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Restoring Productivity on Degraded Forest Soils: Two Case Studies

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ABSTRACT

The use of a green fallow as part of site rehabilitation measures was tested on a coastal forest soil that had been subject to accelerated erosion and on an interior forest soil that had been subjected to landing construction. In the coastal study, substantial enhancement of site nutrient capital occurred within 5 years. The nitrogen, phosphorus, and potassium pools all benefited greatly from the green fallow. Nitrogen showed the greatest gain (890 kg/ha), primarily because of the abundance of legumes in the revegetation cover. Douglas-fir seedlings responded with improved foliar N and K concentrations and a 300% increase in height growth.

In the interior study, decompacted landings were treated with broadcast applications of a legume seed mix and fertilizer. After only 2 years, the legume green fallow had improved site nutrient capital. Once again, N showed the greatest gain (332 kg/ha) because of the presence of the legumes. Potassium and P levels improved to a lesser degree. Although seedling foliar nutrient concentration and seeding height growth had not increased, the total soil N concentration exceeded minimum levels for adequate growth of medium nutrient-requiring coniferous species. The use of a green fallow system for accelerating the recovery of forest productivity was successful in both the coastal and interior studies.

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1 PROBLEM STATEMENT

Forest road building and timber harvesting have been recognized as principal causes of forest soil degradation. These activities can result in accelerated soil erosion, the removal of surface soil horizons, and increased soil densities which may result in a reduction of the productive capability of a site. Although it is recognized that logging operations cause unavoidable disturbances of vegetation and soil, when the extent of excessive disturbance and site degradation exceeds acceptable limits for a given area, efforts must be made to restore the productive capability.

One of the main objectives of the newly proposed Ministry of Forests policy, Reduction of Site Disturbance from Logging Operations (1984), is the rehabilitation of unacceptable site disturbances in accordance with firmly established guidelines and procedures. Unfortunately, no such guidelines have been provided for rehabilitation of areas subject to accelerated soil erosion, and those that exist for landing construction deal only with increases in soil density. The removal of fertile surface soil horizons through accelerated erosion or scalping procedures, and the incurrence of possible soil fertility problems, have yet to be adequately addressed. Much work and some reassessment are warranted if this policy is to meet its primary objective "... of protecting and conserving the attainment of maximum productivity..."

There is little in forestry literature that deals with the recovery or enhancement of soil fertility after degradation, except in regard to erosion control. It is more appropriate to borrow from mined land reclamation and agriculture for methodologies to recover site productivity. These disciplines deal with degraded soil material where most of the effort is directed to accelerating soil development *in situ*.

2 LITERATURE REVIEW

In agriculture, soil degradation due to repeated cropping may necessitate putting land under fallow cover crops for 5 or more years (Agboola 1975). The establishment of a self-sustaining, productive plant cover is often used as the main criterion to define successfully reclaimed land (Ziemkiewicz 1979). In both cases, the establishment of a high biomass producing cover crop (often containing grasses and legumes) is considered essential to improvement of the physical and chemical properties of degraded soils and the enhancement of site productivity.

A green fallow or cover crop enhances soil fertility through several processes. Deep penetrating roots can encourage "biological weathering" of parent material, thus promoting nutrient availability. The surface horizon concentration of phosphorus, potassium, and other nutrients can be greatly enhanced through nutrient "mining" — the translocation of available nutrients in an organic form to the surface, and subsequent release through detritus decomposition (Agboola 1975). The rapid accumulation of soil nitrogen under a fallow crop depends upon the presence and activity of leguminous and non-leguminous species which can fix gaseous nitrogen in available forms.

The rapid turnover of the fallow crop root mat plays an important role in the storage and release of carbohydrates and nutrients. Sloughed root material provides an available energy source for soil microbes, which promote cycling of slough nutrients. The accumulation of organic matter in the soil through root decomposition enhances soil nutrient retention, aggregation, buffering capacity, and chelate formation (Allison 1973).

The accumulation of surface detritus, though slow to break down and to be incorporated in the soil, will eventually enter the active nutrient cycle. In the meantime, this organic mat acts as a mulch, modifying soil moisture and temperature regimes. This, in turn, will promote soil biological activity and assist in maintaining the cycling of nutrients. The use of green fallow crops on severely degraded forest land appears to be a viable approach to the problems of restoration or enhancement of site productivity.

3 OBJECTIVES

The objective of the case studies presented below is to evaluate the effectiveness of a green fallow crop in restoring productivity on severely degraded forest sites. Based on the literature, the green fallow system appears to be a low cost method of enhancing soil fertility, with the additional benefit of controlling soil erosion. A comparison of soil nitrogen, potassium pools from treated and control (untreated) sites was used to predict productive capacity to evaluate the effectiveness of soil restoration measures. The enhancement of soil nutrient levels to acceptable minimum levels for commercial tree growth, combined with an evaluation of seedling performance, was used to determine the feasibility of restoring productivity through green fallowing.

4 LIMITATIONS

Due to budget limitations, only two test sites, representing coastal and interior conditions, were established for evaluation of the green fallow system. The chosen sites were representative in their respective regions of the principal degrading processes that follow forest harvesting. The coastal study, monitored for 7 years, was established on subsoil material exposed by road construction and subject to accelerated soil erosion. The results from this study are applicable to coastal areas subject to surface soil removal by mass wasting. The interior study, monitored for 2 years, was established on summer landings that had been subject to scalping and soil compaction. The landing areas had been deep-ripped according to standard landing rehabilitation procedures. No measures had been taken to enhance the fertility of the "rehabilitated" landings.

A limitation to this approach was the short time period over which restoration effects were measured. Soil changes or seedling responses associated with "restoration" measured over a short period of time may not represent changes in the long run. This may bias the conclusions regarding recovery of productivity at the time of timber harvest. However, a short-term analysis can give a preliminary indication of whether a proper course of action has been undertaken and whether long-term studies are warranted.

5 MATERIALS AND METHODS

Two test sites were established for a preliminary evaluation of the effectiveness of a green fallow crop in restoring site productivity on severely degraded forest soil. At each site, forest harvesting activities had resulted in the removal of surface soil horizons and the exposure of the C horizon or parent material. The green fallow crop at each site was selected with soil and climatic limitations in mind, as well as management objectives. At the coastal site (Koksilah), a grass-legume cover crop was established to control soil erosion and restore site productivity. Only legumes were included in the fallow crop for the interior study (Vanderhoof) where recovery of site productivity was the only goal and grass-tree competition was expected to be a problem.

For each study, a comparison of site nutrient capital (nitrogen, N; phosphorus, P; and potassium, K) between treated (revegetated) and control plots was carried out. Nutrient pools from the treated plots included soil and organic matter (cover crop shoot, root, and detritus) components, while the control nutrient pools included only the soil. In addition, height growth and vigor (as indicated by foliar nutrient concentration) of seedlings established on the plots were compared.

5.1 Site Description

COASTAL STUDY — KOKSILAH

The study site is located approximately 15 km northwest of Shawnigan Lake in the Koksilah River watershed. The coordinates of the area are 123° 48' 30" W and 48° 48' 50" N. The natural soil is an Orthic Dystric Brunisol, part of the Shawnigan Gravelly Sandy Loam association (Keser and St. Pierre 1973). Road construction and soil erosion had removed the forest floor (7-0 cm), Ae (0-1 cm), and Bm (1-50 cm) horizons. The residual soil material is a compact gravelly, glacial till with a sandy-loam texture. The average bulk density for the site is 1500 kg/m^3, as determined by the core method (three sub-samples per plot).

According to Klinka *et al.* (1979), the site lies within the Drier Eastern Vancouver Island variant of the Coastal Western Hemlock biogeoclimatic zone (CWHa2/05). This is a complex of *Tsuga (heterophylla) - Pseudotsuga (menziesii) - Hylocomium (splendens) - Stokesiella (oregana).* The variant is considered to be mesotrophic - mesic site (nutrient rich - well drained). The area was opened up for logging in 1973 and part of it still supports a highly productive Douglas-fir and western hemlock stand (Douglas-fir site index 42 m at 100 years).

In June 1976, two replicates of paired treated and control plots were established on an extensive area of subsoil material that had been exposed during road construction. Each plot was approximately 50 x 25 m and the slope gradient ranged from 40 to 90%. The revegetated plots were seeded at a rate of 100 kg/ha with a grass-legume seed mix (Appendix 1) and received a 450 kg/ha application of 10-30-10 fertilizer. Vegetative cover on the treated plots was estimated at 70% in April 1977, with no vegetation on the control plots (Carr and Ballard 1980). In May 1977, Douglas-fir seedlings (1-2 stock) were planted at 1.5 x 1.5 m spacing on all plots.

INTERIOR STUDY — VANDERHOOF

The study site is located approximately 30 km south of Vanderhoof near Corkscrew Creek on the Kluskus Forest Road. The coordinates of the chosen cutblock are 124° 21' 30" W and 53° 51' 10" N. The natural soil of the area was identified as part of the Chilako Stony Sandy loam complex (Farstad and Laird 1954) and is classified as a Degraded Dystric Brunisol, Alix series (Cotic *et al.* 1974). The forest floor (5-1 cm), Ae (0-1 cm), and Bm (1-25 cm) horizons were removed by scalping during landing construction. The residual soil material is a gravelly, glaciofluvial deposit with a sandy loam-sand texture.

The area lies within the Sub-Boreal Spruce biogeoclimatic zone (Krajina 1965) and was recently further classified as a False Sarsaparilla — Prince's Pine - Moss ecosystem unit (SBSk2/04) by Delong and McLeod (1985). This is a complex of *Pinus contorta - Pseudotsuga menziesii - Roas acicularis - Aralia nudicaulis - Chimaphila umbellata - Pleurozium schreberi.* The moisture regime is submesic and the nutrient regime is submesotrophic - mesotrophic (poor-medium). This area, which was clearcut in the late summer of 1976, supported a medium site class stand of *Pinus contorta* and *Picea glauca* x *engelmannii* (lodgepole pine and hybrid spruce).

In August 1980, 28 landings and connecting skid roads were deep-ripped to a depth of approximately 50 cm, using an experimental three-toothed plow. The ripping trial was considered successful in reducing soil density to acceptable levels, approximately 1350 kg/m^3 as determined by the core method.

In 1981, four of the ripped landings were selected for this study. These landings were selected for similarity in soil condition and topographic orientation. Prior to the treatment, four subsampling locations within each landing were randomly selected for soil analysis. The plots were then seeded with a legume seed mix (Appendix 2) at a rate of 40 kg/ha and given a starter fertilizer application of 19-19-19 at a rate of 300 kg/ha. In June 1981, lodgepole pine seedlings (2-0 bareroot stock) were planted on three control and three treated plots at a spacing of 1.5 x 1.5 m. By August 1982, cover establishment on the treated plots was estimated visually as 65% and the control plots as less than 5%.

5.2 Field Sampling Procedures

COASTAL STUDY — KOKSILAH

Soil and organic matter analyses were performed in September 1980 and 1982. Within each plot, two treated and two controls, three subsampling locations were randomly selected. All subsamples were analyzed separately and later averaged to represent the plot value. For the control plots, a soil sample was taken to a depth of 30 cm, using a 5-cm diameter soil core. The soil samples were stored in plastic bags for transport. On the treated plots, the sample collection procedure was carried out by layers. The above-ground organic matter (shoot and standing detritus) was clipped from within a 25x25 cm frame and placed in paper bags for transport, and a 5-cm soil core was taken to a depth of 30 cm. Care was taken to label the layered samples from each subsample location so that the total nutrient pool could be estimated.

In 1982, the current year foliage was collected from five randomly selected seedlings in each plot for foliar nutrient concentration analysis (N, P, and K). Total height and internodal length of the seedlings were measured and the height in previous years estimated.

INTERIOR STUDY — VANDERHOOF

Initial soil analyses prior to treatment were performed in 1981, and final soil, organic matter, and seedling analyses in September 1983. On each landing, four subsample locations were randomly selected for before (i.e., the control) and after (seedling) sampling. For the control sampling, a composite soil sample consisting of two 5-cm diameter soil cores taken to a 30 cm depth was collected at each subsample location. The composite soil samples were stored in plastic bags for transport. For the post-treatment assessment, the sample collection procedure was carried out in layers. At each subsample location, above-ground organic matter (shoot and standing detritus) was clipped from within a 0.385-m^2 circular plot (radius of 0.35m) and stored in paper bags for transport. A composite soil sample was then taken, using the same procedure as on the control plots. The layered samples from each subsample location were carefully labelled so that the total nutrient pool could be estimated.

For the evaluation of the effect of the fallow crop establishment on regeneration performance, 30 seedlings from each of the planted landing areas (three control and three treated) were randomly selected for height measurement. Additionally, six composite samples of the current year's foliage (five seedlings per composite) were collected from each landing and analyzed for foliar nutrient concentration.

5.3 Laboratory Procedures

COASTAL STUDY — KOKSILAH

Preparation and analysis of soil, shoot, standing detritus, and foliar samples were conducted at UBC's Department of Soil Science in 1980, and at Pacific Soil Analysis Inc., Vancouver, in 1982. (The same analytical procedures were followed at each laboratory with similar equipment). Soil samples were air-dried for at least 24 hours at 20°C. The organic components (roots and fallen detritus) were separated from the treated plot soil samples by hand clearing under a microscope. The air-dried soil material from all plots was sieved to separate the coarse (>2 mm) and fine (<2 mm) fractions, and these were then weighed. The fine fraction was used for the chemical analyses.

The root and fallen detritus samples (referred to as R + D) were oven-dried for 24 hours at 80°C, weighed, and expressed as a percentage of the original soil sample. With a mortar and pestle the R + D sample was then ground into a fine powder for chemical analysis. The shoot and standing detritus samples (referred to as S + D) were oven-dried in the paper bags at 80°C for 24 hours, weighed (corrected for bag weight), and ground in a Wiley Mill fitted with a 1-mm sieve. The foliar samples were air-dried for at least 24 hours and needles were separated from branches. The needles were dried for 24 hours at 80°C in a forced draft oven and ground to a uniform powder for analysis, using a small blender fitted with special blades. All vegetative material was analyzed for N, P, and K.

All laboratory analysis procedures were based on the *Methods Manual— Pedology Laboratory*, Department of Soil Science, UBC (Lavkulich 1977), except the foliar analysis which was based on Ballard (1980a). The following analyses were performed:

total soil N:	using a semi-micro Kjeldahl digest with colorimetric determination using a Technicon autoanalyzer;
available soil P:	using the Bray P-1 method;
available soil K:	using a Morgan's extraction (1.0 M NaOAc) in conjunction with atomic absorption determination;
fallow crop and foliar N, P, and K:	using a Caro's acid digest with N and P colorimetrically determined on a Technicon autoanalyzer, and K measured by atomic absorption.

The comparison of nutrient pools between treated and control plots was based on total nutrient pools. The treated plots included both fallow crop and soil components. The use of total nutrient pool assisted the problem of component separation in the layered sampling scheme, particularly with separation of the fallow detritus and root component from the soil. Hand cleaning of soil samples for roots and detritus can miss a substantial portion of fine root and detritus material. Although this results in the underestimation of the root and detritus contribution to site nutrient capital, the missed organic material and its nutrient content are accounted for in the soil component. The use of total nutrient pool for comparative purposes removes this problem.

Statistical analysis of the effect of fallow crop establishment on site nutrient capital was conducted using analysis of variance (ANOVA) based on a split-plot design. The main effect is treatment differences (two replications), with the year of sampling representing the split-plot effect. This technique is recommended by Little and Hills (1978) for repeated sampling of an experimental unit. Changes in the three components within the treated plots over time were tested for, using ANOVA (single factor, two replications). Statistical analysis of effect on regeneration was also conducted using ANOVA (single factor, two replications).

INTERIOR STUDY — VANDERHOOF

Preparation and analysis of soil, biomass, and foliar samples were performed at Pacific Soil Analysis Inc. in 1981 and 1983. Sample preparation and laboratory analysis procedures were the same as those used in the Koksilah study. Statistical analysis of the effects on site nutrient capital was conducted using ANOVA (single factor, four replications). For effects on regeneration performance, single factor ANOVA with three replications was performed.

6 RESULTS AND DISCUSSION

6.1 Site Nutrient Pools - Koksilah

VEGETATIVE AND SOIL COMPONENTS

The quantity of vegetative matter produced by the green fallow crop is summarized in Table 1 for the S + D and R + D components and for total production. There was no significant change in the production of vegetative matter (components or total) between years 5 and 7. The green fallow crop appears to be in a quasi-steady state of production. The invasion of native tree and shrub species, combined with the growth of planted seedlings, should eventually result in a decline in fallow crop production and an accumulation of detritus material. This increase in the detritus pool should increase soil biological activity, resulting in the eventual release of the nutrients tied up in the detritus, and the incorporation of the organic matter into the soil. The process is expected to enhance soil properties and nutrient levels; however, the time required for these benefits to accrue is not known.

TABLE 1. Green fallow vegetative matter (kg/ha) — Koksilah

Year	**Component**		**Total**
	S + D	**R + D**	
1980	11 700 ± 2 100[a]	38 900 ± 800	53 600 ± 2 700
1982	15 900 ± 3 500	31 300 ± 3 300	47 200 ± 6 900
	ns[b]	ns	ns

[a] Values are means ± SE of two replications.

[b] ns denotes no significant difference between years using ANOVA, single factor - two replications.

A comparison of nutrient concentrations in the S + D and R + D vegetative components (Table 2) reveals a fluctuation in N and K concentration between the two sampling periods. The nutrient concentration in herbaceous vegetation can vary greatly, depending on the stage of growth. Ziemkiewicz (1979) demonstrated this for high-altitude native and agronomic herbaceous species. Although care was taken to sample the vegetation at the same date in September, the vegetation appears to have been in a more dynamic growth phase in 1980. This is indicated by higher N and K concentrations in the above-ground component and the K concentration in the below-ground component. In 1982, a higher N concentration in the R + D vegetation component paralleled a lower S + D concentration, and did not affect total soil N (Table 3). The decrease in K concentration of both vegetative components in 1982 paralleled an increase in available soil K concentrations of the treated plots over the 1980 level. There was significant increase in soil available K concentration between 1980 and 1982, probably a result of accelerated weathering of the mineral soil. There was no significant change in the total soil N and available soil P concentrations of the control plots, or the available soil P concentration of the treated plots between sampling dates.

TABLE 2. Concentration (%) of N, P, and K in the vegetative components — Koksilah

Component	**Year**	**N**	**P**	**K**
S + D	1980	1.91 ± 0.08[a]	0.189 ± 0.029	1.47 ± 0.01
	1982	1.52 ± 0.05	0.140 ± 0.016	0.88 ± 0.01
		**[b]	ns[b]	**
R + D	1980	0.96 ± 0.01	0.089 ± 0.017	0.29 ± 0.02
	1982	1.26 ± 0.06	0.118 ± 0.006	0.15 ± 0.01
		**	ns	**

[a] Values are means ± SE of two replications.

[b] **, ns denote and significant difference, no significant difference respectively, respectively, between years at 95% level of probability using ANOVA, single factor - two replications.

TABLE 3. Soil N, P, and K concentrations — Koksilah

Year	Total N (%)	Available P (ppm)	Available K (ppm)
		Control	
1980	0.014 ± 0.001[a]	12.3 ± 2.0	33 ± 2
1982	0.016 ± 0.001	14.4 ± 1.8	43 ± 3
	ns[b]	ns	**
		Treated	
1980	0.026 ± 0.004	16.0 ± 3.6	45 ± 6
1982	0.031 ± 0.005	16.4 ± 2.5	95 ± 12
	ns	ns	**

[a] Values are means ± SE of two replications.

[b] ns,** denote no significant difference and significant difference, respectively, between years at 95% level of probability using ANOVA, single factor - two replications.

NUTRIENT TOTALS

Although there was a shift in component contribution in the treated plot K pool between years, the total pool was not affected (Table 4). There was no change in the N and P nutrient pool totals on the treated areas or the N, P, and K totals from the control plots between sampling periods (Table 5). Statistical analysis of the N, P, and K pool totals indicate a significant increase in the site N, P, and K levels due to the establishment of the fallow crop (Appendix 3). The increase was evident in the 1980 sampling and had not significantly changed by 1982. It appears that the increase in site N, P, and K nutrient pools had reached a maximum within the first 5 years, with no change between years 5 and 7. This pattern of maximum change during the first five years was also evident in the green fallow vegetation matter production (Table 1).

The gain in the N pool, based on the 1980 data, was 827 kg/ha (allowing for an initial fertilizer input of 45 kg/ha). It may be assumed that this increase of approximately 165 kg/ha/yr over the first 5-year period was primarily a function of N fixation by the legume species in the green fallow. The process of nutrient "mining" would contribute little to this increase because of a low natural total soil N concentration (0.014% in the control, 1980). The magnitude of this increase in the N pool is within the values reported by Sprent (1979) of 150-300 kg/ha/yr for mixed grass and legume stands. Once the treated plots had reached a total N pool and cycling level adequate to sustain the fallow crop, further accumulation ceased, as has been reported by Agboola (1975), Singh (1975), Sprent (1979), and many others.

The P increase of approximately 63 kg/ha (1980) could be accounted for solely by the initial fertilizer application only if all of the P fertilizer stayed in the available pool and was not fixed in the soil. However, forage crops use approximately 30% of applied fertilizer P, the remainder of which is fixed in the soil (Hinish, 1980). A small percentage of the fixed P can become available each year and may eventually result in the recovery of most of the applied P (Thompson 1978). The acid soil condition, coupled with a relatively high soil clay content of (approximately 15%), would favour P fixation. Nutrient "mining" from deeper depths may have accounted for the remaining 70% of the increase, or about 44 kg/ha. According to Stanford and Pierre (1953), the growing of a deep-rooted legume crop may be the most efficient means of achieving greater utilization of subsoil P.

The K pool showed a substantial increase after fallow crop establishment, approximately 260 kg/ha once the initial fertilizer application was accounted for. Since the K content in a soil does not change much even over long periods of time, nutrient "mining" by deep penetrating roots must have been the principal cause of the increase. Thompson (1978) reports that a good alfalfa crop can withdraw up to 150 kg/ha/yr of soil K. The 1980 sampling showing 70% of the K pool to be associated with the vegetative components (Table 4) would seem to verify the importance of vegetation establishment for K accumulation within the soil surface.

6.2 Site Nutrient Pools — Vanderhoof

VEGETATIVE AND SOIL COMPONENTS

The data for the green fallow vegetative components at Vanderhoof are presented in Table 6, along with the corresponding N, P, and K concentrations. There is a wide gap between the S + D and R + D components in vegetative matter production. This site is naturally submesic, and with the removal of surface soil horizons during landing construction, drier conditions probably exist. In grasslands, xeric conditions result in a reduction of shoot mass and promote production of a large root mass (Rodin and Basilevich 1967). This appears to be the case at Vanderhoof.

Comparison of control (before) and treated (after) data (Table 7) revealed a significant increase in total soil N and available K concentration 2 years after fallow crop establishment. This trend was similar to that at Koksilah. The available P concentration had not shown a significant increase, as was also the case in the coastal study.

TABLE 4.Total N, P, and K (kg/ha) pools for treated plots — Koksilah

Year	**Component contribution**			**Total**
	S + D	**R + D**	**Soil**	
		Nitrogen		
1980	244 ± 31[a]	352 ± 14	727 ± 74	1303 ± 152
1982	240 ± 50	393 ± 56	729 ± 61	1362 ± 178
		Phosphorus		
1980	22 ± 1	35 ± 3	45 ± 8	102 ± 5
1982	22 ± 3	36 ± 2	38 ± 1	96 ± 5
		Potassium		
1980	172 ± 30	110 ± 8	126 ± 10	408 ± 30
1982	134 ± 30	47 ± 5	220 ± 13	401 ± 56
		**[b]	**	

[a] Values are means ± SE of two replications.

[b] ** denotes a significant difference between years at 95% level of probability using ANOVA, split-plot model.

TABLE 5.Comparison of total N, P, and K pools between treated and control plots — Koksilah

Year	**Treated**	**Control**
	Nitrogen	
1980	1303 ± 152[a]	431 ± 91 **[b]
1982	1362 ± 178	398 ± 57 **
	Phosphorus	
1980	102.1 ± 5.3	38.9 ± 8.1**
1982	96.3 ± 5.2	37.4 ± 11.1**
	Potassium	
1980	408 ± 30	105 ± 11 **
1982	401 ± 56	109 ± 20 **

[a] Values are means ± SE of two replications.

[b] ** denotes a significant difference between years at 95% level of probability using ANOVA, split-plot model.

TABLE 6. Green fallow vegetative matter and nutrient concentrations (N, P, and K) — Vanderhoof

Cmpt.	Production (kg/ha)	N (%)	P (%)	K (%)
S + D	2 400 ± 200[a]	1.50 ± 0.08	0.224 ± 0.014	1.70 ± 0.10
R + D	36 200 ± 8400	0.52 ± 0.06	0.192 ± 0.022	0.25 ± 0.0

[a] Values are means ± SE for four replications.

TABLE 7. Soil nutrient concentration (N, P, and K) — Vanderhoof

Plots	Total N (%)	Available P (ppm)	Available K (ppm)
Control	0.038 ± 0.008[a]	55.7 ± 18.4	118 ± 18
Treated	0.052 ± 0.010 **[b]	64.0 ± 16.4 ns[b]	169 ± 24 **

[a] Values are means ± SE for four replications.

[b] ** ,ns denote significant differences and no significant differences, respectively, at the 95% level of probability using ANOVA, single factor - four replications.

NUTRIENT TOTALS

The component contribution to the total site nutrient pools is presented in Table 8. The high production (kg/ha) of the R + D component dominates the vegetative contribution of N and K. The P pool is less dominated by the R + D component than are N or K.

A comparison of N, P, and K pools before and after legume establishment is presented in Table 9. The P pool shows a very significant increase, at the 95% level of probability, due to green fallow crop establishment (Appendix 4). The N and K pool increases are also significant, but at a lower level of probability (90%). Both the P and K increases would indicate nutrient "mining" by the crop root system. The N pool increase would be, in part, a result of N fixation by the legumes.

The P pool increase is approximately 58 kg/ha, excluding the 25 kg/ha fertilizer application. As is evident in Tables 8 and 9, the increase in P is totally accounted for in the vegetative components, with no additional available P in the soil. Agboola (1975) reports only a minor increase in soil available P concentration after 1 year of a legume fallow crop. Phosphorus is tightly cycled and highly mobile within the plant and translocates to areas of active growth from areas of senescence. There would be little P in the detritus for release into the soil, and that which was released is subject to phosphate fixation.

The soil K pool is approximately 120 kg/ha, excluding the 47 kg/ha fertilization. Unlike P, part of the increase in the K pool has reached the soil (approximately 44 kg/ha available K). Agboola (1975) reported a similar level of increased soil K (45 kg/ha exchangeable K) under a legume fallow crop. Plant residues are generally high in K, which is not in an organic form in the plant. Potassium can be added to the soil by leaching of plant detritus or after detritus decomposition, and is readily available for crop use (Allison 1973).

The increase in the N pool of approximately 156 kg/ha/yr (after deduction of fertilizer N) is within the range reported in the literature for legume stands (Allison 1973; Sprent 1979), and agrees closely with the level reported by Simpson(1976) for clover stands. Part of this increase has affected the total soil N concentration, raising from 0.038 to 0.052% in 2 years (Table 7). One could speculate that the increase in N capital, as well as of P and K, should continue until a self-sustaining, stable nutrient cycle establishes on the plots as happened at Koksilah. Determination of the eventual magnitude of nutrient pool increase was beyond the scope of this case study.

TABLE 8. Total N, P, and K pools (kg/ha) for treated plots — Vanderhoof

Component contribution			Total
S + D	R + D	Soil	
		Nitrogen	
37 ± 9[a]	188 ± 30	1175 ± 106	1400 ± 133
		Phosphorus	
41 ± 3	68 ± 11	150 ± 28	250 ± 32
		Potassium	
5 ± 1	77 ± 15	417 ± 65	499 ± 76

[a] Values are means ± SE for four replications.

TABLE 9. Comparison of total N, P, and K pools (kg/ha) between treated and control plots — Vanderhoof

Nutrient	Treated	Control
N	1400 ± 133[a]	1005 ± 110 *[b]
P	259 ± 32	145 ± 18 **
K	499 ± 76	332 ± 23 *

[a] Values are means ± SE for four replications.

[b] *, ** denote significant difference between treated and control plots at 90% and 95% level of probability using ANOVA, single factor - four replications.

6.3 Regeneration Performance — Koksilah

Foliar N, P, and K concentrations for the Douglas-fir seedlings at Koksilah are presented in Table 10. Statistical analysis (Appendix 5) indicates a significant increase in foliar N and K concentrations in response to the fallow crop establishment and the increase in soil concentrations. The foliar N concentration at Koksilah is the more critical factor. A foliar level of 1.2% N is viewed as a minimum level for satisfactory growth of Douglas-fir (Ballard 1980a), which the control plots do not meet. A low growth rate would be expected in the control plots, but not in the treated plots which easily exceed the minimum for foliar N concentration. There was no significant effect during periods of sampling on the foliar N levels.

The use of a fallow crop resulted in a significant increase in foliar K concentration. This response to increased soil availability of K, though statistically significant, is not biologically significant and probably indicates luxury consumption of K. This was also evident in the significant increase in foliar K levels on the control plots between 1980 and 1982, which could be in response to higher available K in the soil (Table 3).

While there was no significant effect of treatment on the foliar P concentration, there was a significant effect due to year of sampling of the treated plot. The decrease in foliar P level indicates a dilution effect of foliar P due to an increase in foliar biomass. However, the foliar P concentration, for both control and treated plots, is above the minimum level to maintain adequate growth (Ballard 1980a).

TABLE 10. Foliar N, P, and K concentrations (%) in Douglas-fir seedlings — Koksilah

Plots	1980		1982
	Nitrogen		
Control	1.08 ± 0.16[a]		0.94 ± 0.05
Treated	1.72 ± 0.07		1.77 ± 0.02
**[b]			
	Phosphorous		
Control	0.298 ± 0.034		0.252 ± 0.022
Treated	0.330 ± 0.026	*[c]	0.241 ± 0.008
	Potassium		
Control	0.516 ± 0.004	*	0.724 ± 0.046
Treated	0.839 ± 0.005		0.887 ± 0.064
**			

[a] Values are means ± SE of two replications.

[b] * denotes a significant difference between year levels within treatments at the 95% level of probability using ANOVA split-plot model.

[c] ** denotes a significant difference between treated and control levels at 95% level of probability using ANOVA, split-plot model.

The height data (Table 11) indicate a substantial difference in tree seedling growth between the control and treated plots (Appendix 6). There is a three-fold difference in total height, and five-fold difference in the last annual increment. The control seedlings have grown much more slowly than seedlings in the treated plots. Based on the age correction-height table for Douglas-fir (Hegyi *et al.* 1979), the control plots are below the low-site classification. The treated plots are classed as medium to good sites, which corresponds to the original site classification.

TABLE 11. Douglas-fir seedling height (cm) — Koksilah

Age (years)	Control	Treated	
9	43.1 ± 9.4[a]	140.1 ± 14.2	**[b]
8	32.4 ± 6.8	85.3 ± 09.2	**
7	24.1 ± 5.4	45.5 ± 06.2	**
6	19.1 ± 5.0	32.0 ± 07.4	**

[a] Values are means ± SE of two replications.

[b] ** denotes a significant difference between control and treated plots at the 95% level of probability using ANOVA, single factor - two replications.

TABLE 12. Foliar N, P, and K concentration (%) and height (cm) of lodgepole pine seedlings — Vanderhoof

Plot	N	P	K	Height
Control	1.68 ± 0.20[a]	0.170 ± 0.012	0.734 ± 0.029	36.5 ± 1.7
Treated	1.72 ± 0.07 ns[b]	0.172 ± 0.005 ns	0.744 ± 0.025 ns	43.3 ± 2.0 ns

[a] Values are means ± SE of three replications.

[b] ns denotes no significant differences between plots using ANOVA, single factor - three replications.

6.4 Regeneration Performance — Vanderhoof

The seedling foliar nutrient concentration and height growth data for the lodgepole pine seedlings planted at Vanderhoof are presented in Table 12. Statistical analysis of the data (Appendix 7) indicated no significant effect on any measured parameters 2 years after fallow crop establishment. Although there is an increase in total soil N and available P, there is no reflection of these increases in the seedling foliar concentrations. The levels in both the control and treated plots are above those suggested by Ballard (1979) as being adequate for satisfactory lodgepole pine growth. The seedling height data bear this out. However, this trial is still quite young and as seedling requirements for adequate nutrients increase, there may be a response to the higher nutrient levels that result from the green fallow treatment.

6.5 Summary

The use of a green fallow crop on severely degraded forest soils appears to be a viable management tool for the enhancement and possible eventual recovery of site productivity. In the coastal trial, the N, P, and K nutrient pools had increased to a plateau within 5 years and resulted in improvement of seedling performance to that expected from a comparable undisturbed site (medium site-class Douglas-fir). Of the improvement in soil nutrient concentrations, the increase in total soil N was the most important. According to Bockheim (1982), the approximate minimum level of total soil N essential for satisfactory growth of medium nutrient-requiring species, such as Douglas-fir, is 0.05%. Due to the fallow crop, the total soil N concentration exceeds the limit for low requirement species (0.02%) and is approaching that of the medium requirement species. The higher level of foliar N concentration — currently above an adequate level, combined with greater seedling height growth, confirms this enhancement in site quality. Although the plant-soil nutrient relationship had stabilized by year 5, eventual changes in plant cover composition should increase the fallow crop detritus pool. The decay and accumulation of this organic matter will further improve soil nutrient levels and enhance soil properties.

After 2 years, the legume fallow crop established at the interior site had enhanced site nutrient capital (N, P, and K) and concentrations of total soil N and available soil K. The post-treatment total soil N concentration now exceeds the minimum level for medium nutrient-requiring species (Bockheim 1982). Although there was no growth response in the lodgepole pine seedlings, the enhancement of site nutrient capital should eventually benefit commercial forest production. Further gains to soil nutrient levels and soil properties may be expected as the fallow crop continues to mature.

6.6 Conclusion

Within the limited time of this project, both fallow crop trials can be viewed as successful in enhancing productivity on severely degraded forest soils. The benefits to the site begin soon after crop establishment (within 2 years at Vanderhoof) and reach an initial maximum fairly quickly (within 5 years at Koksilah). A second increment of site benefits can be expected with the eventual accelerated decay and incorporation of the detritus component as the site matures. Whether the increases in site nutrient capital, soil nutrient concentration, and seedling performance are enough to assure recovery of commercial tree production is beyond the scope of this project. However, based on these preliminary results, it appears that the risks inherent in doing nothing far outweigh the risks of action.

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APPENDIX 1. Seed mix used at Koksilah

Grasses	Percentage by weight
Lolium multiflorum	5.5
Loilum perenne	5.5
Phleum pratense	5.5
Agrostis alba	4.0
Dactylis glomerata	13.0
Festuca arundenacia	20.0
Festuca rubra	12.0
Festuca ovina	9.0
Legumes	
Trifolium repens	4.0
Trifolium pratense	7.0
Trifolium hybridum	5.5
Lotus corniculatus	9.0

APPENDIX 2. Seed mix used at Vanderhoof

	Percentage by weight
Medicago sativa	35
Trifolium subterraneum	15
Trifolium repens	15
Trifolium hybridum	15
Lotus corniculatus	20

APPENDIX 3. Statistical analysis of total N, P, and K pools for treatment effects — Koksilah

Analysis: ANOVA for split-plot design (main factor-treatment, split factor-year), two replications

Nitrogen

Source	df	SS	MS	F
Treatment	1	1 683 613	1 683 613	124.6
Error (a)	2	27 057	13 514	
Year	1	365	365	< 1
Treatment x Year	1	4 231	4 231	1.10
Error (b)	2	7 659	3 830	
Total	**7**	**172 294**		

Phosphorous

Source	df	SS	MS	F
Treatment	1	7 887.7	7 887.7	85.6
Error (a)	2	184.2	92.1	
Year	1	57.2	57.2	<1
Treatment x Year	1	0.4	0.4	<1
Error (b)	2	118.9	59.4	
Total	**7**	**8 248.4**		

Potassium

Source	df	SS	MS	F
Treatment	1	165 888	165 888	56.1
Error (a)	2	5 914	2 957	
Year	1	112	113	<1
Treatment x Year	1	12	12	<1
Error (b)	2	262	131	
Total	**7**	**172 188**		

APPENDIX 4. Statistical analysis of total N, P, and K pools for treatment effects — Vanderhoof

Analysis: ANOVA: single factor, four replications

Nitrogen

Source	df	SS	MS	F
Treatment	1	311 261	311 261	5.21
Error	6	358 657	59 776	
Total	**7**	**669 918**		

Phosphorous

Source	df	SS	MS	F
Treatment	1	25 538	25 538	9.6
Error	6	15 928	2 655	
Total	**7**	**41 466**		

Potassium

Source	df	SS	MS	F
Treatment	1	56 113	56 113	4.45
Error	6	75 627	12 605	
Total	**7**	**131 740**		

APPENDIX 5. Statistical analysis of foliar N, P, and K concentrations in Douglas-fir seedlings — Koksilah

Analysis: ANOVA for split-plot design (main factor - treatment, split factor-year), two replications

Nitrogen

Source	df	SS	MS	F
Treatment	1	1.080	1.080	43.2
Error (a)	2	0.050	0.025	
Year	1	0.004	0.004	<1
Treatment x Year	1	0.367	0.36	2.21
Error (b)	2	0.331	0.165	
Total	**7**	**1.832**		

Phosphorous

Source	df	SS	MS	F
Treatment	1	0.0002	0.0002	<1
Error (a)	2	0.0035	0.0017	
Year	1	0.0091	0.0091	15.16
Treatment x Year	1	0.0009	0.0009	1.50
Error (b)	2	0.0012	0.0006	
Total	**7**	**0.0149**		

Potassium

Source	df	SS	MS	F
Treatment	1	0.1179	0.1179	45.35
Error (a)	2	0.0052	0.0026	
Year	1	0.0329	0.0329	9.14
Treatment x Year	1	0.0128	0.0128	3.56
Error (b)	2	0.0072	0.0036	
Total	**7**	**0.1760**		

APPENDIX 6. Statistical analysis of Douglas-fir seedling height — Koksilah

Analysis: ANOVA: single factor, two replications

Age 9

Source	df	SS	MS	F
Treatment	1	8313.7	8313.7	1409.10
Error	2	11.8	5.9	
Total	**3**	**8325.5**		

Age 8

Source	df	SS	MS	F
Treatment	1	2381.4	2381.4	243.00
Error	2	19.7	9.8	
Total	**3**	**2401.1**		

Age 7

Source	df	SS	MS	F
Treatment	1	410.1	410.1	78.87
Error	2	10.4	5.2	
Total	**3**	**420.5**		

Age 6

Source	df	SS	MS	F
Treatment	1	92.2	92.2	40.98
Error	2	4.5	2.2	
Total	**3**	**96.7**		

APPENDIX 7. Statistical analysis of foliar N, P, and K concentration and height of lodgepole pine seedlings — Vanderhoof

Analysis: ANOVA: single factor, three replications

Foliar N

Source	df	SS	MS	F
Treatment	1	0.002	0.002	<1
Error	4	0.292	0.073	
Total	**5**	**0.294**		

Foliar P (x 10^4)

Source	df	SS	MS	F
Treatment	1	4	4	<1
Error	4	1090	273	
Total	**5**	**1094**		

Foliar K (x 10^3)

Source	df	SS	MS	F
Treatment	1	17	17	<1
Error	4	435	109	
Total	**5**	**452**		

Seedling Height

Source	df	SS	MS	F
Treatment	1	70.04	70.04	3.86
Error	4	72.61	18.15	
Total	**5**	**142.65**		

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