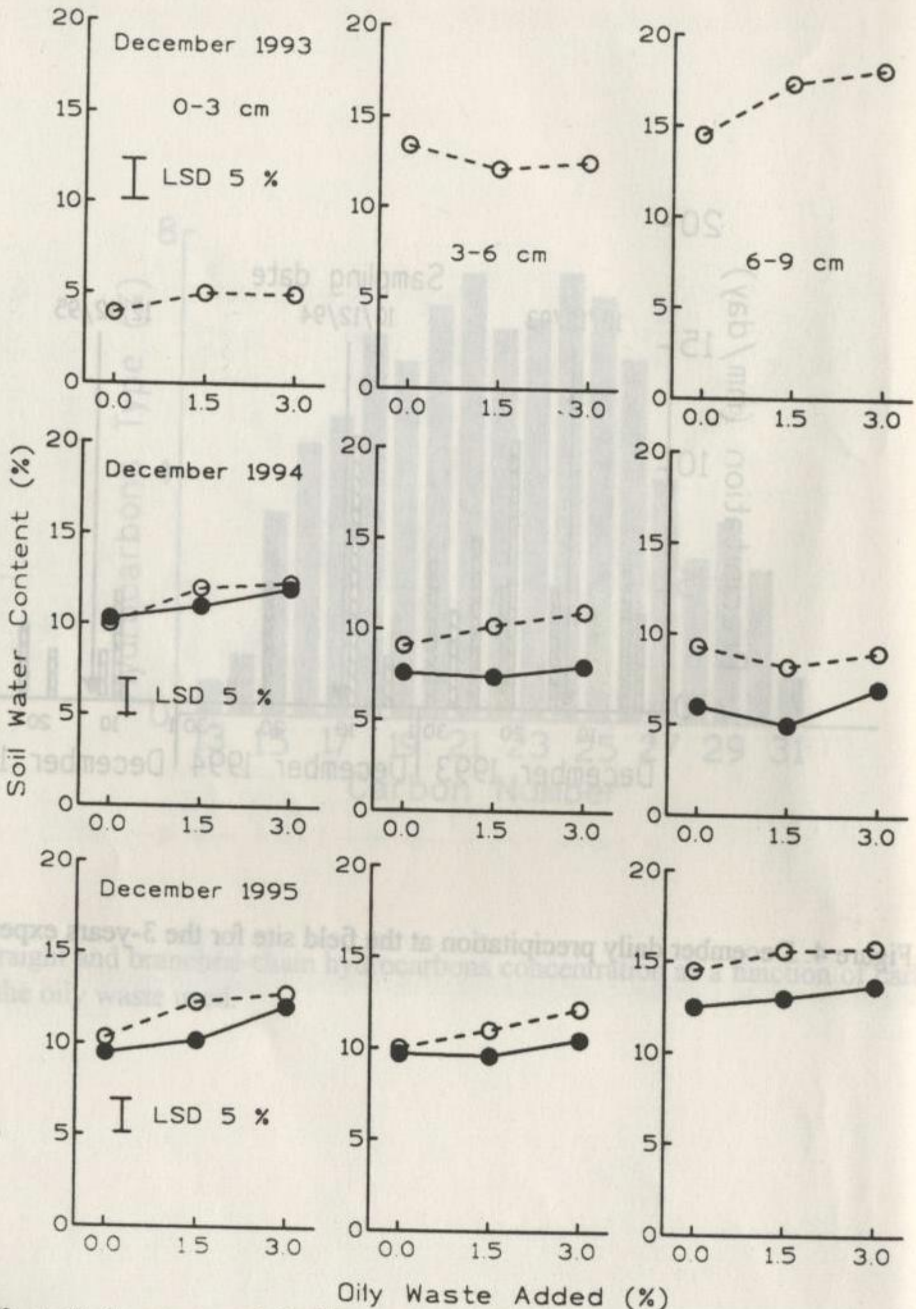

Figure 5. Effect of oily waste and fertilization on soil water content at the field site. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

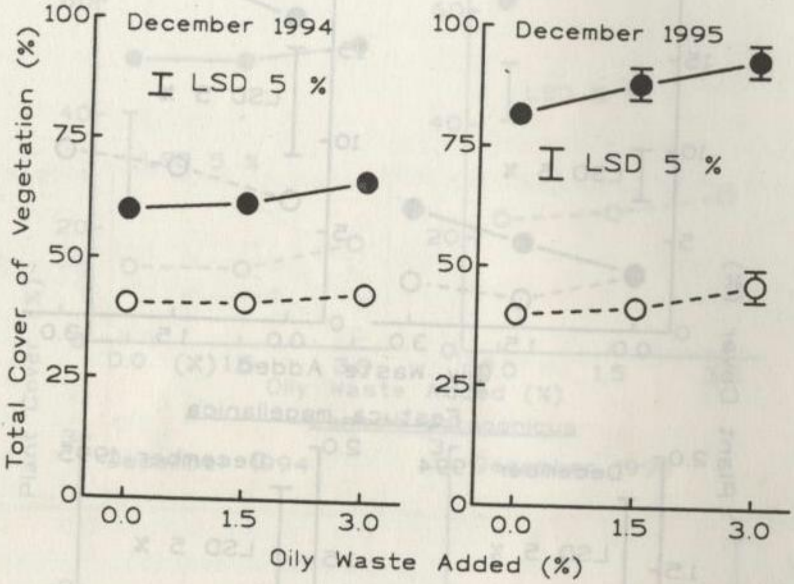

Figure 6. Total plant cover of vegetation for 2-years sampling affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

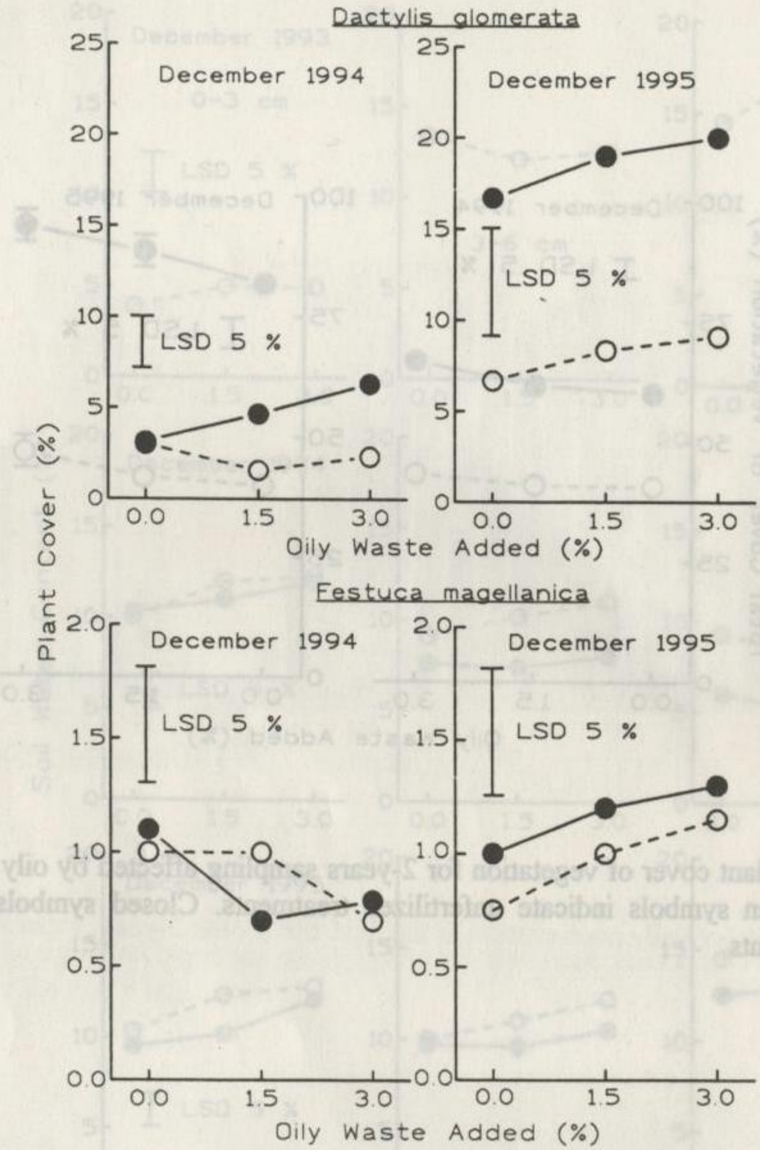

Figure 7. Percentage cover of predominat grasses (*D. glomerata* and *F. magellanica*) for 2-years sampling affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

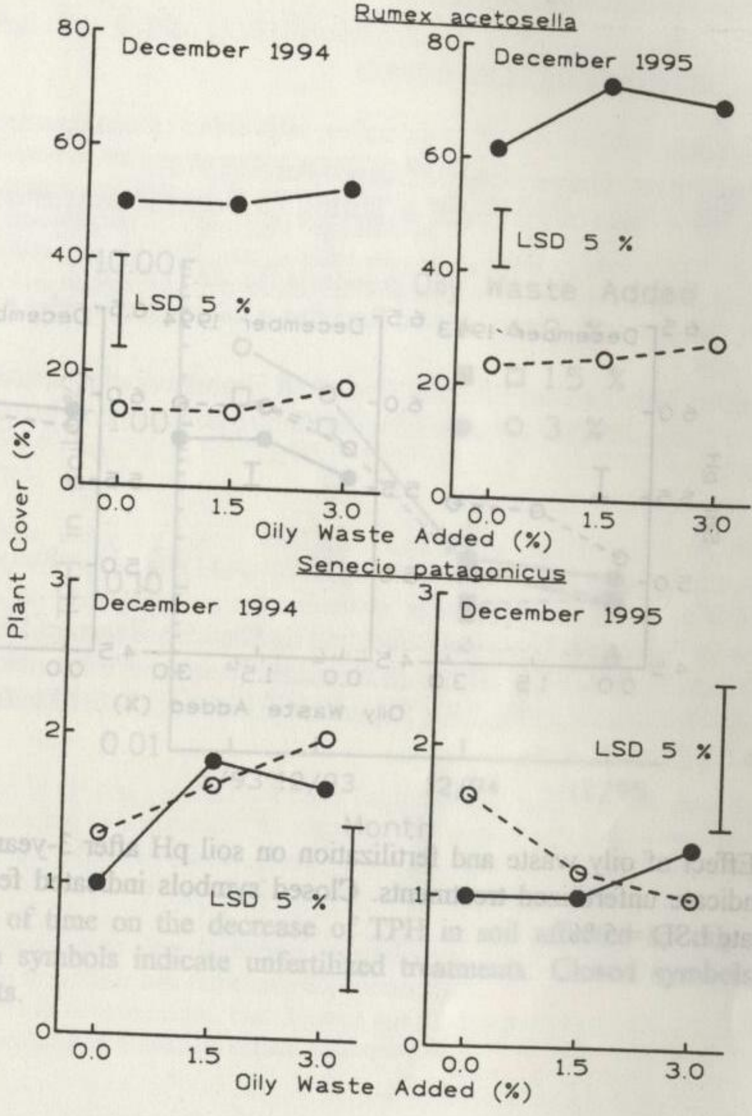

Figure 8. Percentage cover of predominat forbs (*R. acetosella* and *S. patagonicus*) for 2-years sampling affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments. Bars indicate LSD = 5 %.

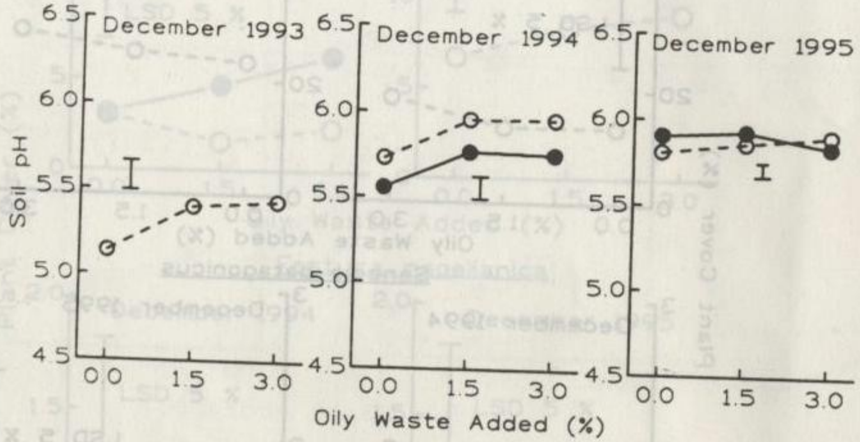

Figure 9. Effect of oily waste and fertilization on soil pH after 3-years sampling. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments Bars indicate LSD = 5 %.

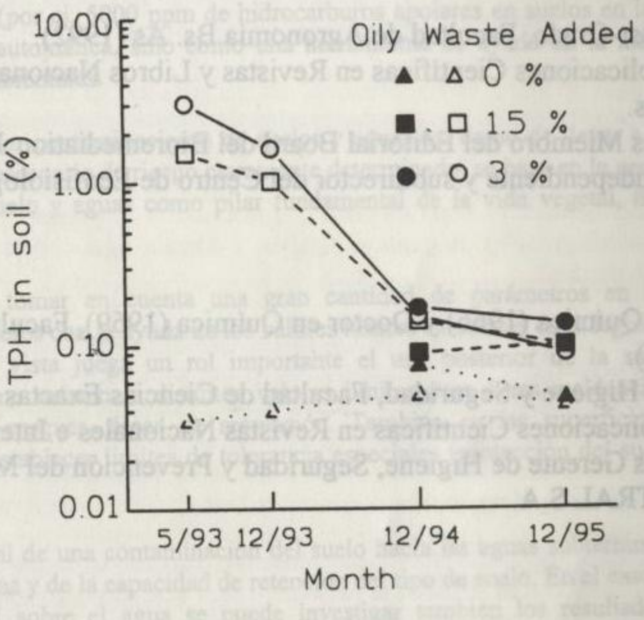

Figure 10. Effect of time on the decrease of TPH in soil affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

CHANGES IN SOIL CHARACTERISTICS AND VEGETATION BY LANDFARMING OF PETROLEUM WASTES IN A COLD DRY CLIMATE

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