Report

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Effects of acid mist containing N and S on a Sitka spruce forest plantation established in 1986 at Deepsyke

A. Crossley, L.J. Sheppard, F.J. Harvey and J.N. Cape

Summary of effects of one season's mist fumigation of a forest.

- Significant effects detected after one year's treatment.
- No treatment effects on growth, either as volume or stem area increment.
- No visible injury or changes in ion leakage from shoots.
- Significant reduction in frost hardiness in shoots receiving additional N. No effects of SO_4^{2-} or acidity detected.
- No treatment effects on water and ethanol soluble sugars.
- Treatment differences in foliar nutrient concentrations: where N and/or S were supplied there have been increases in S, organic S and N but reductions in Mg.
- Annual differences in foliar S concentrations.
- The nutrient content of the bryophyte ground flora is very sensitive to treatment with N, S and acidity. These ions appear to cause significant amounts of cation leaching.

Table 1: Differences in growth parameters for Sitka spruce trees after one year's treatment at Deepsyke forest (superscripts denote treatment rankings for each measurement).

	Time	Unit	No treat	NH_4NO_3	Na_2SO_4	pH 5	pH 2.5 *1	pH 2.5 *2	ANOVA	
									P value	LSD
Stem volume start	Apr. 96	cm^3	4438^1	4295^2	3931^5	4284^3	4165^4	3646^6	0.64	1054
*Basal volume inc.	96-97	cm^3	1333^3	1313^4	1382^1	1236^5	1363^2	1185^6	0.85	371
Top volume inc.	96-97	cm^3	1049^1	995^3	834^5	1008^2	914^4	819^6	0.78	415
Total volume inc.	96-97	cm^3	2383^1	2308^2	2216^5	2244^4	2278^3	1994^6	0.90	720
Stem volume + 1 year	Apr. 97	cm^3	6821^1	6604^2	6147^5	6528^3	6442^4	5640^6	0.76	1758
Rel base volume inc.	96-97	%	44.6^4	43.4^6	47.9^1	43.5^5	46.4^2	46.1^3	0.28	4.5
Rel **top volume inc.	96-97	%	76.1^3	73.6^5	83.5^1	72.5^6	79.4^2	73.7^4	0.37	11.8
Rel total volume inc.	96-97	%	53.8^4	52.2^6	56.5^1	52.6^5	55.0^2	54.1^3	0.62	5.7

*Basal below dbh at approximately 1.3 m height up stem

**Top above dbh at approximately 1.3 m height up stem, up to first sign of leader loss.

Table 2: Mean nutrient concentrations (% dwt) and needle weight (mg) in one-year-old foliage taken from the untreated treatment, 28 February 1996 and 3 December 1996 (n = 4).

	Pre-treatment 28.02.96	After first season's treatment 3.12.96	P value	LSD
N	1.37	1.17	0.16	0.34
S	0.12	0.09	**0.03***	0.02
S in	0.054	0.035	**0.05***	0.02
S org	0.063	0.057	0.52	0.03
P	0.16	0.15	0.31	0.03
K	0.53	0.53	0.84	0.07
Ca	0.28	0.32	0.69	0.24
Mg	0.13	0.09	**0.01***	0.02
Wt 100 needles	34.1	33.9	0.91	6.6
P:K:S ratio (Linder 1995)	12:39:9	13:45:8		

Table 3: Nutrient concentrations (% dwt) in current Sitka spruce foliage collected in December, after one season's mist treatment. The NH_4NO_3, pH 2.5 *1 and *2 treatments supplied 48 and 76 kg N ha^{-1} respectively. The $(Na)_2SO_4$ and pH 2.5 *1, *2 treatments supplied 50 and 80 kg S ha^{-1} respectively.

	No treatment	NH_4NO_3	Na_2SO_4	pH 5	pH 2.5 *1	pH 2.5 *2	P value	LSD
Needle wt.	33.9	33.9	34.6	33.2	35.9	33.9	0.96	6.3
N	1.17 **b**	1.25 **b**	1.27 **b**	1.22 **b**	1.27 **b**	1.45 **a**	**0.012***	0.136
S	0.092 **b**	0.097 **b**	0.112 **a**	0.092 **b**	0.112 **a**	0.125 **a**	**<0.001*****	0.012
S inorg.	0.035	0.035	0.045	0.035	0.045	0.047	0.112	0.012
S org.	0.057 **b**	0.062 **b**	0.067 **a**	0.057 **b**	0.067 **a**	0.072 **a**	**0.011****	0.009
P	0.15	0.14	0.15	0.15	0.14	0.15	0.766	0.02
K	0.53	0.43	0.49	0.44	0.48	0.51	0.374	0.11
Ca	0.32	0.29	0.35	0.28	0.35	0.34	0.197	0.07
Mg	0.095 **a**	0.110 **ab**	0.112 **a**	0.097 **a**	0.112 **b**	0.107 **a**	**0.037***	0.013

Table 4: Nutrient concentrations (% dwt) in current + 1 year Sitka spruce foliage collected in December after one season's mist treatment. The NH_4NO_3, pH *1 and *2 treatments supplied 48 and 76 kg N ha^{-1} respectively. The $(Na)_2SO_4$, pH 2.5 *1 and *2 treatments supplied 50 and 80 kg S ha^{-1} respectively.

	No treatment	NH_4NO_3	Na_2SO_4	pH 5	pH 2.5 *1	pH 2.5 *2	P value	LSD
+Needle wt.	31.1	29.1	28.0	35.6	33.2	29.6	0.535	10.6
N	1.10 **b**	1.17 **ab**	1.15 **b**	1.12 **b**	1.15 **b**	1.25 **a**	**0.037***	0.09
S	0.090 **b**	0.105 **ab**	0.112 **a**	0.090 **b**	0.102 **ab**	0.112 **a**	**0.024***	0.016
S inorg.	0.030	0.035	0.040	0.027	0.032	0.037	0.284	0.012
S org.	0.060 **b**	0.070 **ab**	0.070 **ab**	0.062 **ab**	0.070 **ab**	0.075 **a**	**0.047***	0.010
P	0.117	0.117	0.127	0.112	0.115	0.120	0.356	0.014
K	0.039	0.34	0.40	0.33	0.37	0.39	0.273	0.07
Ca	0.63	0.58	0.69	0.62	0.65	0.63	0.198	0.08
Mg	0.102	0.127	0.115	0.105	0.110	0.110	0.513	0.028

+dry weight of 100 needles

Table 5: Effect of field misting on ion leakage from current year Sitka spruce foliageat +2 °C, (n = 4) and the frost hardiness LT_{50}, lethal temperature causing 50% shoot death based on critical kd = 1.2% day^{-1}, (n = 3). (Linear interpolation was not possible for the 4th block.)

	-20 °C	LT_{50} °C
	% day^{-1}	
No treatment	0.66	-31
NH_4NO_3	0.66	-28
Na_2SO_4	0.53	-32
pH5	0.60	-29
pH 2.5 *1	0.61	-27
pH 2.5 *2	0.63	-27
P value	0.11	0.12*
LSD	0.10	4.2

(NB pH 2.5* 1 value atypical very cold LT_{50}, if omitted, P = 0.02*)

	Contrast analysis for the LT_{50} °C					
	+N	-N	+S	-S	+H	-H
LT_{50}	-27.3	-30.8	-29.4	-28.7	-28.0	-29.2
P value	**0.006****		0.661		0.493	
LSD	2.3		2.0		3.7	

Table 6: Effect of acid mist treatment on ethanol and water soluble sugars (Gilbert and Farrar, unpub.) from current year foliage of Sitka spruce sampled October and December 1996.

	Ethanol soluble sugars (glucose, sucrose and fructose) g g^{-1} structural dry weight	
	October 1996	December 1996
pH 5	0.42	1.24
pH 2.5 *1	0.55	1.22
pH 2.5 *2	0.52	1.28
P value	0.40	0.87
LSD	0.24	0.28
	Water soluble (sugars, fructans) g g^{-1} structural dry weight	
pH 5	0.054	0.078
pH 2.5 *1	0.051	0.063
pH 2.5 *2	0.058	0.075
P value	0.40	0.39
LSD	0.01	0.0

Table 7: Effect of field exposure to mist containing NH_4^+, H^+, SO_4^{2-} or NO_3^- ions in various combinations on the nutrient concentrations of the understorey moss flora predominantly *Rhytidiadelphus squarrosus*. pH 5 and 2.5 mist contain equimolar concentrations at 0.01 and 1.6 mol m^3 respectively, made up from NH_4NO_3 + H_2SO_4.

	N	S	P	K	Ca	Mg
No treatment	1.08 **c**	0.092 **b**	0.18 **a**	0.94 **a**	0.17 **a**	0.20 **a**
NH_4NO_3	1.75 **a**	0.092 **b**	0.12 **b**	0.70 **b**	0.14 **ab**	0.15 **b**
Na_2SO_4	1.22 **c**	0.100 **b**	0.19 **a**	0.96 **a**	0.15 **ab**	0.19 **ab**
pH 5	1.27 **bc**	0.100 **b**	0.18 **a**	0.90 **a**	0.15 **ab**	0.18 **ab**
pH 2.5 *1	1.62 **a**	0.137 **a**	0.18 **a**	0.76 **ab**	0.12 **bc**	0.12 **c**
pH 2.5 *2	1.52 **ab**	0.120 **a**	0.13 **b**	0.36 **c**	0.09 **c**	0.06 **d**
P value	**<0.001*** **	**<0.001** **	**0.014***	**<0.001*** **	**<0.01** **	**<0.001*** **
LSD	0.26	0.18	0.04	0.20	0.04	0.04

Progress from December 1996 sampling

Completed - nutrient analysis, frost hardiness, cytokinins, sugars.

Outstanding - lipid analysis (Kuopio, Finland); phloem sap content - amino acids, ascorbate and glutathione (Freiburg); anatomical studies and pigments (Graz).

Ongoing monitoring

Diameter bands, volume calculations: completed April 1997.

Girth bands: fitted April 1997 from whence weekly measurement commenced.

Phenology: bud burst scored April, May.

Tree condition: coning, defoliation due to aphid attack, spring frost damage to new shoots scored April, May

Soil samples: May 1997, 10 cm soil cores removed for laboratory studies in collaboration with Aberdeen University. Samples of soil solution removed to estimate within plot variability.

Sugars: Pre-bud burst sampled April 1997

Cytokinins: " " " "

Leaf microflora: sampled March 1997

N_2O fluxes from the pH 5 and pH 2.5 treatments.

Future work

Maintain girth band measurements.

Re-sample July, August for sugars, cytokinins.

Monitor ion leakage, buffering capacity of new needles.

December: repeat multi-disciplinary sampling - frost nutrients etc.

Site details

Maintenance and site repairs are ongoing.

Spraying commenced mid April, one month ahead of bud burst. Up to the middle of June regular

spraying has been accomplished and the double dose treatment is up to date. By 16 June, 20 single and 20 double sprayings had been undertaken, providing 40% of the treatment dose.

Update of main findings

Growth - 1996 growing season (first year of treatment)

Stem area increment (SAI)

: expansion ceased by October, no changes from those presented in October which indicated **no treatment effects** (P = 0.854).

Stem volume

: Pre-treatment all blocks of 10 trees not significantly different (P = 0.64), however volume from trees allocated to 'no treatment' were 18% larger than trees in the pH 2.5 *2 treatment.

: No treatment effects after one season P = 0.62 (Table 1)

: Volumes increased by 52-56%

: Relative basal volumes increased by significantly more in the $+SO_4^{2-}$ treatments (+47%) compared with (+44%) in those without SO_4^{2-} (P = 0.017).

Visible injury

: No red needles typical of acid mist damage observed.

: Significant amounts of defoliation but no relation to treatment.

Foliar nutrition

: Prior to the treatment growing season, nutrient concentrations (on the untreated plots) were higher than those one-year-old, end 1996, but differences were not significant except for S and inorganic S (table 2).

: Needle weights were very similar and nutrient ratios were adequate in both years (Linder, 1995).

Current year needles expanded under treatment

: Treatment had no effect on 1996 current year needle weights (Table 3).

: Treatment with N increased foliar N concentrations but only significantly in the double dose treatment (table 3).

: Treatment with S increased S concentrations in keeping with the dose.

: Organic S was most sensitive to treatment.

: Treatment with a high ion concentration 1.6 mol m^{-3} increased Mg^{2+} concentrations

: No treatment effects on needle weights

One-year-old

: Treatment with the double dose significantly increased foliar N and S.

: The single dose did not significantly enhance foliar N or S.

: No effects on P, K, Ca or Mg.

Frost hardiness

: Methodology can be found in Sheppard *et al.*, 1994.

: Critical leakage rate 1.2% d^{-1}

: Leakage rates from unfrozen shoots ranged from 0.53 to 0.66% d^{-1} indicated no foliar mediated effects on membrane leakiness.

: Treatment effects not significant but trees receiving additional N were significantly less hardy than those which had no extra N ($P = 0.06$). Neither SO_4^{2-} nor acidity affected hardiness (Table 5).

Foliar sugar concentrations (December 1996)

: Ethanol soluble sugars, (glucose, fructose and sucrose) more than twice those measured in October whereas water soluble sugars, (fructans) only increased by <30%.

: No treatment effects (Table 6).

Mineral concentrations of understorey mosses

: Plots receiving NH_4NO_3 exhibited significantly more bleached mosses following the cold winter. Symptom not however unique to this treatment - photographed.

: Nutrient concentrations significantly affected by treatment though misting *per se* had no effect (Table 7).

: Treatment with N (NH_4NO_3) significantly increased N status, reduced concentrations of K, Mg and P.

: Treatment with $(Na)_2SO_4$ no effect.

: Treatment with pH 2.5 *1 increased N and S concentrations by 28 and 37% respectively while reducing Ca and Mg.

: pH 2.5 *2 increased N and S by only 20% despite the addition of 60% more N and S.

: Ca and Mg were reduced in proportion to the dose.

: P and K were only reduced by pH 2.5 *2.

Comments

Field applications of acid mist providing 2 to 3 times the dose of S and N recorded at a high altitude site can cause significant, detectable changes in trees.

Significant changes in tree 'characteristics' in the first year of treatment have now been recorded on both a base rich mineral soil growing a single genotype (Glencorse) and for a stand comprised of mixed provenances growing on an acid organic soil (Deepsyke). However the changes observed on this acid organic soil at Deepsyke were often different from those observed on the base rich soil and from seedlings grown in compost in open-top chambers OTCs:-

In OTCs significant reductions in frost hardiness were observed in response to SO_4^{2-}, with or without added acidity but NO_3^- appeared to increase hardiness (Sheppard, 1994).

On the base rich soil, tree height influenced the treatment response so that the larger, acid mist treated trees exhibited a 15% reduction in basal area increment compared with control trees. Acid mist treatment also reduced frost hardiness, significantly in the small trees.

After 1 year no treatment has resulted in a significant effect on growth at the Deepsyke (acid) site and the reductions in frost hardiness appear to be N rather than S driven.

Initial conclusion

The response of trees to acidic mist containing N and S appear to be strongly determined by the nature and chemistry of the soil. The strength of the foliar mediated effects will depend on the length of time and frequency of immersion in mist.

References

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