LANDFARMING OF PETROLEUM WASTES IN A COLD DRY CLIMATE OF TIERRA DEL FUEGO. EFFECT ON SOIL AND VEGETATION.

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The effect of adding organic oily wastes on plant cover and on soil water content was studied in a soil covered by a community of low forage value in Tierra del Fuego (Argentina). Oily wastes were mixed with the top 3 cm of the soil in May 1993 at rates of 1.51 and 3.03 % (w/w basis). 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 0-3, 3-6 and 6-9 cm depths were taken in December of 1993-1995, and analyzed 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.

Key words: landfarming, cold climate, oily wastes, soil water, plant cover.

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 most of the year. In this region, as a consequence of intensive sheep-grazing during the last 100 years, prostrate evergreen shrubs 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 consisted of pumping and recovering the free petroleum. Nevertheless, a considerable amount of contaminant residues that remain on the surface must be eliminated.

Landfarming is one technology for eliminating 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, Genes 1989). Soil temperature and water content are important factors controlling the oil degradation by the microbial community (Atlas 1981). Previous studies in soil from Tierra del Fuego have shown that oily waste applications increased soil temperature and soil water content (Mendoza *et al.* 1995a). In addition, low water content and nutrient availability in these soils were identified as potential factors that limited plant growth (Collantes *et al.* 1989; Mendoza *et al.* 1995b).

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 amount of residue to dilute with the topsoil 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.

The purpose of the present field experiment was to evaluate the effect of adding petroleum residues to the soil on soil characteristics that, in turn, may affect plant growth. In addition, to evaluate the decline of petroleum hydrocarbons with time in order to know the impact of large applications of oily waste residues at full-scale. This work is particularly important because no direct documentation is available on landfarming in cold and dry climate at the latitude of the field site in the southern hemisphere.

MATERIALS AND METHODS

Site Description and Soil Characterization

The study was located in Northern Tierra del Fuego (Argentina) in a complex of moraine deposits and melting plains. The climate is cold, dry and windy during most of the year. The average maximum temperature in July (winter) is about 0 ºC, and in January (summer) it reaches 15 ºC. The mean annual rainfall over a 10-year period, ranged from 250 to 350 mm. At the field site, the water table elevation varies from 12 m (summer) to 8 m (winter) below the ground surface. The temperature and rainfall at the field site were recorded.

The experimental site was on an acid heath soil 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 grasses comprising only 7%, *Festuca magellanica* (5%) and *Deschampsia flexuosa* (2%). The soil was a loam classified as a Umbrept. It was characterized by high acidity, high organic matter, and low base saturation, and is nutrient deficient for plant growth (Table 1). The criteria used to select the 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 water content, and low nutrient availability in the soil have been identified as potential factors limiting plant growth (Collantes *et al.* 1989; Mendoza *et al.* 1995b). Adding oily waste and fertilizers may increase plant growth by increasing water content and nutrient availability in soil.

3. Previous studies in a laboratory have demonstrated both the capacity of the soil to retain petroleum hydrocarbons, thus decreasing the risk to contaminate the groundwater, and that hydrocarbon concentrations of oily waste decreased significantly in soil with time (Mendoza, Rodriguez 1996; Mendoza, 1998).

The experiment

The topsoil (10 cm) was ploughed and oily wastes were distributed on the surface at rates of 0, 0.5 and 1 kg/m^2 and mixed homogeneously into the top 5 cm. 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

Table 1. Initial physical and chemical characteristics of the topsoil used.

Parameter. (Method used)	Value
Texture: (Gee, Bander 1986).	loam
Sand (%)	46.7
Loam (%)	33.7
Clay (%)	19.6
pH (1:2.5, water). (Peech 1965)	5.1
pH (1:2.5, 0.01 *M* $CaCl_2$). (Peech 1965)	4.7
Electrical conductivity (dS/m). (Bower, Wilcox 1965)	0.4
Total organic carbon (%). (Richter, Wistinghausen 1981)	9.6
Organic matter (% estimated).	19.2
Nitrogen (%). (Bremmer, Mulvaney 1982)	0.52
Phosphorus (ppm). (Bray, Kurtz 1945)	2.4
Cation exchange capacity ($cmol_{(c)}$/kg). (Chapman 1965a)	23.24
Exchangeable bases. (Chapman 1965b).	
Calcium ($cmol_{(c)}$/kg)	6.8
Magnesium ($cmol_{(c)}$/kg)	5.0
Sodium ($cmol_{(c)}$/kg)	1.1
Potassium ($cmol_{(c)}$/kg)	1.3

was cut and then partially removed from the experimental site. Plots were 5 x 3 m, and the treatments were replicated three times. The experiment was initiated in May 1993 when the oily waste was applied. From each plot, a composited 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 analyzed for pH, CEC (cation exchange capacity), exchangeable bases (Ca, Mg, Na and K), soil water content and total petroleum hydrocarbon (TPH) concentration. TPH was measured by the infrared (IF) spectrometer method (EPA test method No. 418.1; Kopp, 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 of ploughing nine months earlier. This permitted an appropriate preparation of the soil surface for sowing. No subsequent cultivation occurred during the experiment. 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). In addition, the presence and the number of different plant species per plot were identified.

The Oily Waste Used

The oily waste was a weathered mix of a viscous petroleum (97%) with a small proportion of rock and soil (3%). The oily waste residue was collected in May 1993 from a lagoon near an abandoned petroleum well. The residue was characterised 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}, and 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.

Statistical Analysis

Differences among treatments were determined by an Analysis of Variance (ANOVA) Type III Sums of Squares, and the LSD test at a $P < 0.05$ was used to analyzed the multiple comparisons.

RESULTS AND DISCUSSION

Oily Waste and Soil Water Content

The water 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 water losses from the soil. In 1993, there had been no rain ten days prior to sampling. Furthermore, the plant cover was sparse because of the ploughing nine months earlier and the slow plant growth in the cold climate. At this time the observation indicated that vegetation was dominated by *Rumex acetosella* with a 10% 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 (Figure 1). On this occasion, the oily waste had not been effective in preserving water in the top layers, but had been effective at the 6-9 cm depth.

In 1994, 11 mm of rain fell on the day prior to sampling. Consequently, the highest water content was in the surface layer, and there were no effects of fertilizer within this layer (Figure 1). For the deeper layers, water content decreased with depth and was lower for the fertilized plots. For this sampling, the oily waste did not affect water content but there

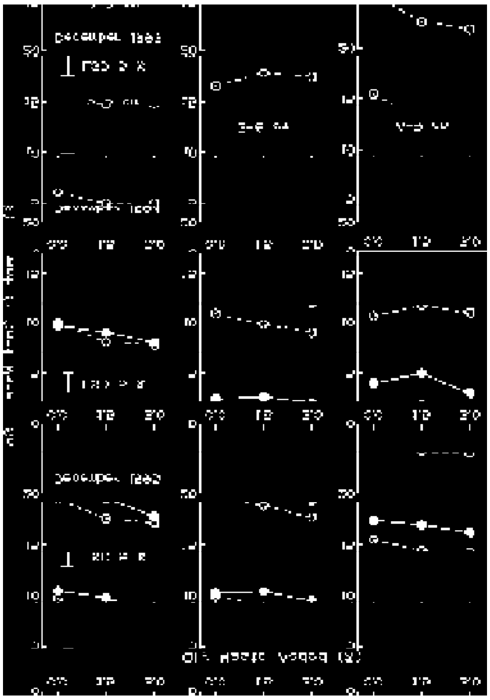

Figure 1. Effect of oily waste and fertilization on soil water content at the field site for the 3-years experiment. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

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. For this sampling in all layers, soil water content increased with increasing levels of oily wastes added (Figure 1). 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 (Figure 1). This effect was independent of the amount of oily waste added, presumably as a consequence of a greater water use by plants in fertilized plots. Plant roots in dry heath ecosystems do not normally absorb water from superficial layers because soil water is strictly limited to times when a recent rain has occurred (Pate 1994). Thus differences in water absorption by plants are expected to occur mostly below the first centimeters 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 water in soil reported in previous experiments. In a glasshouse, the addition of oily waste on the soil increased water retention and soil temperature. In a field study, it was suggested that oily waste applications enhanced potato yield by increasing water conservation in soil (Mendoza *et al*. 1995a).

Oily Waste, Plant Cover, Diversity and Fertilization

Total plant cover of vegetation was increased both by addition of oily wastes and fertilizers, but these variables did not have an interacting effect on plant cover (Figure 2). Furthermore, the benefit from fertilization was greater in 1995 than in 1994 reflecting the slow development of plants in the cold climate (Figure 2). In 1994 and 1995, *Dactylis glomerata* and *Festuca magellanica* were the predominant grasses, and *Rumex acetosella* and *Senecio patagonicus* the predominant forbs. *D. glomerata* reached a maximum of 20 % of total plant cover 1995, whereas *R. acetosella,* that is a typical alien specie present in areas highly disturbed by grazing, adapted to acid and nutrient deficient habitats (Collantes, Anchorena 1993), had near of 75% of total plant cover.

The number of different species of plant identified per plot did not change with oily waste but decreased in the fertilized plot (Figure 3), suggesting no effect of the oily wastes on plant diversity. However, by increas-

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..

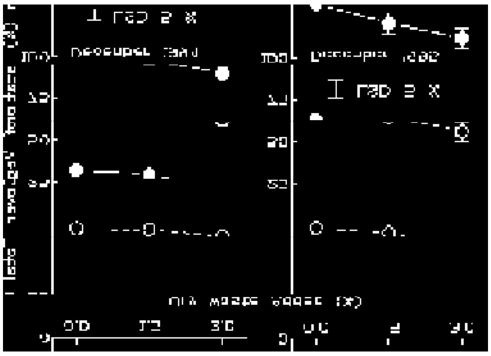

Figure 2. Total plant cover of vegetation for 2-years sampling affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

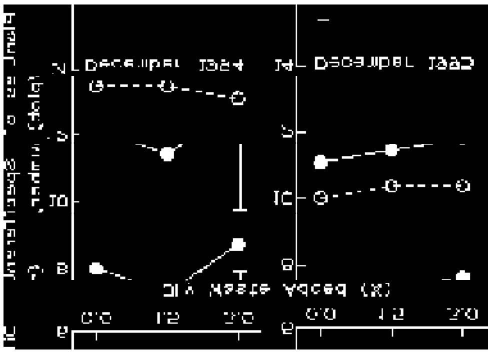

Figure 3. Effect of oily waste and fertilization on different number of plant species identified. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

ing the rates applied, oily wastes may decrease plant diversity (Lawlor *et al.* 1997). Fertilization increases total cover of vegetation (Figure 2). As consequence, the competition among the species present also increases but this effect may decrease plant diversity (Figure 3). This may explain the negative effect of fertilization on plant diversity.

Three factors had an interacting effect on soil water content and on 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 use of water especially from below the first centimeters of the soil profile where most roots are generally concentrated. Thus, the differences in soil water content between fertilized and unfertilized plots tend to be greater with depth rather in the superficial layer (Figure 1). This is the second field experiment in which 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 water when the water supply is limiting for plant growth (Mendoza *et al.* 1995a).

Oily Waste and Soil Characteristics

Oily wastes applications increased the soil pH. This effect was mainly observed in the first two samples (Fig. 4). The increase in soil pH with oily waste applications has been previously reported (Mendoza, Rodriguez 1996; Mendoza 1998), and was 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 (Figure 4).

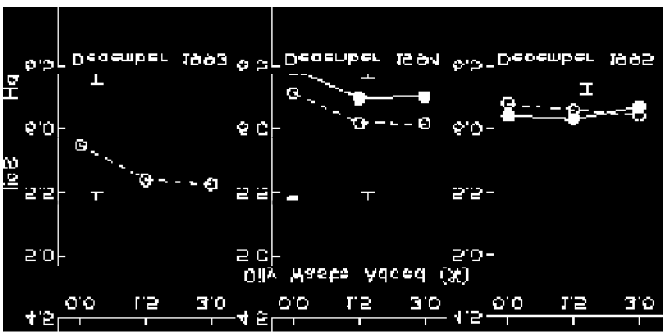

Figure 4. Effect of oily waste and fertilization on soil pH after 3-years sampling. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments Bars indicate LSD = 5 %.

The soil pH also increased with time. This increase was independent of the level of oily wastes added but was observed also for the control treatments (Figure 4). 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, 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 have caused the increase in soil pH with time.

The cation exchange capacity (CEC), and exchangeable bases (Ca, Mg, Na and K) of the soil were not changed by the addition of oily waste after 7 months from the applications. Thus, these were measured only for the first sampling in December 1993 (not shown).

Total Petroleum Hydrocarbon with Time

The TPH concentration in soil decreased consistently during the experimental period (Figure 5). 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 interfered with the method used (Gaglione, 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 acceptable values for plant growth.

Previous studies showed that clay minerals and organic matter can adsorb organic pollutants, thereby decreasing hydrocarbon movement 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 from a study in which 8.5 % TPH (w/w) was applied on the top 3 cm of the soil. Only 0.97 and 0.08 % TPH were found at 6 and 9 cm depths, respectively (Mendoza *et al.* 1996).

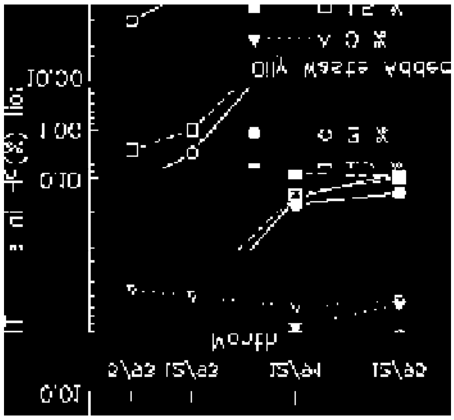

Figure 5. Effect of time on the decrease of TPH in soil affected by oily waste and fertilization. Open symbols indicate unfertilized treatments. Closed symbols indicated fertilized treatments.

During the present 3-year experiment the precipitation was higher than the mean for a 10-year period. 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, suggests that from September to March both soil water and soil temperature were suitable to promote oily waste degradation.

CONCLUSIONS

The previous and the current studies suggest that in a dry cold climate and nutrient deficient soils, 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 may increase plant growth. Increasing plant growth and soil water content are important factors to promote oily waste degradation (Banks *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, the 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 no risk to contaminate groundwater.

Even though not 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 existing at the field site. Further research is needed to determine appropriate levels and kinds of fertilizers to reach maximum plant growth and maximum rates of oily waste degradation.

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REFERENCES

Atlas RM. 1981. Microbial degradation of petroleum hydrocarbons: An environmental perspective. Microbiological Re., 45: 180-209.

Banks MK, Pekarek S, Rathbone K, Schwab P. 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 CA, Wilcox W. 1965. Soluble salts. In: *Methods of Soil Analysis, Agronomy Nº 9*. Part 2, pp 933-940 (Black C. A. *et al.*, Eds.). American Society of Agronomy. Madison. Wisconsin. USA.

Bray RH and Kurtz LT. 1945. Determination of total, organic and available form of phosphorus in soils. Soil Sci. 59: 39-45.

Bremmer JM, Mulvaney MS. 1982. Nitrogen-total. In: Methods of Soil Analysis, Agronomy Nº 9. Part 2, pp 610-616. (Page A. L. *et al.*, Eds.). American Society of Agronomy. Madison. Wisconsin. USA.

Chapman HD. 1965a. 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 HD. 1965b. 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 MB, Anchorena J, Koremblit G. 1989. A soil nutrient gradient in Magellanic *Empetrum* heathlands. Vegetatio 80: 183-193.

Collantes MB, Anchorena J. 1993. Las malezas exóticas y plantas escapadas de cultivo en la Región de Estepa de Tierra del Fuego. Parodiana 8: 213-217.

Gaglione RJ, Johnston RS. 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 GW, Bauder JW. 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 TF, Schmetzer MJ, Wallace MN, Deardorff TM. 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.

Kopp J, Mc Kee G. 1983. Method for chemical analysis of water and wastes. Technical Report EPA 600/4-79-020.

Kowalska M, Guler H, Cocke D. 1992. Interactions of clay minerals with organic pollutants. Sci. Total Env. 141: 223-240.

Lawlor K, Sublette K, Duncan K, Levetin E, Buck P, Wells H, Jennings E, Hettenbach S, Bailey S, Berton Ficher J, Todd T. 1997. Long-term effect of crude oil contamination and bioremediation in a soil ecosystem. Bioremediation J. 1(1): 41-51.

Loehr RC, Martin JH, Neuhauser EF. 1992. Land treatment of an aged oily sludge-organic loss and change in soil characteristics. Water Research 26: 805-815.

Lynch J, Genes R. 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 RE. 1998. Hydrocarbons Leaching, Microbial Population and Plant yield in Soil Amended with Petroleum. Bioremediation J. 1(3): 223-231.

Mendoza R, Caldiz D, Caso O, Vater G, Portal R. 1996. Empleo de residuos orgánicos de petróleo (ROP) en suelos sgrícolas. 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 RE, Collantes M. 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 16: 58-64.

Mendoza RE, Collantes M, Anchorena J, Cainzos S. 1995b. Effect of liming and fertilization on forage yield and vegetation in dry heath soil from Tierra del Fuego. J. Plant Nutrition 18: 401-420.

Mendoza RE, Rodriguez R. 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, Taboada M, Rodriguez D, Caso O, Portal R. 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.

Pate JS. 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 Nº 9. Part 2, pp 914-926. (Black C. A. *et al.*, Eds.). American Society of Agronomy. Madison. Wisconsin. USA.

Preslo L, Miller M, Suyama W, Mac Learn M, Kostecki P, Fleischer E. 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, von Wistinghausen E. 1981. Unterscheidbarkeit von Humusfraktionen in Boden bei Unterschiedlicher Bewirtschaftung. Z Pflanzenernaehr. Bodenk. 144: 395-406.

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