J. Range Manage.
46:262-270, May 1993

Forage response to N, P, and S fertilization on clearcut lodgepole pine sites

BRIAN M. WIKEEM, REG F. NEWMAN, AND A.L. VAN RYSWYK

Authors are range scientist and assistant range scientist, Research Branch, British Columbia Ministry of Forests, 3015 Ord Road, Kamloops, B.C. V2B 8A9; and soil scientist, Research Branch, Agriculture Canada, 3015 Ord Road, Kamloops, B.C. V2B 8A9.

Abstract

The response of selected plant species to a single application of factorial combinations of nitrogen (N), phosphorus (P), and sulfur (S) on 2 lodgepole pine (*Pinus contorta* Dougl.) clearcut-logged sites in British Columbia was evaluated over 3 years. Increasing N rates typically resulted in higher forage standing crop on both sites, in all years, but standing crop at Fly Creek was nearly double that at Beaverdam Lake. On both sites, forage yields peaked at 400 kg N/ha in 1982 and carry-over of the fertilizer effect lasted for 3 years although yields declined annually. Addition of P to N applications enhanced ($P<0.05$) total standing crop, other grass standing crop, and pinegrass (*Calamagrostis rubescens* Buckl.) standing crop at Beaverdam Lake and grass standing crop at Fly Creek, but had no effect ($P>0.05$) on other species and groups. Sulfur, added to N applications, enhanced total yields compared to control on both clearcuts although at Fly Creek this response nearly doubled that produced at Beaverdam Lake. Nitrogen fertilization increased ($P<0.05$) pinegrass crude protein (CP) content, particularly in the first year after fertilization. Acid detergent fiber (ADF) generally increased in response to increasing N levels in 1982, but declined compared to control in 1983 and 1984. Elevated forage CP levels, litter N concentrations, and soil N levels in 1984 indicated that the carry-over response on these forest sites resulted directly from N remaining in the soil or again becoming available for plant growth.

Key Words: forage standing crop, forage quality, nitrogen, phosphorus, sulfur, urea

Interior Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco.) forests extend from southern British Columbia (B.C.), to northern Mexico (Daubenmire 1978) and account for nearly 6 million ha of the grazing resource in B.C. Throughout much of this zone, lodgepole pine (*Pinus contorta* Dougl.) often dominates the forest stand because of disturbances such as logging and fire (Tisdale and McLean 1957). Once clearcut-logged, these areas are extremely valuable to the livestock industry because of their high forage capability compared to adjacent forest. Productivity of this transitory forage resource, which may persist for 10–15 years, can be enhanced further by seeding domestic forage species (Clark and McLean 1975, Clark and McLean 1978, Clark and McLean 1979), but less is known about the response of these sites to fertilization.

Nitrogen (N) deficiencies often limit plant growth on forestland. Freyman and van Ryswyk (1969) found that ammonium nitrate, applied at 100 and 200 kg/ha on an open-forest site dominated by pinegrass (*Calamagrostis rubescens* Buckl.) in Interior Douglas-fir (IDF) biogeoclimatic zone (Lloyd et al. 1990) near Kamloops, B.C., improved palatability, nutritive value, and forage standing crop. Both forage standing crop and quality were further enhanced when sulfur (S) was applied with N but this response lasted only 1 growing season (Freyman and van Ryswyk 1969).

Clark and McLean (1979) applied ammonium nitrate, alone and in combination with S, to Engelmann spruce (*Picea engelmannii* Parry)—subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) clearcuts near Kamloops, B.C. Nitrogen application rates of 16, 33, and 66 kg N/ha, and the same rates of N combined with 5, 11, and 21 kg S/ha, were applied on cutblocks seeded to a mix of timothy (*Phleum pratense* L.), smooth brome (*Bromus inermis* Leys.), crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and alsike clover (*Trifolium hybridum* L.). Their results indicated that forage standing crop increased 2–4 times following N application but response lasted only 1 year. The addition of S did not improve yields beyond N alone.

This study assessed the potential for fertilization as a range improvement technique on lodgepole pine clearcuts in the IDF zone of southern interior B.C. Specifically, we studied the effects of 5 rates of N, 3 rates of P, and 2 rates of S, alone and in factorial combinations, on forage standing crop, forage quality, litter N content, and soil N status following fertilization.

Study Area and Methods

Two lodgepole pine sites were studied in the south Cariboo region of interior B.C. The Beaverdam Lake site (51° 16′ N; 121° 3′ W) was located in the Very Dry Mild IDF subzone (Lloyd et al. 1990) 16 km southwest of 70 Mile House, B.C. The site was clearcut-logged in 1977, drag scarified, and broadcast seeded at 6 kg/ha in 1978. The seed mix consisted of 60% crested wheatgrass, 10% intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), 10% smooth brome, 10% Rambler alfalfa (*Medicago sativa* L.), and 10% white clover (*Trifolium repens* L.) by seed weight.

The Fly Creek site (51° 19′ N; 121° 12′ W) occurred in the Dry Cool IDF subzone, 23 km east of 70 Mile House. Following clearcut-logging in 1979, the area was aerially seeded at 4.5 kg/ha in 1980 with a seed mix comprised of 26% orchard grass (*Dactylis glomerata* L.), 10% timothy, 15% smooth brome, 15% intermediate wheatgrass, 10% perennial ryegrass (*Lolium perenne* L.), 10% white clover, and 12% alsike clover by seed weight.

Despite seeding, pinegrass dominates the herbaceous native vegetation at both sites. Naturally regenerating lodgepole pine, which occurs infrequently within the experimental areas, represents the dominant tree species. Soils are Degraded Eutric Brunisols (Eutochrept; pH 6.2) and Orthic Gray Luvisols (Boralfs; pH 5.5) at Beaverdam Lake and Fly Creek, respectively. Both sites have level topography, occur at 1,070 m elevation, and were fenced to prevent livestock grazing.

Annual precipitation at 70 Mile House, (51° 18′ N; 121° 24′

Manuscript accepted 14 Nov. 1992.

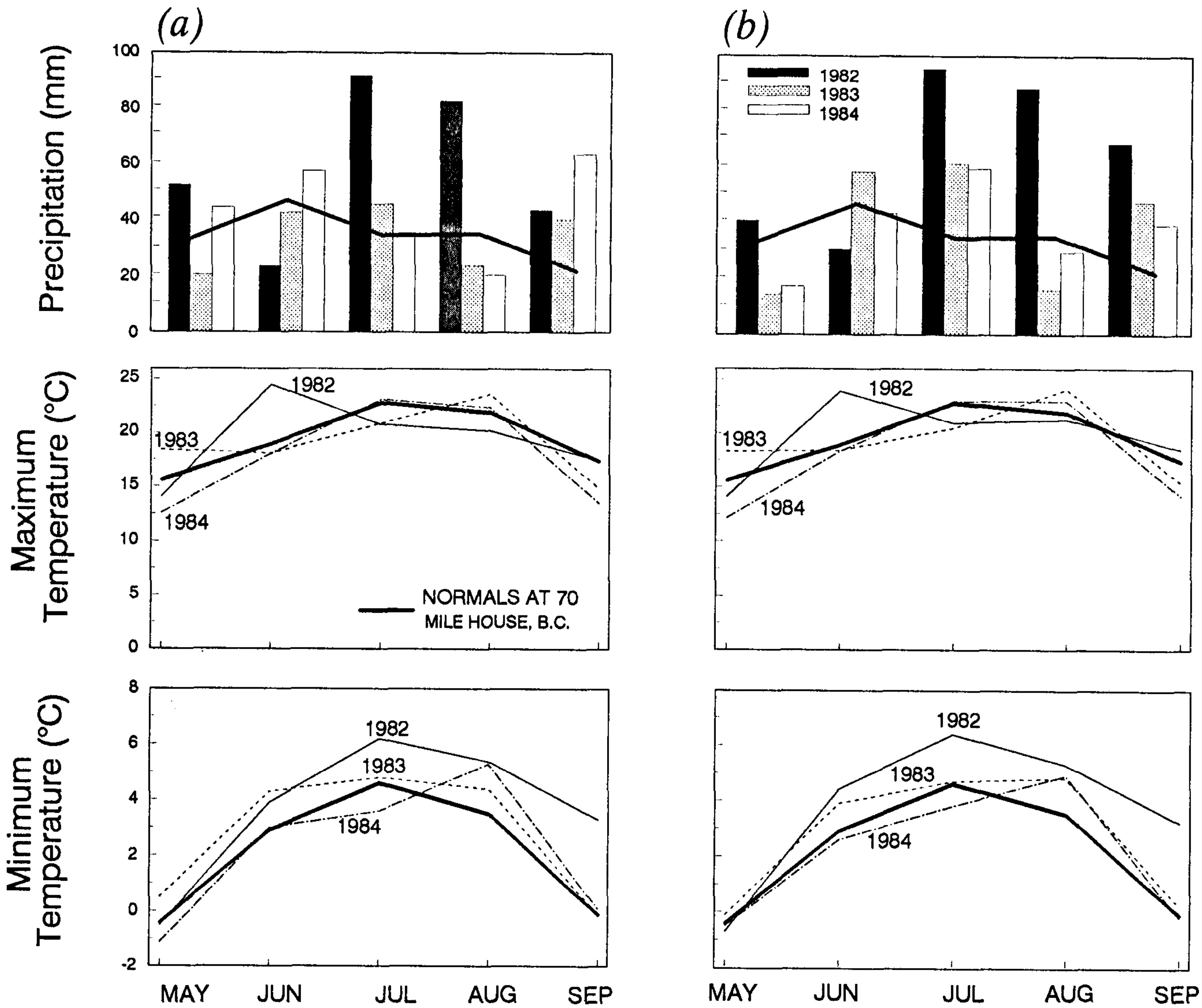

Fig. 1. Precipitation, maximum, and minimum temperatures throughout the 1982, 1983, and 1984 growing seasons for (a) Beaverdam Lake, and (b) Fly Creek compared to normals for 70 Mile House, B.C.

1,080 m elevation), the nearest permanent weather station to both sites, averages 227 mm with nearly 75% occurring during the growing period (Fig. 1). Bimodal peaks in precipitation occur in January (35 mm) as snow and in June (45 mm) as rain. Highest mean daily maximum temperatures occur in July (23° C); coldest daily mean temperatures prevail in January (-17° C). The frost-free period averages only 33 days (Environment Canada 1982).

Standing Crop

Plots were established in a randomized complete block design consisting of 5 blocks, each with 30 main plots of 4 × 4 m area. Each of the main plots was further subdivided into 4 subplots of 2 × 2 m area to provide for 4 years of destructive sampling.

Each 4 × 4-m main plot was hand fertilized in 1981 using factorial combinations of N, P, S, and an untreated control. Forest grade urea (45-0-0) was applied at 100, 200, 300, and 400 kg N/ha; triple super phosphate (0-45-0) at 25 and 50 kg P/ha; and elemental S at 55 kg S/ha. Annual herbaceous standing crop was clipped in late-July 1982, 1983, and 1984 to a 5-cm stubble height on a 1 × 1-m area located centrally within each of the 2 × 2-m subplots. Clipped vegetation was hand sorted into pinegrass, orchard grass, timothy, smooth brome, other grasses, timber milkvetch (*Astragalus miser* Dougl.), other forbs, and litter. Samples were oven dried at 70° C and weighed.

Forage Quality, Litter Nitrogen, and Soil Constituents

Nutrient analyses on pinegrass and litter N concentrations were determined to provide an index of fertilizer effects on forage quality and to establish the extent to which litter acted as a N sink. Only samples collected at the Fly Creek site were analyzed. Three replications per treatment combination were selected from oven-dried material collected to estimate pinegrass standing crop. These samples were ground through a 40-mesh screen in a Wiley mill and analyzed for crude protein (CP), acid-detergent fiber (ADF), calcium (Ca), and phosphorus (P). Additional litter samples were similarly collected and analyzed for N.

Following plant dormancy in September, soil samples were collected annually at both sites on subplots previously clipped for standing crop. Only control plots and those treated with different N levels alone were sampled. At each subplot, 8 cores (2 cm diam) were collected to a 15-cm depth and composited. After removing undecomposed organic material, the samples were air dried, passed through a 2-mm sieve, and analyzed for total nitrate-N. The British Columbia Ministry of Agriculture and Fisheries soil, feed, and tissue testing laboratory, at Kelowna, B.C., conducted chemical analyses on all forage, litter, and soil samples.

Statistical Analysis

Data were analyzed with analysis of variance (ANOVA) using SAS PROC GLM (SAS 1979). Standing crop data were analyzed with a split-plot ANOVA in a randomized complete-block design with 30 treatment combinations (N, P, and S), a split-plot (Years) and 5 replications (Blocks). Forage quality data were analyzed similarly except only 3 replications were used. Data from the soil N experiment were analyzed with a split-plot ANOVA in a randomized complete-block design with N levels as the main plots, years as the split-plot, and 5 replications (Blocks). The nature of the fertilizer response over N rates was assessed using orthogonal polynomial contrasts ($P<0.05$) to the second degree polynomial in all experiments.

Results and Discussion

I Forage Yields

All four-way interactions involving N, P, S, and year, were insignificant ($P>0.05$). Significant 3-way interactions are discussed in text.

Nitrogen Effect

Beaverdam Lake

Increasing N rates typically resulted in higher total standing crop on both sites and in all years (Tables 1, 2, 3, 4). Total standing crop at Beaverdam Lake peaked at 400 kg N/ha in 1982, the year following urea application, producing 320% more herbage than the control (Table 1). Even though N response declined from 1982 to 1984, forage standing crop still remained 36%, 70%, 91%, and 99% higher than control at the 100, 200, 300, and 400 kg N/ha rates, respectively, in 1984. Some of the decline in response from 1982 to 1984 likely resulted from the moister conditions throughout the 1982 growing season (Fig. 1), although stand aging also may have been a factor.

At Beaverdam Lake, fertilization increased standing crop for all species and groups except other forbs and timber milkvetch (Table 1, 2). Other grasses, predominated by Kentucky bluegrass (*Poa pratensis* L.), accounted for 35% of the total standing crop before fertilization in 1982. Following N application, increases in other grass standing crop had both significant linear and quadratic components (Table 2) with this group comprising an increasingly larger portion of total standing crop as the fertilizer rates increased from 100 kg N/ha (48%) to 400 kg N/ha (63%) (Fig. 2). At 400 kg N/ha, other grass standing crop increased by 927 kg/ha (657%) compared to control and standing crop may have increased even further at higher N rates because the growth response had not peaked at 400 kg/ha.

A significant nitrogen × year interaction (Table 2) indicated that other grass standing crop increased directly with higher N rates but trends among years were different. Other grass response continued into 1983, producing 645 kg/ha more forage than the control at 200 kg N/ha. By 1984, other grass standing crop declined significantly with the maximum standing crop produced at 300 kg N/ha (Table 1).

Pinegrass, which accounted for 23% of total standing crop in 1982, responded similarly to other grasses after N fertilization, although standing crop increases were lower than for other grasses (Table 1). For example, pinegrass standing crop increases over control ranged from 48% and 211% in 1982 to 27% and 54% in 1984 at the 100 kg N/ha and 400 kg N/ha, respectively. In 1982, maximum pinegrass standing crop occurred at 400 kg N/ha (Table 1). Although response continued into 1983, with peak standing crop occurring between 200 and 300 kg N/ha, only negligible standing

Table 1. Effect of nitrogen, phosphorus, and sulfur on forage standing crops at Beaverdam Lake in 1982, 1983, and 1984.

Year	Level	Pine-grass	Orchard-grass	Other grass	Timber milkvetch	Other forb	Total yield
		kg/ha					
Nitrogen							
1982	0	92	9	141	36	128	405
1983		111	15	270	39	240	676
1984		52	3	67	12	154	289
1982	100	136	28	473	13	327	979
1983		128	24	596	15	279	1044
1984		66	4	171	7	144	392
1982	200	179	123	659	16	343	1326
1983		157	35	915	8	111	1233
1984		78	1	275	2	135	492
1982	300	211	162	877	16	266	1534
1983		169	16	919	8	235	1346
1984		67	0	313	2	169	551
1982	400	286	84	1068	23	235	1699
1983		161	20	1012	5	252	1468
1984		80	0	291	2	201	575
Phosphorus							
1982	0	154	77	598	15	252	1100
1983		159	28	538	15	262	1012
1984		74	3	208	2	136	423
1982	25	181	54	589	21	283	1129
1983		166	20	809	12	183	1195
1984		79	1	201	8	185	474
1982	50	207	113	744	27	244	1337
1983		111	18	881	18	226	1253
1984		53	2	262	5	161	482
Sulfur							
1982	0	162	51	473	20	289	998
1983		167	15	511	13	216	922
1984		83	2	150	3	180	417
1982	55	200	111	814	22	230	1379
1983		123	29	974	17	230	1385
1984		54	2	297	6	142	502

Table 2. Forage standing crop contrasts at Beaverdam Lake.

Contrast	Pine-grass	Orchard-grass	Other grass	Timber milkvetch	Other forb	Total yield
Year (Y)						
YL	*	*	*	*	*	*
YQ	NS	*	*	NS	NS	*
Nitrogen (N)						
NL	*	*	*	*	NS	*
NQ	NS	*	*	*	NS	*
NL × YL	*	*	*	NS	NS	*
NQ × YL	NS	*	NS	NS	*	*
NL × YQ	NS	*	NS	*	NS	NS
NQ × YQ	NS	NS	NS	NS	*	NS
NL × PL	NS	NS	*	NS	NS	*
NQ × PL	NS	*	NS	NS	NS	NS
NL × PQ	NS	NS	NS	NS	NS	NS
NQ × PQ	NS	NS	NS	NS	NS	NS
NL × SL	NS	*	*	*	NS	*
NQ × SL	NS	NS	NS	NS	NS	NS
Phosphorus (P)						
PL	NS	NS	*	NS	NS	*
PQ	NS	NS	NS	NS	NS	NS
PL × YL	*	NS	NS	NS	NS	NS
PL × YQ	*	NS	*	NS	NS	NS
PQ × YL	NS	NS	NS	NS	NS	NS
PQ × YQ	NS	NS	*	NS	*	NS
PL × SL	NS	NS	NS	NS	NS	NS
PQ × SL	NS	NS	NS	NS	*	NS
Sulfur (S)						
SL	NS	*	*	NS	NS	*
SL × YL	*	*	*	NS	NS	*
SL × YQ	*	NS	*	NS	NS	*

L = Linear
Q = Quadratic
* = Significant at $P<0.05$
NS = Not significant

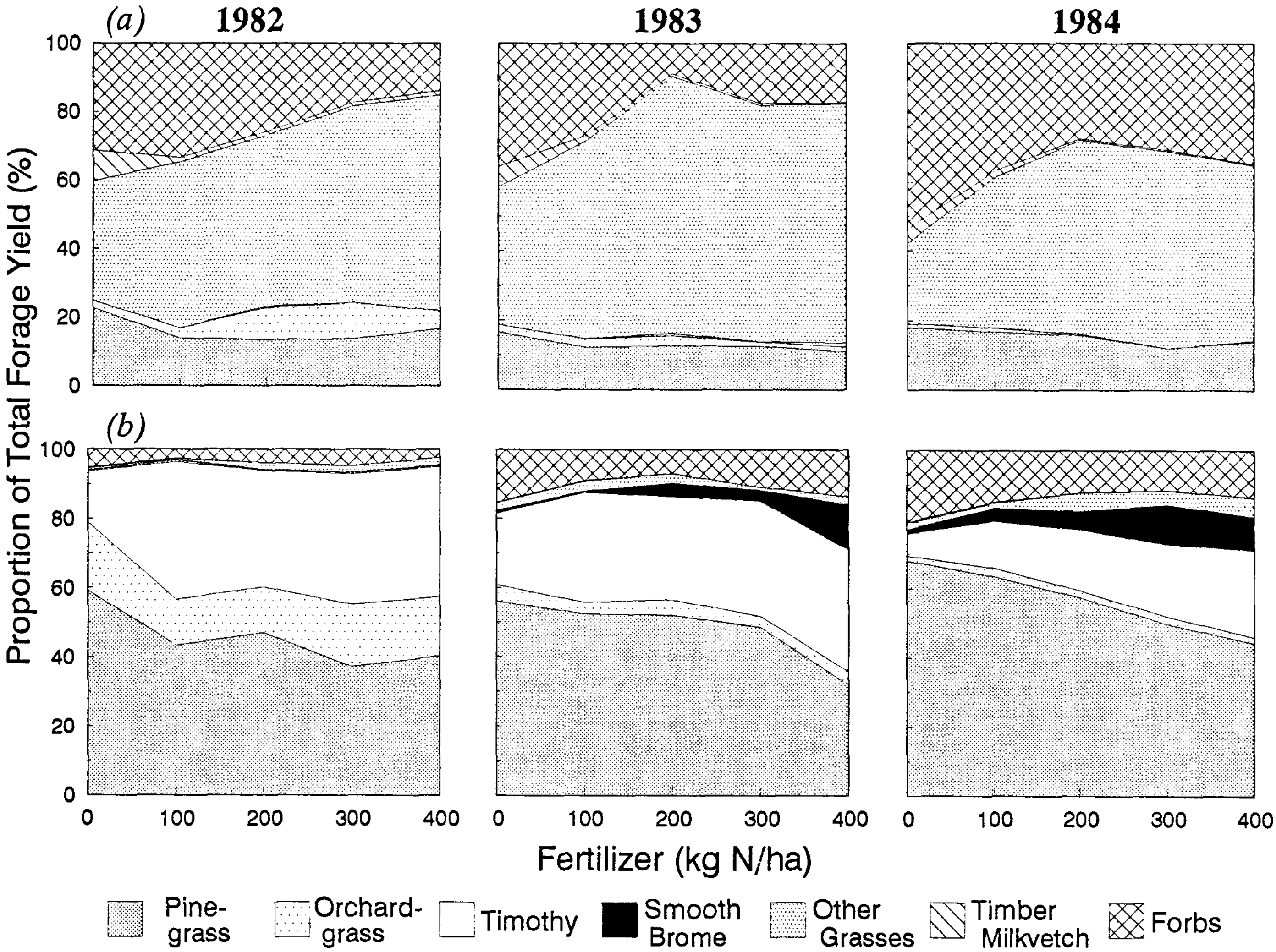

Fig. 2. Proportion of total yield of pinegrass, orchard grass, timber milkvetch, other grasses, and and other forbs at (a) Beaverdam Lake, and of pinegrass, orchardgrass, timothy, smooth brome, other grasses, and other forbs at (b) Fly Creek over N fertilizer rates from 1982 to 1984.

crop increases were evident by 1984 (Table 1). In contrast to other grasses, the proportion of pinegrass in total yield correlated ($P<0.10$) inversely with N application rate in 1983 ($r^2 = 0.68$, n = 5), and 1984 ($r^2 = 0.76$, n = 5), suggesting that other grasses competed more effectively for N than pinegrass (Fig. 2). Moreover, these changes indicate that N fertilization may be a useful tool to alter species composition on clearcut forest sites.

Orchard grass responded to N applications similarly to pinegrass (Table 1, 2), but this species only represented 2% of total yield on the control plots in 1982. Orchard grass response peaked at 300 kg N/ha, producing 150 kg/ha more herbage than control in 1982, but by 1983 standing crop on the fertilized plots was similar to the control (Table 1).

Significant nitrogen × year interactions for other forb standing crop (Table 1) result partly from an inconsistently low response at the 200 kg N/ha rate in 1983. In addition, the expected reduction of standing crop over time, caused changes in the nature of the response to N in each year.

The proportion of other forbs increased from nearly 32% to 53% of total yield on the control plots between 1982 and 1984, but showed little response to N application rates (Fig. 2). Like pinegrass, the contribution of other forbs to total yield declined as N rates increased in 1982. By 1984, the proportion of other forbs in total yield was lower than the control at all N rates, suggesting that other grasses competed more effectively for applied N than other forbs.

Timber milkvetch standing crop was reduced in all years and by all levels of N application (Tables 1, 2). Nitrogen fertilization often reduces legume standing crop by inhibiting N-fixation (Woodhouse and Griffith 1974), enabling other plant species to compete more effectively for limiting growth factors other than N. These losses in timber milkvetch standing crop may be beneficial to cattle by reducing its availability. Nitrogen fertilization may also reduce toxin levels of timber milkvetch, particularly at later growth stages (Majak and Wikeem 1986).

Fly Creek

At the Fly Creek site, a slightly more mesic site than Beaverdam Lake (Fig. 1), standing crop was nearly double that of Beaverdam Lake (Table 1, 3). Maximum total yields were 365% greater than control and occurred at 400 kg N/ha in 1982 (Table 3). Fertilizer response declined from 1982 to 1984 but total yields still averaged 23% (144 kg/ha) and 72% (444 kg/ha) higher than the control at 100 and 400 kg N/ha, respectively by 1984.

Forage standing crop was increased by N fertilization ($P<0.05$) for all other species and groups at Fly Creek (Table 3) with pinegrass, timothy, and orchard grass accounting for 35%, 44%, and 16% of the total yield increase, respectively, in 1982. Standing crop increases of the remaining species groups were negligible (Table 3).

Table 3. Effect of nitrogen, phosphorus, and sulfur on forage standing crops at Fly Creek in 1982, 1983, and 1984.

Year	Level	Pinegrass	Orchardgrass	Timothy	Smooth brome	Other grass	Other forb	Total yield
		kg/ha						
Nitrogen								
1982	0	396	132	99	2	4	36	669
1983		417	35	153	6	16	116	743
1984		418	8	40	8	9	128	614
1982	100	1042	319	954	13	9	65	2402
1983		611	39	367	6	35	105	1165
1984		482	18	103	29	10	113	758
1982	200	1353	383	971	8	58	110	2884
1983		692	62	395	54	36	94	1334
1984		511	18	154	49	46	108	887
1982	300	1088	528	1101	13	57	138	2926
1983		701	44	481	45	13	162	1444
1984		459	20	195	104	38	108	924
1982	400	1255	532	1170	15	66	72	3109
1983		566	68	626	230	41	244	1775
1984		468	19	266	103	56	147	1058
Phosphorus								
1982	0	1044	323	791	2	23	78	2262
1983		677	36	388	63	19	141	1325
1984		471	20	136	52	8	108	796
1982	25	995	408	877	15	34	75	2405
1983		563	60	371	23	28	120	1166
1984		474	20	163	50	34	114	856
1982	50	1042	405	909	13	59	100	2527
1983		552	52	454	118	38	171	1385
1984		459	9	156	74	54	140	891
Sulfur								
1982	0	1040	257	784	4	21	54	2161
1983		651	23	332	19	25	27	1177
1984		493	7	130	17	23	14	784
1982	55	1013	501	933	16	57	115	2635
1983		543	76	477	118	31	161	1408
1984		443	27	173	100	40	127	912

Unlike the pinegrass standing crop response at Beaverdam Lake which was greatest when fertilized at 400 kg N/ha, pinegrass standing crop at Fly Creek was greatest when fertilized at 200 kg N. Pinegrass standing crop declined when N was applied at rates greater than 200 kg/ha, suggesting that pinegrass was unable to use N fully at higher rates, or that other species were able to use N more effectively. Although fertilization at 200 kg N/ha resulted in the highest level of pinegrass standing crop in 1982 (957 kg/ha increase over control), N application at 100 kg/ha produced the best forage return per kg of N applied in all years (Table 3). Contrary to earlier research (Freyman and van Ryswyk 1969), which indicated that N effects declined after 1 year, pinegrass standing crop on fertilized plots was still higher than the control 3 years after a single application of N (Table 3). Similar to Beaverdam Lake, the relative proportion of pinegrass to total yield was inversely correlated ($P<0.10$) with N fertilization levels in 1982 ($r^2 = 0.66$, n = 5), 1983 ($r^2 = 0.77$, n = 5), and 1984 ($r^2 = 0.99$, n = 5) resulting in a greater percentage of timothy and smooth brome (Fig. 2).

Orchard grass standing crop ranged from 187 to 400 kg/ha more than the control in 1982 at 100 and 400 kg N/ha rates, respectively, but standing crops were only slightly higher than control in 1983 and 1984 at all N rates (Table 3). In contrast to orchard grass, timothy produced 864% more standing crop than control at 100 kg N/ha but higher N rates did not improve yields substantially in 1982 (Table 3, 4). Moreover, nitrogen × year interactions (Table 4) indicated that timothy responded differently across N levels among years and, even at 400 kg N/ha, timothy standing crops over control declined in 1983 (473 kg/ha) and 1984 (226 kg/ha) compared to 1982 (1,071 kg/ha).

Phosphorus Effect

Except for total standing crop, other grasses, and pinegrass at Beaverdam Lake, and other grasses at Fly Creek, most species were unaffected ($P>0.05$) by P over all N and S fertilization rates (Tables 2, 4). Averaged over all N and S levels, total yield at Beaverdam Lake responded directly ($P<0.05$) to P applications with the greatest yield increase over control (24%) occurring in 1983 from 50 kg P/ha. By 1984, however, these increases equaled only 12% and 14% at the 25 and 50 kg P/ha rates, respectively (Table 1).

A nitrogen × phosphorus × sulfur interaction at Beaverdam Lake indicated that adding P alone had little effect on pinegrass standing crop across N levels. Addition of P to N and S suppressed standing crop at 100 kg/ha N, but at rates higher than 200 kg/ha N, phosphorus enhanced pinegrass growth (Fig. 3).

At Beaverdam Lake, significant phosphorus × year interactions (Table 2) indicate that other grasses responded at both P levels in 1983 but only at 50 kg P/ha in 1982 and 1984. Peak increases in grass standing crop above control (343 kg/ha) occurred at the combined rates of 50 kg P/ha and 400 kg N/ha in 1983. This delayed response likely resulted from the relative immobility of P to leach into the rooting zone compared to N which was exacer-

Table 4. Forage standing crop contrasts at Fly Creek.

Contrast	Pinegrass	Orchardgrass	Timothy	Smooth brome	Other grass	Forb	Total yield
Year (Y)							
YL	*	*	*	*	NS	*	*
YQ	*	*	NS	*	NS	*	*
Nitrogen (N)							
NL	*	*	*	*	*	*	*
NQ	*	NS	*	NS	NS	NS	*
NL × YL	*	*	*	NS	NS	NS	*
NQ × YL	*	NS	*	NS	NS	*	*
NL × YQ	NS	*	NS	*	NS	*	*
NQ × YQ	NS	NS	NS	*	NS	*	*
NL × PL	NS	NS	NS	NS	*	NS	NS
NQ × PL	NS	NS	NS	NS	NS	NS	NS
NL × PQ	NS	NS	NS	NS	NS	NS	NS
NQ × PQ	NS	NS	NS	NS	NS	NS	NS
NL × SL	NS	*	NS	*	NS	*	*
NQ × SL	NS	NS	NS	*	NS	NS	NS
Phosphorus (P)							
PL	NS	NS	NS	NS	*	NS	NS
PQ	NS	NS	NS	NS	NS	NS	NS
PL × YL	NS	NS	NS	NS	NS	NS	NS
PL × YQ	NS	NS	NS	NS	NS	NS	NS
· PQ × YL	NS	NS	NS	NS	NS	NS	NS
PQ × YQ	NS	NS	NS	NS	NS	NS	NS
PL × SL	NS	NS	NS	NS	NS	NS	NS
PQ × SL	NS	NS	NS	NS	NS	NS	NS
Sulfur (S)							
SL	NS	*	NS	*	*	*	*
SL × YL	NS	*	NS	NS	NS	NS	*
SL × YQ	NS	NS	NS	NS	NS	NS	NS

L = Linear
Q = Quadratic
* = Significant at $P<0.05$
NS = Not significant

bated by the drier than normal conditions in May and June 1982 when most plant growth occurs in this area.

A significant phosphorus × sulfur × year interaction for pinegrass (Fig. 3) indicated that standing crop increased compared to the control when P was applied with S in 1982 at both 25 and 50 kg P/ha. In 1983 and 1984, the combination of P with S depressed forage production, especially at the 50 kg P/ha rate (Fig. 3). Since P generally stimulates root growth, the lower standing crop in the last 2 growing seasons may have resulted from an allocation of plant resources to increased root-growth at the expense of top-growth.

At Beaverdam Lake, maximum standing crop for orchard grass occurred at 300 kg N/ha when P was added at 50 kg/ha. This response, however, diminished rapidly and by 1984 there were no differences among P levels (Fig. 3).

Addition of P to N increased other grass standing crop beyond N application alone at Beaverdam Lake and Fly Creek. A nitrogen × phosphorus interaction for other grasses at Beaverdam Lake (Table 2), suggests that this increase only resulted partly from direct effects of P on plant growth, while additional response resulted from increased use of available N. For example, other grasses did not utilize N applied at rates higher than 200 kg/ha except with P. Apparently, N fertilization increased other grass growth which resulted in soil P deficiencies and ultimately limited further production. Our results suggest that P became limiting in the soil at Fly Creek when N application rates exceeded 100 kg/ha.

Sulfur Effect

Sulfur enhanced total yields compared to control on both sites (Table 1, 3). However, at Beaverdam Lake standing crop was only about one half as much as Fly Creek in 1982. Although maximum total yields were experienced at Fly Creek, S applications produced relatively more forage compared to control at Beaverdam Lake (22% vs. 38%). Significant 3- and 2-way interactions involving N, S, and year at both sites (Tables 2, 4) indicate that S improved forage yielded more as the N level increased.

At Beaverdam Lake, total yield increased by more than 50% when S was added to 400 kg N/ha compared to N alone at the same rate. Significant sulfur × year interactions at both sites (Table 2, 4) revealed that by 1984 response had declined to 20% and 16% more than control at Beaverdam Lake and Fly Creek, respectively.

Pinegrass response to S application differed on the 2 sites. Pinegrass standing crop at Beaverdam Lake increased with S application in 1982 and was less than control in 1983 and 1984 (Tables 1, 2). At Fly Creek, however, S did not enhance pinegrass standing crop at any year (Table 3), suggesting that other plant species more effectively utilize combined N and S than pinegrass at Fly Creek.

A nitrogen × sulfur interaction (Table 2) at Beaverdam Lake indicated that S increased grass standing crop beyond that attained with N alone even at the lowest N rate. The other grass standing crop equaled 72%, 90%, and 98% more than control in 1982, 1983, 1984, respectively, when S was applied with N, but part of this response likely resulted from plants becoming more vigorous each year.

At Fly Creek, orchard grass was most productive when both N and S were applied (Fig. 3). Although orchard grass declined from 1982 to 1984, the standing crop remained higher in 1984 on the S

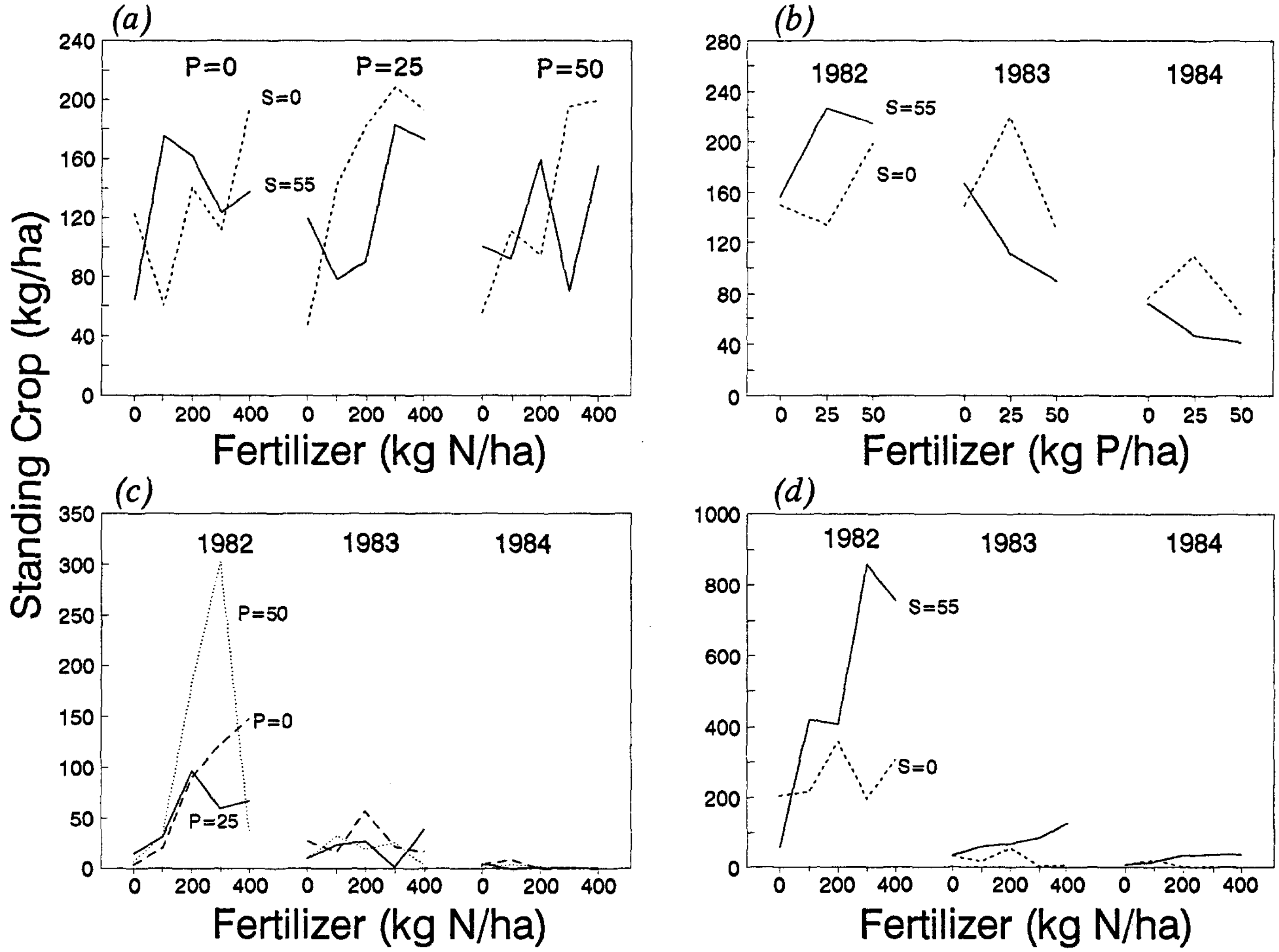

Fig. 3. Three-way interactions ($P<0.05$) demonstrating the effects of (a) nitrogen, phosphorus, and sulfur on pinegrass standing crop at Beaverdam Lake, (b) phosphorus and sulfur from 1982 to 1984 on pinegrass standing crop at Beaverdam Lake, (c) nitrogen and phosphorus from 1982 to 1984 on orchard grass standing crop at Beaverdam Lake, and (d) nitrogen and sulfur from 1982 to 1984 on orchard grass standing crop at Fly Creek.

treated plots than on the controls, indicating a carry-over of yields to 1984.

Similarly, significant nitrogen × sulfur interactions for smooth brome and total forbs at Fly Creek, and for orchard grass at Beaverdam Lake (Table 2, 4), indicated that all species benefited when both N and S were added. However, forb and orchard grass standing crops declined by 1984, but standing crops of smooth brome remained higher in 1984 compared to 1982 (Table 1, 3). Moreover, standing crops for all 3 species remained higher in 1984 on the S treated plots than on the control plots, indicating a yield carry-over to the third year. The relationship between N and S likely occurs because both elements are required for plant protein synthesis, and at high N rates, S can limit plant growth when soil S becomes depleted or unavailable.

II Forage Quality

At 300 kg N/ha, pinegrass crude protein (CP) increased by 28% compared to control in 1982. This increase over control was still evident in 1984 although absolute amounts of CP were lower (Table 5, 6). Crude protein levels of unfertilized pinegrass were generally lower in 1984 than in other years. These lower CP levels in 1984 possibly reflected the relatively cooler and drier condition in 1984 (Fig. 1) which may have resulted in plants maturing earlier.

Significant nitrogen × year interactions (Table 6) indicated that pinegrass acid detergent fiber (ADF) generally increased in response to N levels in 1982 but declined compared to control in 1983 and 1984 (Table 5). Pinegrass Ca content declined over all N rates compared to control in 1982 but by 1983 Ca levels were the same over all N rates (Table 5). In contrast to Ca, P concentrations increased linearly as both N and P rates increased (Table 5, 7) but by 1984 P levels for all fertilized samples were the same as control.

Enhanced crude protein levels in 1984 suggests that part of the forage yield carry-over response observed on these forest sites resulted from soil N remaining or again becoming available for plant growth. Indeed, elevated N concentrations were evident in litter samples at Fly Creek and in soil extracts from both sites following urea application (Table 5, 7). For example, even in 1984, soil N levels at the Beaverdam Lake site were still higher ($P<0.05$) on N fertilized plots compared to controls although residual soil N declined each year.

At Fly Creek in 1982, soil N levels were enhanced for all fertilizer rates greater than 100 kg N/ha but by 1984 virtually no residual soil N remained (Table 7). Similarly, litter N content at Fly Creek increased ($P<0.05$) with N application rates in 1982 but by 1984 litter N levels were similar to control (Table 5). The greater depletion of soil N at Fly Creek compared to Beaverdam Lake may have occurred because of higher leaching losses and/or higher plant uptake because of the wetter weather conditions at Fly Creek

Table 5. Effects of nitrogen, phosphorus, and sulfur on pinegrass forage quality and litter nitrogen at Fly Creek from 1982 to 1984.

Year	Level	Crude protein	Acid detergent fiber	Calcium	Phosph-orus	Litter nitrogen
	kg/ha	%				
Nitrogen						
1982	0	8.9	41.2	0.44	0.19	
1983		7.4	42.1	0.42	0.21	0.54
1984		1.8	41.7	0.30	0.22	0.10
1982	100	8.5	43.9	0.30	0.20	
1983		7.8	41.2	0.38	0.19	0.59
1984		2.5	40.9	0.28	0.23	0.11
1982	200	9.8	43.9	0.24	0.23	
1983		8.6	40.4	0.36	0.25	0.75
1984		3.1	40.4	0.29	0.23	0.14
1982	300	11.4	42.7	0.25	0.25	
1983		8.7	39.3	0.35	0.23	0.88
1984		2.4	40.0	0.29	0.24	0.13
1982	400	11.4	44.8	0.23	0.26	
1983		8.5	39.8	0.35	0.23	0.90
1984		2.8	40.3	0.28	0.22	0.16
Phosphorus						
1982	0	10.3	42.6	0.32	0.21	
1983		8.4	40.6	0.37	0.21	4.4
1984		2.3	40.7	0.29	0.22	0.9
1982	25	9.8	43.9	0.28	0.22	
1983		8.0	40.7	0.38	0.23	4.8
1984		2.9	41.1	0.29	0.23	0.7
1982	50	9.9	43.4	0.28	0.23	
1983		8.2	40.4	0.38	0.23	4.6
1984		2.3	40.3	0.29	0.23	0.8
Sulfur						
1982	0	9.8	43.5	0.29	0.22	
1983		8.3	41.1	0.37	0.22	4.4
1984		2.6	41.0	0.29	0.23	0.8
1982	55	10.2	43.1	0.30	0.23	
1983		8.1	40.4	0.37	0.22	4.7
1984		2.4	40.3	0.28	0.22	0.8

during the study period (Fig. 1).

Summary and Management Implications

Nitrogen fertilization quadrupled forage yields and increased pinegrass crude protein content by 28% on clearcut-logged lodgepole pine sites. This response, however, was most evident in the first year after fertilizer application and forage yields declined in the following 2 years. Increases in crude protein content only occurred in the first year after the fertilizer was applied. Sustained increases in forage production can only be maintained on Douglas-fir forest range with annual, or almost-annual, applications of nitrogen fertilizer.

Interior Douglas-fir forests in B.C. are used as late-spring, summer, and early-fall range only. Although increases in forage production potentially can increase carrying capacity for livestock, the viability of using fertilization as a range management tool on forest range depends on both economics, and the availability of other range and forage crops to feed livestock during fall, winter, and spring. If forage supplies are not available during these periods there is little incentive to increase cow/calf herds.

Single applications of nitrogen fertilizer that provide short-term increases in high quality forage, could be used to attract and hold stock on selected areas of range temporarily so that other areas can be rested. Moreover, a single application of N also might be used to

Table 6. Contrasts for pinegrass forage quality and litter nitrate-N at Fly Creek.

Contrast	Crude protein	Acid detergent fiber	Calcium	Phosph-orus	Litter Nitrate-N
Year (Y)					
YL	*	*	NS	NS	*
YQ	*	*	*	NS	
Nitrogen					
NL	*	NS	*	*	*
NQ	NS	NS	*	NS	NS
NL × YL	*	*	*	*	*
NQ × YL	NS	NS	*	NS	NS
NL × YQ	NS	*	NS	NS	
NQ × YQ	NS	NS	NS	NS	
NL × PL	NS	NS	NS	NS	NS
NQ × PL	NS	NS	NS	NS	NS
NL × PQ	NS	NS	*	NS	NS
NQ × PQ	NS	NS	NS	NS	NS
NL × SL	NS	NS	NS	NS	NS
NQ × SL	NS	NS	NS	NS	NS
Phosphorus					
PL	NS	NS	NS	*	NS
PQ	NS	NS	NS	NS	NS
PL × YL	NS	NS	NS	NS	NS
PL × YQ	NS	NS	NS	NS	
PQ × YL	NS	NS	NS	NS	NS
PQ × YQ	NS	NS	NS	NS	
PL × SL	NS	NS	NS	NS	NS
PQ × SL	NS	NS	*	NS	NS
Sulfur (S)					
SL	NS	NS	NS	NS	NS
SL × YL	NS	NS	NS	NS	NS
SL × YQ	NS	NS	NS	NS	

L = Linear
Q = Quadratic
* = Significant at $P<0.05$
NS = Not significant.

Table 7. Effects of fertilizer application on soil nitrogen from 1982 to 1984 at Beaverdam Lake and Fly Creek.

Year	Nitrogen level	Beaverdam Lake	Fly Creek
	kg/ha	µg/ml	
1982	0	3.6	1.0
1983		1.0	1.0
1984		3.4	1.8
1982	100	2.0	1.2
1983		3.8	1.0
1984		4.2	2.2
1982	200	5.8	7.2
1983		2.8	1.0
1984		3.8	2.2
1982	300	18.6	18.2
1983		3.8	1.0
1984		7.4	4.0
1982	400	27.2	41.4
1983		17.0	1.0
1984		8.4	2.8
Contrast			
Year (Y)			
YL		*	*
YQ		NS	*
Nitrogen (N)			
NL		*	*
NQ		NS	NS
NL × YL		*	*
NQ × YL		NS	*
NL × YQ		NS	*
NQ × YQ		NS	NS

L = Linear
Q = Quadratic
* = Significant at $P<0.05$
NS = Not significant

offset shortfalls in forage created by canopy closure on older clearcuts which occur before new areas are harvested. More research needs to be conducted to determine if these possibilities are biologically and economically practical.

Sulfur increased forage standing crop by up to 50% beyond N alone on both clearcuts. Since most of the cost of fertilization results from labour and equipment during application, the addition of S to N might make fertilizer application more economically attractive on these sites.

Changes in species composition can occur following N application on forested sites. Indeed, timber milkvetch declined in the stand following N applications which may be an important secondary benefit of fertilization. This treatment, however, must be carefully considered when the forage stand includes other legumes with high forage value.

Literature Cited

Clark, M.B., and A. McLean. 1975. Growth of lodgepole pine seedlings in competition with different densities of grass. B.C. Forest Service, Res. Note 70.

Clark, M.B., and A. McLean. 1978. Compatibility of grass seeding and coniferous regeneration of clearcuts in south central interior British Columbia. B.C. Forest Service, Res. Note 83.

Clark, M.B., and A. McLean. 1979. Growth of lodgepole pine seedlings in competition with grass. B.C. Forest Serv., Res. Note 86.

Daubenmire, R. 1978. Plant geography with special reference to North America. Academic Press, N.Y.

Environment Canada. 1982. Canadian climate normals 1951–1980. British Columbia. Atmos. Environ. Serv., Downsview, Ont.

Freyman, S., and A.L. van Ryswyk. 1969. Effect of fertilizer on pinegrass in southern British Columbia. J. Range Manage. 6:390–395.

Lloyd, D., K. Angove, G. Hope, and C. Thompson. 1990. A guide to site identification and interpretation for the Kamloops region. Parts 1 & 2, Res. Br., B.C. Minist. Forest., Land Manage. Handbook 23.

Majak, W., and B.M. Wikeem. 1986. Miserotoxin levels in fertilized *Astragalus miser* var. *serotinus*. J. Range Manage. 39:130–131.

Tisdale, E.W., and A. McLean. 1957. The Douglas-fir zone of southern British Columbia. Ecol. Mono. 27:247–266.

Woodhouse, W.W., and W.K. Griffith. 1974. Soil fertility and fertilization of forages, p. 403–415. *In:* Heath, M.E., D.S. Metcalfe, and R.F. Barnes, (eds.). Forages 3rd Ed., Iowa State Univ. Press, Ames, Iowa.