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Fertilizing and Seeding Oil-Damaged Arctic Tundra to Effect Vegetation Recovery

Prudhoe Bay, Alaska

A Paper Prepared

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ABSTRACT

Vegetational recovery from an accidental oil spill on a wet tundra site at Prudhoe Bay, Alaska, was studied during six growing seasons. The spilled oil consisted of 22^{o} API gravity, Prudhoe-Bay crude from which diesel and heating oil fractions had been removed by a topping process. Damages from the winter spill ranged from killing the moss layer and above-ground parts of vascular plants to killing all the macro-flora. Damage to the oil sensitive mosses persisted throughout the study even in lightly oiled areas. Test plots where commercial phosphorus fertilizers had been applied were an exception to this. Moss cover began re-establishing during the first growing season with phosphorus fertilization and continued to improve thereafter. Growth of sedges and grasses, not killed by the oil, was significantly enhanced by phosphorus fertilizations, even though oil persisted in the soil.

Revegetation attempts in a barren area during the fourth growing season after the spill resulted in establishing *Puccinellia borealis* (alkaligrass) seedlings and mosses in phosphorus-fertilized plots. Neither nitrogen nor potassium fertilizers alone and combined with each other improved growth of either resident or seeded plant species on the spill area. The more significant response was to phosphorus.

INTRODUCTION

The opportunity to study the recovery of arctic tundra vegetation following an oil spill occurred following the 10 June 1972 discovery of a leak from a 4-inch injection line near the Atlantic Richfield Company's topping plant at Prudhoe Bay, Alaska. We were commencing a tundra revegetation research project at Prudhoe Bay in June of 1972 and were invited by Atlantic Richfield to incorporate the oil-affected area into our project.

Approximately 750 to 1500 liters of crude oil leaked from the line which had not been used for nearly a year. Apparently, warming temperatures in late winter thawed ice that had been preventing oil from escaping through a rupture in the line. Moisture condensation and freezing were believed to have caused the break. The affected area included about 860 m^2 of wet tundra.

The spilled oil was Prudhoe Bay (22^o API gravity) crude, which had had the diesel and heating oil fractions removed. The product was the 538^o+ residuals with the naptha fraction added back following distillation.

Cleanup included the use of absorbents, of burning and of leaving a portion of the area alone. Trampling by cleanup crews caused a great amount of physical damage to the vegetation and soil. Since this was possibly the first opportunity for anyone to monitor recovery of oil-damaged arctic tundra in Alaska, our objectives were to: 1) attempt to stimulate plant recovery by fertilization, and 2) document natural vegetation recovery. After we discovered fertilizers were effective where some vascular plants had survived the spill, we attempted seeding and fertilizing to establish grass in an area where macro plants failed to survive the spill.

METHODS

On 30 June 1972, several tundra plots were selected, marked and photographed to commence a photographic series designed to document vegetation recoveries, (McKendrick, 1976). Unfortunately, after four growing seasons a gravel pad was constructed over the key photo-plot, destroying what promised to become a remarkable photo sequence showing the recovery of severely-trampled, oil-damaged tundra (Figure 1).

Six rectangular plots, 1.2 m x 1.8 m each, were marked in the burned area and fertilized with a commercially mixed nitrogen, phosphorus and potassium fertilizer, 11-22-22. Three plots were fertilized at 785 kg/ha (700 lbs/acre) and 1570 kg/ha (1400 lbs/acre). Elemental N, P and K rates were 86, 75 and 143 kg, respectively per hectare for the low rate and twice that for the high fertilization rate. Since, during the summer of 1972 and 1973, vascular plants and mosses responded markedly to the fertilizer, a second set of plots was established 6 Sep 1973 to test effects of individual and combinations of N, P and K. Twelve plots (0.8 m x 1.2 m each) were fertilized. An incomplete, randomized block design was used. Individual rates of N, P and K were identical to those applied the previous year.

In a portion of the spill which remained devoid of vegetation, an autumn seeding experiment was established on 19 Sep 1974. Soil pH averaged $7.55 \pm .07$, which was typical for that locality. Sixteen rectangular plots (1.2 m x 1.5 m) were marked and fertilized with commercial sources of N, P, K and Mg at 160, 190, 110 and 90 kg/ha, respectively. The entire area of the plots, including unfertilized controls and alleys between plots, was seeded to an arctic Alaskan alkaligrass (Puccinellia borealis), designated at Alaska Agricultural Experiment Station by accession number 620D25, and common spring rye (Secale cereale). Seeding rates were 67 kg/ha for the alkaligrass and 78 kg/ha for the rye.

Soil cores, 2 cm x 15 cm, were taken in 1975 from the spill area and tested for pH and nutrient availabilities. Dry-matter production was estimated by clipping and weighing plants from 0.1 m^2 circular plots in the fertilized and unfertilized portions of the burned area and the 1974 fall-seeded plots in 1976 and 1977. Plant tissues from those plots were tested for N, P, K, Ca and Mg contents at the Palmer Research Center's soil and plant analysis laboratory, and compared to mineral nutrient levels required in ruminant diets.

RESULTS AND DISCUSSION

1972 fertilizer trial

The most noticeable responses to fertilizer were increases in cover and a greener and taller growth of sedges and grasses which survived the spill (Figure 2). There was an increased tendency to produce inflorescences where fertilizer had been applied. Fertilized plants senesced slower in autumn, making the plots particularly visible in late August and early September. Close examination revealed a green carpet of new moss and liverworts on the surface of the organic mat (Figure 3). That green bloom remained confined to the fertilized area throughout the study period. Under certain conditions, the natural reinvasion by mosses on disturbed tundra sites has been noted elsewhere (Babb and Bliss, 1974). Those investigators reported that protection from vascular plants enhanced moss development in the high Arctic. We noticed, on physically disturbed tundra plots at Prudhoe Bay, that the presence of grasses appeared necessary for re-established mosses to persist where they had been stimulated to invade by fertilizing.

Plant community composition and percent moss cover data for this oil spill area were presented in another report (McKendrick and Mitchell, 1978, this volume). The recovery of moss cover on oil-damaged arctic tundra sites is a most significant aspect to revegetation (Figure 3), since mosses are probably the key vegetative element affecting soil thermal properties in the Arctic (Addison, 1975). Haag and Bliss (1974) reported that thermal stability in tundra soils was controlled primarily by the peat layer. Consequently, the vascular plant components of tundra probably affect soil thermal properties indirectly by protecting mosses from desiccating winds and bringing mineral nutrients to the surface.

Quantitative data for dry-matter production by vascular plants is shown in Table 1. Production of fertilized vascular plants averaged about 80 g/m^2 or about four times that of unfertilized plants during the four years of data collection. Chemical analyses of plants from both areas showed little differences due to fertilization. The chemical data indicated that, except for P and possibly Mg, mineral quality of plants was adequate for domestic ruminant animal diets. Because the wet tundra is an important rangeland for caribou, domestic reindeer and waterfowl, the nutritional quality of forages is a fundamental consideration.

1973 fertilizer trial

The most obvious response was a consistent and marked increase in growth of graminoids and re-establishment of moss in plots receiving P fertilizer (Table 2). Neither N nor K applications seemed to visibly affect plant growth and recovery. There were no differences in dry matter production between the light and heavy fertilization rates. Potassium, despite its lack of visible effect seemed to significantly depress dry matter yields. However, that apparent influence was due to the absence of some of the PK fertilizer plots in the incomplete block. At the low levels of K, the PK treatments were present, causing a substantial response, but at the higher K levels there were no PK combinations. Consequently, plant responses to P were absent on the higher K-treated plots; hence it appeared as if increasing K depressed plant growth. Seventy-five kilograms of P per hectare (7.5 g/m^2) increased the average dry-matter production from 12-15 g/m^2 to about 42-47 g/m^2, comparing with the average four-fold increase in production noted previously for three growing seasons on the 1972 fertilizer plots. That three-to-four-fold increase explained the high visibility of P-treated plots. A more exacting experiment would be needed to refine estimates of quantitative responses to the various increments in P application rates.

<u>1974 fertilizer and seeding trial</u>

This seeding experiment possibly represents the first successful establishment of grass seedlings on an arctic tundra site from which all macro-flora had been annihilated by oil. The autumn-seeded alkaligrass germinated during the 1975 growing season. Spring rye failed to germinate. However, the most noticeable effect was in the growth and establishment of alkaligrass (Figure 4), mosses and liverworts in the P-treated plots (Table 3). Without P, alkaligrass seedlings failed to establish and no moss and liverwort bloom developed (Figure 5). The critical need for P by grass seedlings in the Prudhoe Bay area has been well established in other of our experiments (unpublished) on barren mineral soils. Our findings contrasted with those reported by Bliss and Wein (1972) wherein Western Canadian Arctic soils were found deficient in N and not P. We do not know if P was as effective on this Alaskan oil spill site in accelerating oil decomposition as it was in improving plant vigor. Oil retained in the root zone was not quantitatively measured, but it was still visible on soil cores taken from these plots in 1975.

The dry-matter productions of seeded alkaligrass during the second and third growing seasons following germination were compared (Table 3). The data support what appeared in the field to be substantial improvement in vigor and growth following initial establishment. In 1977, production on the seeded plots receiving P-fertilization (Table 3) approached that of unfertilized tundra plants which had survived the spill (Table 2). During the observation period seedlings in plots not fertilized with P failed to gain vigor, even though some apparently survived three growing seasons (Figure 5).

The available soil N levels (Table 3) appeared quite low, averaging less than 1/6 the N level measured in barren tundra soil south of the laboratory building at NARL, Barrow, Alaska. Available N in a moist tundra soil at Prudhoe Bay from which the vegetation had been mechanically removed averaged 42 ppm, about 5 times greater than levels measured on this oil-damaged wet tundra site. Since both Prudhoe Bay soils had been fertilized and sampled identically, that comparison seemed valid. However, soil P, K and Mg availabilities were not different between the two Prudhoe Bay tundra sites. But N additions on the mechanically disturbed site at Prudhoe improved yields on plots receiving phosphorus and had little effect when applied alone.

CONCLUSIONS

Restrictions in the availability of P in the soil at Prudhoe Bay, Alaska limited the recovery rate of native plants which had been weakened by oil, and also limited seedling and moss establishment on the oil-damaged site. The response to a single P treatment was marked and persistent over several years. No such response to N or K occurred. A grass was successfully seeded when combined with P fertilization on a site badly damaged by oil from which certain fractions had been removed by a topping process.

Several unanswered questions remain, including:

(1) How did phosphorus fertilization increase vegetation recovery rates in these Prudhoe Bay soils? Was it by increasing oil decomposition or simply by improving plant vigor?

(2) Why did nitrogen fertilization fail to improve vegetation recovery when soil tests for available N suggested a possible deficiency? What are soil test standards for evaluating fertilities of these arctic soils in terms of seedling establishment and plant dry-matter production?

(3) What species of mosses are re-invading the P-fertilized plots compared to those species present in the adjacent undisturbed community, and has fertilization significantly altered species dominance?

(4) Could grass seedlings have been established as easily if the spill had occurred during the summer when the active layer of the soil was thawed?

(5) What are the long-term effects of fertilization versus leaving the spill untreated and awaiting natural recovery by vegetation?

(6) What are the long-term fertilizer requirements for grass plants established on such tundra sites?

(7) What would have been the effects of a different hydrocarbon spill such as gasoline, diesel, fuel oil or whole crude, all of

which are commonly spilled in this region?

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TABLE 1

Average g/m^2 dry matter production and percent N, P, K, Ca, and Mg for vascular plants (primarily graminoids) on wet tundra that had been exposed to 22^0 API gravity Prudhoe Bay crude oil and subsequently burned. Fertilized plots were treated once with N, P and K in 1972 and sampled four times during the 1973-1977 period. Adjacent unfertilized controls were sampled simultaneously for comparisons. Minimum mineral requirements for sheep and beef cows are given as reference for comparisons of range plant forage quality.

Parameter	Fertilized				Unfertilized				Minimum mineral requirements in rations	
	'73	'74	'76	'77	'73	'74	'76	'77	Mature Sheep	beef cows
dry matter (g/m^2)	52	74	96	90	19	31	8	18		
%N	-1/	1.47	1.18	1.13	-	1.43	1.02	1.23	0.5	1.0
%P	-	.11	.08	.16	-	.05	.09	.13	.24	.18
%K	-	1.24	.49	.80	-	.87	.77	.58	.50	.60
%Ca	-	1.1	2.1	-	-	1.3	1.9	-	.25	.21
%Mg	-	.16	.23	-	-	.14	.24	-	.06	.18

1/ - indicates no data collected that year.

TABLE 2

Average vascular plant dry-matter yields (g/m^2) for 1976 and 1977 under three fertilization rates (kg/ha) of N, P and K, applied to oil-damaged wet tundra.

Nitrogen		Phosphorus		Potassium	
fertilizer rate	dry-matter yield	fertilizer rate	dry-matter yield	fertilizer rate	dry-matter yield
0	45.8 a 1/	0	15.1 a	0	54.7 b
86	43.0 a	75	61.9 b	143	35.3 a
172	41.0 a	150	65.4 b	286	30.7 a

1/ Averages followed by the same letter within a column were not statistically different at the .05 level of probability according to Duncan's New Multiple Range test.

TABLE 3

Comparisons of means and 95% confidence limits for dry matter production (g/m^2) in 1976 and 1977 and soil pH and available N, P, K and Mg in 1975 between successful and unsuccessful seeding test plots on oil-damaged tundra at Prudhoe Bay, Alaska.

Seeding	Dry Matter			Soil Parameters (1975) ppm available (w/w)			
Response	1976	1977	pH	N	P	K	Mg
Successful	2.4±.2* 1/	14±10.6*	7.59±.11	9.1±2.5	114±75.8*	37±2.7	296±26
Unsuccessful	0#	0#	7.57±.11	7.6±2.1	41±1.5	36±3.7	256±21

yields too low to measure

1/ ± values are 95% confidence interval limits; * denotes means within parameters where confidence intervals do not overlap.

FIGURE LEGENDS

Figure 1. Photo sequence showing striking recovery of severely trampled portion of wet arctic tundra affected by an oil spill. Photo on left was taken 30 June 1972, twenty days after the spill was discovered. The photo on the right was taken 30 August 1974, three growing seasons after the spill occurred. Vehicle tracks along the right edge of the photos were made during exploration of the Prudhoe Bay oil field and unrelated to the spill.

Figure 2. Fertilized plot (8 September 1976) of arctic tundra five growing seasons after burning a late-winter oil spill. Notice the effects of phosphorus fertilizer on plant vigor and cover.

Figure 3. Comparison between unfertilized (left) oil-damaged tundra and fertilized (right), two growing seasons following oil damage and fertilization. Notice the restoration of moss due to phosphorus fertilization.

Figure 4. A portion of the spill area on 1 September 1977 which was seeded to alkaligrass in September 1974. Seedlings established only in plots fertilized with phosphorus.

Figure 5. Close-up view of oil-damaged wet tundra 1 September 1977, which had been seeded to alkaligrass. The vigorous growth of alkaligrass on right edge of photo was a response to phosphorus fertilization, and the seeding failed without phosphorus fertilization.

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