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Responses of a Sitka Spruce Ecosystem after 4 Years of Simulated Wet N Deposition: Effects of NH_4NO_3 Supplied with and without Acidity (H_2SO_4 pH 2.5)

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Summary

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This paper describes changes in stem basal area, foliar nutrition and litterfall in relation to changes in soil chemistry resulting from simulated wet N deposition to a Sitka spruce ecosystem beginning to close canopy. The impacts of these changes are described for the vitality and chemistry of the understorey mosses. Wet N deposition has been provided almost continuously to the canopy, as mist, since 1996. Six treatments, providing 48 or 96 kg N ha^{-1} yr^{-1} and 50 or 100 kg S ha^{-1} yr^{-1} have been applied as NH_4NO_3, NH_4NO_3 + H_2SO_4 at pH 5, 2.5 and 2.5 double dose, no spray and Na_2SO_4 (pH 5) to 4 replicate plots each containing 10 trees. Changes in tree growth have been slow to evolve and difficult to detect above the level of natural variation, despite good replication. Measurements indicate that, for this acid peat, soil N is not limiting growth. N supplied in the absence of acidity had a small (<10%) detrimental effect on stem area increment, in contrast to the growth improvement (+20-30%) when supplied with H_2SO_4. Litterfall was greatly enhanced, 4-fold and 2-fold in the acidified NStreatments. The pleurocarpous mosses in these acid plots were heavily stressed and by the end of year 2 of spraying were all dead in the double dose acid treatment.

Introduction

Potential impacts of anthropogenic N deposition in rain or cloud on forests have tended to be predicted from long-term studies of fertiliser applications (TAMM 1989), $(NH_4SO_4)_2$ + Mg application e.g. ARINUS project in the Black forest (RASPE & al. 1998), or the multiple applications of wet N to the soil surface, e.g.

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NITREX project (EMMET & al. 1995, WRIGHT & TIETEMA 1995). Such experiments, however, provide only a limited insight into the effects of N inputs as they fail to address changes arising from canopy interaction with rain/cloud or simulate the variable concentration and dose aspect. Likewise, there is little information on effects of individual ions in the field. In the absence of specific ion effects it is more difficult to predict, for instance, forest responses to wet N deposition against a background of declining European S emissions (FOWLER & al. 1998). This paper describes some observations from a field experiment, in a commercial Sitka spruce plantation, where 10 year old trees were treated, at canopy height, with a range of mists containing N, S or a combination, with and without acidity.

Materials and Methods

The experiment covers 1.5 ha on a drained basin peat in the Scottish Borders, 290m asl. The trees, *Picea sitchensis* Bong. Carr, of mixed provenance were planted in 1986 at 2m spacing on mounds formed from the inversion of the material removed to form the drainage ditches. The peat is very acid, around pH 3.6 (H_2O). When treatment commenced basal branches had begun to interlock along the mounds and trees had a mean height of 3.8m. The experimental design, site information and methodologies are explained in considerable detail in SHEPPARD & al. 1999. Treatments are given in Table 1. Each treatment was supplied to the upper canopy in mist droplets (100 – 250 :m diam.) from cone sprayers (2 per tree) supported by a framework of galvanized steel poles. Treatments (6) were replicated over 4 geographically assigned plots, each containing 10 trees in 2 parallel lines. Regular measurements were made of stem area increment using Vernier girth bands, placed between whorls 8 and 9 below the leader (1995) and once a year at breast height and below the leader (1995). Frost hardiness, mineral nutrition, cytokinins (Cambridge UK), stress chemicals (Graz, Austria) and amino acids in phloem sap (Freiburg, Germany) have been determined annually since the start of treatment in 1996. Since 1998 assessments of N_2O fluxes (static chambers), soil water chemistry and throughfall chemistry have been undertaken. Gravitational soil water has been collected periodically since May 1999 at rooting depth using 10 zero-tension plate lysimeters per plot into polythene bottles containing thymol, a chemical preservative. pH and conductivity have been measured on each sample. Throughfall has been collected using a system of open gutters from each line of trees (1 m^2 collecting area) running into the centre of the plot, feeding into a closed pipe draining into two 25 litre polythene bins containing thymol. Litter is collected from these gutters, dried, weighed and ground for chemical analysis. Samples are collected in relation to rainfall. pH, conductivity and NO_3^-, NH_4^+ , PO_4^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+} and K^+ are being measured. The chemistry of the ground flora, mosses and graminoids has been assessed annually.

Results and Discussion

Pre-treatment stem growth data indicated all the assigned treatment trees were growing at similar rates (SHEPPARD & al. 1999). Over successive years of treatment, effects on growth have emerged and been consolidated. After 3 full years (1996-1998 inc.) treatments containing N, S and acidity have enhanced growth relative to the pH5 control. Relative volume increment (RV1) (1996 – 1999 inclusive) for NS Acid, 2NS Acid and N are 222, 223 and 189 % respectively while no spray, S and control performed at 209, 209 and 191 % respectively. The ensuing discussion will concentrate on the measurements currently available which have shown effects of treatment and which may offer some mechanistic explanation for the differential impact of acidified NS versus N alone.

The most noticeable treatment effects were seen in the understorey mosses and more recently in the production of leaf litter and mycorrhizal fruiting bodies. The most common pleurocarpous mosses – *Hylocomium splendens, Rhytidiadelphus squarrosus* and *Pleurozium schreberi* showed significantly depleted levels of cations after one year of treatment with NS Acid and 2NS Acid, and were dead after two years in the 2NS Acid treatment. The detrimental effects on the mosses has been confounded by a significantly enhanced litterfall + 225 % to these 2NS acid plots (Table 2). By contrast *Polytrichum commune* has not been visibly affected by any treatments.

Table 1. Treatments applied in rain water (April – December) annually to 10-year-old Sitka spruce growing on a drained, acid peat at Deepsyke forest (S. Scotland).

Treatment	Description	Ion concentration mol m^{-3}	Dose** kg ha^{-1} a^{-1}		
			S	N	H
No treatment	spray gantry in place, no spray		-	-	-
N	NH_4NO_3	1.6	-	48	-
S	Na_2SO_4	1.6	50	-	-
Control	$NH_4NO_3 + H_2SO_4$	0.1	<1	<1	<1
NS Acid*1	"	1.6 (3.2)*	50	48	1
NS Acid*2	"	1.6 (3.2)	100	96	3

*The mean pH of the rain water is about 4.5. The pH of the acidified solution is approximately pH 2.5.

(3.2)* is the H ion concentration.

** Actual inputs to the treatments exceed those given above because of background wet and dry deposition = ~ 6.7 kg S ha^{-1} a^{-1} and 8 kg N ha^{-1} a^{-1}. N is deposited fairly evenly between wet and dry deposition (52% and 48%) respectively). By contrast 1.7 times more S is deposited as wet rather than dry deposition. The use of rain water to disseminate the treatments will enhance the inputs by a further 10 or 20% of the wet deposited background input (FOWLER & al. 1996).

Scoring of mycorrhizal fruit body production in August 1998 revealed reduced species diversity, but only in the N plots which had exceptionally low numbers of the ectomycorrhizal fruiting body *Lactarius rufus* (Table 2). This observation conflicts with observations from Europe where *L.rufus* has shown increased fruit-body formation in response to N fertilisation (WALLENDA & KOTTKE 1998).

The chemistry of soil core leachate, leached in the laboratory with treatment solutions, indicated substantial levels of heterogeneity both within and between replicate plots. After two years of treatment the NS Acid treatment, sampled in April 1998, resulted in high concentrations of Al, Ca and Mg in the leachate, whereas the 2NS Acid treatment leached fewer base cations but more Al than the NS Acid treatment (Table 2). The 20 % enhancement of water to the site, in the 2NS Acid treatment, may be reflected in the greater mobile anion flux through the profile, causing higher base cation leaching and thus the lower base cation concentration. At some point in the future, this could lead to base cation depletion. After 2 years of treatment with N, the pH of the soil leachate and the soil pH in both H_2O and $CaCl_2$ are all significantly lower than those of the control. This suggests that in the absence of H_2SO_4 significant amounts of NH_4^+ are adsorbed by the soil resulting in the release of H^+. The presence of H_2SO_4 would appear to suppress H^+ exchange with NH_4^+, possibly SO_4^{2-} ions preferentially carry NH_4^+ down the soil profile. pH measured in $CaCl_2$, which indicates the proportion of exchange sites occupied by H^+, i.e. the long-term acidification of the soil, was most acid in the N treatment.

Table 2. Treatment induced changes in a Sitka spruce ecosystem after 3-4 years treatment. Values represent the means of 4 plots ∀ SD

Treatments						
Relative volume increment	No spray	N	S	Control	NS Acid	2NS Acid
RV1% (3yrs)	209	189	209	191	222	223
∀ (SD)	(13)	(22)	(23)	(12)	(23)	(29)
Litter g/m^2 *	65	89	76	84	139	189
∀ (SD)	(13)	(4)	(31)	(25)	(10)	(28)
Fruit bodies *L. rufus*	>150	<10	>100	>100	>100	>100
BC:Al ratio	9.0	3.8	5.3	4.2	7.1	4.8
pH(H_2O)	4.01	3.83	3.92	3.93	3.71	3.71
pH($CaCl_2$)	3.01	2.80	2.94	2.97	2.88	2.84

*May 98-Aug 99

Changes in soil pH may be indicative of long-term acidification in the N plots. However, differences in soil core leachate chemistry provide no clear answer as to why trees on the N plots are growing more slowly than the control and the NS Acid plots are outperforming the control. Soil sampling, by the removal of cores once a year, does not provide a means of monitoring temporal changes, particularly as the chemistry of the soil solution is modified by the level of soil moisture prior to sampling, via changes in ionic strength. Low rainfall will increase ionic strength and reduce the ratio of base cations (BC) to Al^{3+} (MATSHONAT & VOGT 1997). In order to determine temporal effects of treatment on soil solution chemistry, zero tension lysimeters (plastic spades) were inserted into the sides of the drainage ditches alongside each row of trees at variable depth (10-30cm). Results for a trial (one plot only) overwinter for no spray, NS Acid and 2NS Acid showed a BC:Al ratio of 0.04, 0.06 and 0.12 respectively with significantly more SO_4^{2-} (+300 %) in the 2NS Acid treatment. Phosphate concentrations were below detection limits and $NH_4^+$and NO_3^- were variable. No data for the N, S or control treatments are currently available. More recent pH and conductivity data collected since May 1999 indicate that the most acid soil water is 2NS Acid ~ pH 3.4, then NS Acid at pH 3.84. The S treatment and N treatment were more similar ~ pH 4.4.

Effects of treatment on foliar nutrition, in needles removed from the lower 70 to 50 % of the tree, are starting to show some trends. N in current year foliage has increased in the 2NS Acid treatment from 1.35 to 1.52 %, an 18 % increase over the control, and K has decreased in the NS Acid treatment. Relative to the control, % K has increased in the no spray and S treatments. In one–year-old needles P, Ca and Mg contents have fallen by 15 % with respect to the control in the 2NS Acid treatment. Changes in organic, inorganic, and the ratio of inorganic to organic, S are strongly dependent on the year of sampling irrespective of treatment. The enhanced foliar N concentration in the 2NS Acid treatment could well be contributing to the increased productivity in this treatment, although the foliar base cation and P concentrations suggest the growth of trees receiving NS Acid treatments should be slowing down. The elevated base cation concentrations in the soil solution are not reflected in the foliage, but stemwood production per se reflects cambial Ca concentrations (McLAUGHLIN & WIMMER 1999) which were not measured.

Concluding Remarks

Even after 3 years of treatment with up to 96 kg N ha^{-1} yr^{-1} responses to N are relatively small, < 10 %. However, in the presence of sulphuric acid, pH 2.5 (NS Acid) the trees outperform the control, by similar amounts for the NS and 2NS Acid treatment (+20-30 %). No dose effect has been realized except with regard to the production of litter and a higher needle N concentration in the 2NS Acid treatment. Needle loss has been very obvously increased in trees in the NS Acid treatments with accelerated stemwood area increment providing further indication that these trees are growing better than control or N treated trees. The relatively poor performance of the N treatment may be linked to the negative impacts of this treatment on ectomycorrhizal fungi (WALLENDA & al. 1998). Data collected so far suggest growth acceleration and reduction represent the outcome of many different processes. The addition of ammonium nitrate together with sulphuric acid was necessary to obtain a positive increase in stem volume.

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