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Nutrition of Sitka Spruce on Upland Restock Sites in Northern Britain

INFORMATION NOTE

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SUMMARY

A series of 10 experiments with Sitka spruce planted on nutritionally poor restock sites in the 1980s showed significantly increased height and basal area following repeated nitrogen (N) or nitrogen, phosphorus and potassium (NPK) applications. In contrast to experiments on similar site types in the first rotation, these second rotation experiments generally showed no response to fertiliser applied at planting. This is due to the release of nutrients from the decomposition of harvesting residues and forest floor litter. However, this beneficial effect declined over several years and the underlying site fertility became more important, illustrated by foliar N levels declining to marginal or deficient levels, between 5 and 12 after planting for all the unfertilised treatments in the experiment series.

The UK Woodland Assurance Standard (UKWAS) aims to minimise fertiliser inputs and this is best implemented through correct species choice, or in the case of nitrogen deficiency, the use of nursing mixtures appropriate to the underlying site fertility. The general fertiliser prescriptions given in Forestry Commission Bulletin 95 (Taylor, 1991) are still appropriate for restock sites, if the year 0 applications are ignored. However, foliar sampling is recommended to confirm these general prescriptions and ensure that only the necessary nutrients are applied.

INTRODUCTION

Fertilisation was an essential part of establishment practice for new planting in upland Britain. The fertiliser requirements in the first rotation have been well documented (Taylor 1991), however fertiliser requirements for the second rotation are less well-defined. In Britain up to 300 000 hectares of Sitka spruce will be felled over the next 20 years and a significant proportion will be restocked with the same species. A series of experiments was set up to provide guidance on the use of fertiliser on such crops.

This note updates results presented by Taylor (1990) when the experiments were at most 10 years old. Taylor concluded: '*… there is no need for application of fertiliser at the time of replanting irrespective of site type. It is unlikely that subsequent fertiliser will be required on sites where there was satisfactory crop yield in the first rotation without application of fertiliser. However, there are indications that top-dressing may be required on the more infertile sites.*'

These experiments are now 12–20 years old and give important information about the nitrogen (N), phosphorus (P) and potassium (K) requirements of restock crops in the years between planting and full canopy closure (other nutrients were not investigated in any of these experiments).

EXPERIMENTS

Sites

The 10 experiments were all planted in the 1980s across a range of lithology and soil types as outlined in Table 1. Their geographical locations are indicated in Figure 1.

Figure 1

Map of Northern Britain showing the locations of the 10 experiments

Table 1 Summary of the lithology and soil characteristics of the 10 experiments

Experiment name	Year of planting	Soil description and FC soil type	Lithology (UK geological map reference no.)	Nitrogen category*	ESC SMR (soil moisture regime)**	ESC SNR (soil nutrient regime)**
Ae 57	1986	Unflushed deep peat 11b (peaty gley 6p)	Silurian (72)	D	Wet	Very poor
Falstone 10	1984	Flushed deep peat 9b (peaty gley 6p)	Carboniferous (80)	A	Very wet	Poor
Glendaruel 9	1984	Flushed deep peat 9c	Dalradian (19)	C	Wet	Poor
Kilmichael 13	1986	Peaty gley 6	Dalradian (17)	C	Wet	Poor
Glentrool 31	1989	Peaty gley 6p	Ordovician (70–71)	B	Wet	Poor
Falstone 7	1981	Peaty gley 6	Carboniferous (80)	A	Wet	Poor
North York Moors 15	1987	Peaty gley 6e	Jurassic (94–95)	C	Very moist	Very poor
Ennerdale 1	1983	Upland brown earth 1u	Granite (34)	B	Fresh	Poor
Wykeham 144	1982	Intergrade ironpan 4be	Jurassic (98)	C	Slightly dry	Very poor
Craigellachie 15	1981	Podzolic ironpan 4zxe	Dalradian (20)	D	Moist	Very poor

* The Nitrogen category uses the system outlined by Taylor and Tabbush (1990) and Taylor (1991) which categorises sites with reference to the requirements of Sitka spruce and where:
Category A: No heather control or N input is required.
Category B: Herbicide control of heather is sufficient (alternatively N applications alone).
Category C: Herbicide control of heather gives a response but subsequent N input(s) is also required (alternatively N applications alone).
Category D: Control of heather has minimal effect, regular N applications are required (every 3–4 years).

** Ecological Site Classification (ESC) categories for soil moisture regime (SMR) and soil nutrient regime (SNR) are taken from Pyatt *et al.* (2001). All the sites fall into SNR of 'Poor' or 'Very poor'. The deep peat and peaty gley sites all have SMR of 'Very moist', 'Wet' and 'Very wet', whereas the mineral sites tend to be drier and range from 'Moist' to 'Slightly dry'.

Methods

All the experiments used Sitka spruce of Queen Charlotte Islands origin planted following a previous crop of Sitka spruce, except North York Moors 15, Craigellachie 15 and Wykeham 144 where the previous crop was a mixture of Sitka spruce, Scots pine and larch.

The experiments were all of randomised block design, generally with at least 4 replications. Treatment plot size was normally 0.1 ha, each with an internal assessment plot of 0.04 ha. The only exceptions were Craigellachie 15 and Ennerdale 1 which had only 3 replications, and in the case of Ennerdale alone, a plot size of 0.05 ha with 0.02 ha assessment plots.

The control treatment was 'normal' forest practice for the site (i.e. heather control if necessary and brash left on site) with no fertiliser input. N, P and K were applied by hand at the standard recommended rates (Taylor 1991). All the experiments included a 'luxury' treatment that was standard rates of N, P and K repeated every 3 years, except at Wykeham and Craigellachie which had only the N applications repeated every 3 years.

Height measurements were taken at years 3, 6, 8, 10, 12, 15 and 20. Diameter and basal areas were assessed at years 10, 12, 15 and 20. Unless stated otherwise, the data presented are the most recent results and these are from year 15 for all the experiments except for Glentrool 31 which is year 10, North York Moors 15 which is year 12 and Falstone 7 which is year 20. For clarity the results presented are for basal area, with statistical significance taken to be when $p<0.05$. Height growth responses were found to be similar to basal area with the same treatments showing significant differences.

RESULTS

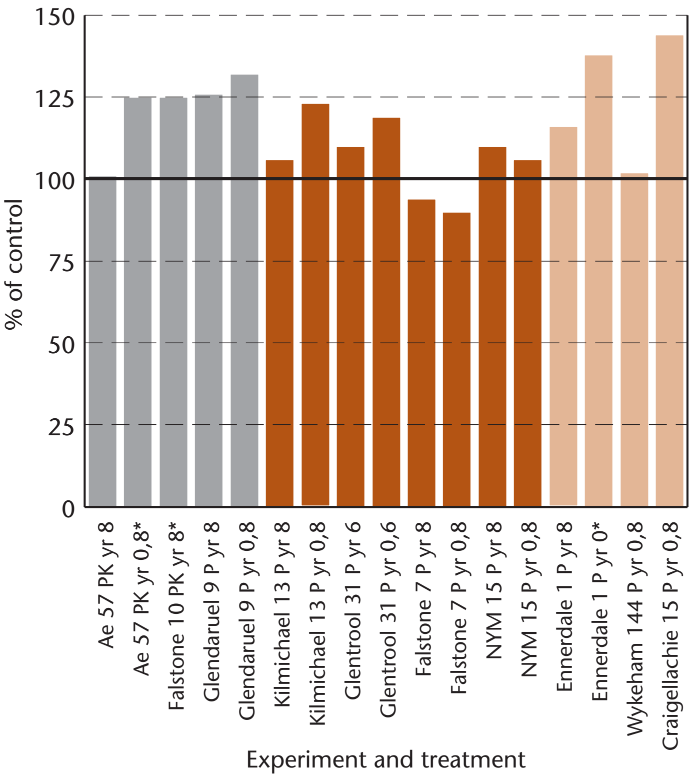
Growth responses

Phosphorus (P) application

Many of the experiments appear to show improvement from P top-dressing, with and without P application at planting, however the effects on growth were generally not statistically significant. Figure 2 illustrates the percentage response in relation to the control treatment (grey = deep peat; dark orange = shallow peat; light orange = mineral soil; * indicates statistically significant result).

Figure 2

Response in basal area to P or PK compared to the control treatment as 100%



There was one statistically significant response to application of P alone. This was on an upland brown earth at Ennerdale 1, where the underlying granite lithology has previously been noted as prone to P deficiency. Here P application at year 0 significantly increased growth over the control by 38%, whereas P applied at year 8 only gave 16% improvement which was not significantly different from either the control or P at year 0 treatment. Foliar analysis results showed optimal levels of P in the treatment with P at planting, whereas it became marginal for 2–3 years in the treatment with P applied at year 8, before being rectified by this application. After 15 years P is now deficient in the control plots.

There was a large response (44% above the control) to P at year 0 and 8 at Craigellachie, however this was not statistically significant due to high experimental variation.

Phosphorus and potassium (PK) application

PK applications were evaluated at two of the deep peat experiments and in both cases there were statistically significant benefits over the control. Given the relative foliar nutrient levels (see page 4) it is most likely that the responses were mainly due to the K.

At Falstone 10 a single PK application at year 8 significantly improved basal area by 25%. There was no treatment with a PK application at year 0 for comparison. Foliar analysis shows that the control plots were marginal for K for several years and are currently the only treatment where K remains at marginal levels.

At Ae 57, PK at year 0 and 8 significantly improved basal area over the control by 25%. However, PK at year 8 alone did not have a significant effect on basal area. Foliar analysis indicates that the treatment with PK at year 0 only declined to marginal levels of K for 1 year whereas treatments without an initial PK application were marginal or deficient for 3 years, before both responded to the PK application at year 8. The control plots are still marginal for K.

Nitrogen (N) application

In 3 experiments a single application of N was made to some treatments at year 12. At year 15, when compared to the equivalent treatments without N top-dressing, there was no difference in total basal area at Ae 57 or Kilmichael 13, although Falstone 10 showed a slight but not statistically significant response.

Regular N or NPK ('luxury' treatments)

Regular NPK, or regular N (Wykeham 144, Craigellachie 15) applications significantly improved basal area in every experiment, as illustrated in Figure 3 (grey = deep peat; dark orange = shallow peat; light orange = mineral soil).

The response on deep peat (mean of 177% of control) tended to be slightly greater than that on shallower peats (mean of 142%). The response on mineral soils was very varied, (ranging from 136% to 219%) reflecting the greater range of soil fertility within this category.

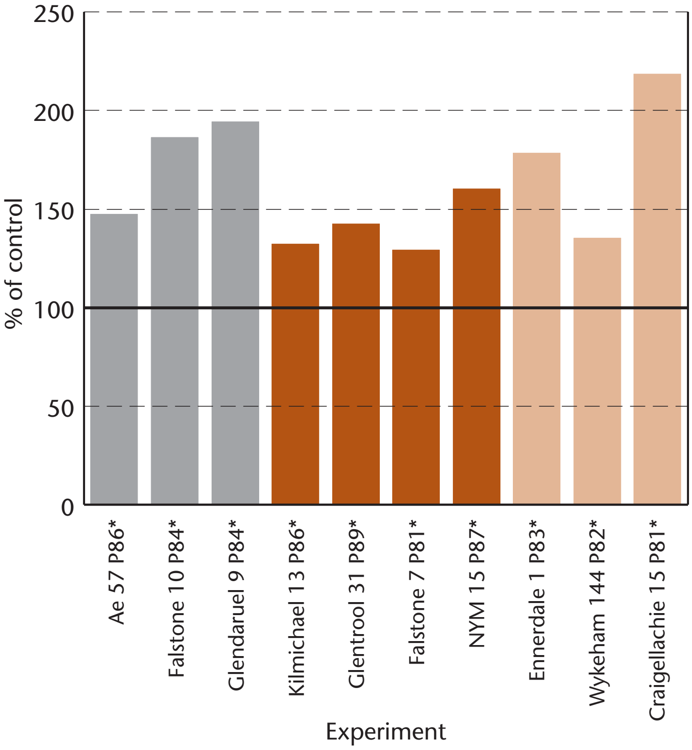
Other treatments

Total brash removal was included in Falstone 7 and, at year 20, significantly reduced the basal area (by 24%) compared to the control. Falstone 10 also included total brash removal, and there were similar significant results at years 3 and 4, however these differences had disappeared by year 10.

Heather control was incorporated in Craigellachie 15 and Wykeham 144. In both cases the basal area of the unfertilised plots without herbicide was significantly poorer (by 44% and 28% respectively) than the control plots with herbicide.

Figure 3

Basal area of regular N or NPK compared to control treatment as 100%



Foliar Analysis

Foliar analysis was undertaken regularly at each of the experiments. The main findings for each of the major nutrient elements (nitrogen, phosphorus and potassium) in the control plots, are outlined in this section.

Nitrogen (N)

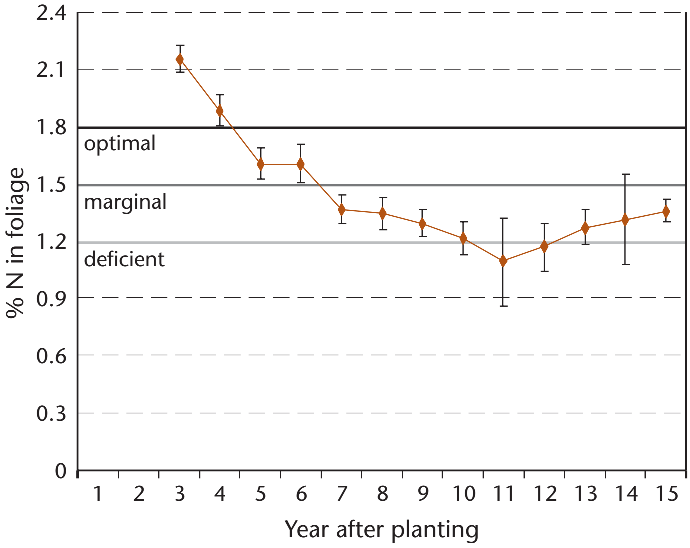
Figure 4 shows the mean values of foliar N from the control plots of the 10 experiments for the 15 years after planting. Despite the various soil types, the trend of foliar N levels was remarkably similar in all the experiments. There is a decline in foliar N of the control plots, starting at an optimal level but declining to marginal levels around 6–8 years after planting, with levels lowest and bordering on deficient around 10–12 years after planting. After this point there is some indication of an increase in foliar N and this could be due to canopy closure and the beginning of nutrient cycling (Miller, 1981).

Phosphorus (P)

There was no clear general trend for foliar P in the control plots. All the experiments started at optimal levels and the deep peats remaining optimal throughout. The shallow peats ranged between optimal and marginal levels,

Figure 4

Mean foliar N for the control treatments in all 10 experiments with standard error



whereas mineral soils appeared to have marginal levels, even bordering on deficient, for much of the time.

Potassium (K)

In general, deep peats appeared to be the only sites where foliar K was at marginal levels for any period of time, especially in the first 8 years. Shallow peats and particularly the mineral soils maintained optimal levels of K.

DISCUSSION

Growth responses

The responses in height and basal area were generally consistent, and in every case there was a statistically significant positive effect from repeated application of N or NPK. This indicates that nutrients, and particularly N, limit Sitka spruce growth on all the restock sites in this series. This is not surprising as they all fall within the 'Poor' or 'Very Poor' soil nutrient regimes of the Ecological Site Classification.

There is generally believed to be no benefit from fertiliser application *at planting* on restock sites, because of the release of nutrients from decomposing litter, brash, stumps and root systems of the previous crop. Whilst this assumption is generally supported by these results, 3 experiments did show benefit from a fertiliser application at planting (year 0).

- Ennerdale 1 gave a significant response to P at year 0 but not to P at year 8. In addition to the lithology being prone to P deficiency, the brash was burnt on this site prior to planting. This may have increased the early loss of nutrients from the site in this high rainfall area and could help to explain the benefit of P application at year 0.

- Ae 57 gave a significant response to PK at years 0 and 8 but not to PK at year 8 alone. Foliar K levels appeared to be the most significant difference between these 2 treatments.

- Kilmichael 13 gave an almost significant response to P at years 0 and 8 but not to P at year 8 alone. Foliar N and P both showed important differences between the 2 treatments.

In 8 of the 10 sites there was a significant growth benefit from the experimental treatment that was most similar to, although not necessarily the same as, the first rotation prescription. This suggests that the underlying nutritional status of the sites, related to the lithology, has not been drastically altered by a single rotation of trees, agreeing with the conclusions of Miller (1988) regarding N.

Implications for sustainable forest management

The use of fertilisers on restock sites may be a questionable practice under current certification schemes. Under UKWAS, synthetic chemical (including fertiliser) use is acceptable when there is no practicable alternative, but the aim is to reduce and eventually avoid the use of synthetic chemicals (UKWAS, 2000 Section 5.2). Minimising fertiliser applications is most effectively achieved through appropriate species choice at planting, although some lithologies will always have a requirement for specific fertiliser (e.g. P on Moine schists and basalts; K on Carboniferous sediments).

It is important to note that many spruce restock sites have no requirement for fertilisation, and even on nutritionally poorer sites applications at planting are generally not beneficial. However, most restock crops show some growth benefit from inputs of N, P or K similar to those recommended for the same site in the first rotation. P and K deficiencies are difficult to overcome through species choice and it is likely that there will always be some justification for application of P and/or K to restock sites with very poor nutrition, especially given the relatively long lasting benefits from a single application (6–8 years). Deep peat restock sites appear to only require K, however PK fertiliser is recommended as, in general, the levels of P are not sufficiently high to support a K application alone.

N applications are more readily avoided through appropriate species choice. On sites known to have required N top-dressing in the first rotation, managers should consider using less demanding species, such as pine or larch, grown either pure or as a nursing mixture with Sitka spruce. Poor initial species choice has long term implications for fertiliser input to a site and it is likely to be more difficult to justify applications of N to restock sites in the future, both on sustainable forestry and economic grounds as the effects last for about 3 years only.

The implications of brash removal have not been fully evaluated by these experiments, however there are indications that this can lead to a significant reduction in growth. Brash removal at Falstone 7 caused significantly poorer growth which was linked to lower foliar nutrient levels, particularly N and P. Titus and Malcolm (1991) previously found that N, P and K levels were higher under brash mats than in clear ground. However, growth was not significantly affected in the neighbouring experiment (Falstone 10) and physical shelter and weed suppression by the brash is also thought to be an important factor (Proe and Dutch, 1994; Nisbet *et al.*, 1997).

Economics

The economics of applying fertiliser need to be carefully considered and fertilisation is unlikely to be justified solely for increasing yield. For example, the repeated application of N or NPK significantly improved yield in all the experiments but is not a realistic option due to the expense, quite apart from not meeting certification criteria. Fertilisation can be justified only when required to overcome a specific nutrient deficiency, causing a considerable reduction in yield. It should be noted that waterlogging can also cause growth check and foliar nutrient deficiency and should be rectified before the evaluation of fertiliser requirement.

CONCLUSIONS

- Second rotation sites have an initially improved nutrient status following clearfelling, however the site will gradually revert to its underlying fertility, related to lithology, shown in the first rotation. Therefore, fertiliser should not be required at time of planting on restock sites, or in the first 5 years after planting. There may be benefits from P or K applications at planting where the underlying lithology has been identified as having a specific P or K deficiency (e.g. P on Moine schists and basalts; K on Carboniferous sediments).

- Second rotation sites of low fertility (poor and especially very poor SNR) should be monitored for symptoms of nutrient deficiency throughout the establishment phase until canopy closure and full nutrient cycling has commenced. If there are concerns, then foliar analysis should be used to guide any remedial application of fertiliser. Waterlogged rooting conditions can lead to foliar nutrient deficiency and drainage should be rectified before fertiliser application is considered.

- Ensure that species choice is appropriate for the underlying site fertility, particularly the lithology and nitrogen availability, to avoid a commitment to a high input regime. Scots pine, lodgepole pine and larch, grown pure or in mixture with Sitka spruce, have a much lower N requirement than pure Sitka spruce but are similar in their requirements for P and K. Douglas fir and Norway spruce have comparable nutritional requirements to Sitka spruce.

- On nutritionally poor sites, brash removal has the potential to reduce growth or increase fertiliser requirements and should not be considered as sustainable forest management.

- In order to satisfy the UKWAS commitments for minimising chemical inputs, standard fertiliser regimes should be used for general guidance only. Site-specific fertiliser prescriptions and top-dressing applications can be developed following representative foliar sampling and analysis. Fertiliser application can be considered to be sustainable forest management since it is maintaining forest productivity, vitality, and economic functions. Assuming best practice is adhered to and the relevant guidelines are followed, biodiversity, ecological and social functions are not compromised and other ecosystems should not suffer damage.

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REFERENCES

MILLER, H. G. (1981).
Forest fertilisation: some guiding concepts.
Forestry **54**, 157–167.

MILLER, H. G. (1988).
Forest site evaluation and long-term productivity. Chapter 10 – Long-term effects of application of nitrogen fertilisers to forest sites, 97–106.

NISBET, T., DUTCH, J. and MOFFAT, A. (1997).
Whole-tree harvesting – a guide to good practice.
Forestry Commission Practice Guide.
Forestry Commission, Edinburgh.

PROE, M. F. and DUTCH, J. (1994).
Impact of whole-tree harvesting on second-rotation growth of Sitka spruce: the first 10 years. *Forest Ecology and Management* **66**, 39–54.

PYATT, G., RAY, D. and FLETCHER, J. (2001).
An Ecological Site Classification for forestry in Great Britain.
Forestry Commission Bulletin 124.
Forestry Commission, Edinburgh.

TAYLOR, C. M. A. (1990).
The nutrition of Sitka spruce on upland restock sites.
Research Information Note 164.
Forestry Commission, Edinburgh.

TAYLOR, C. M. A and TABBUSH, P. M. (1990).
Nitrogen deficiency in Sitka spruce plantations.
Forestry Commission Bulletin 89.
HMSO, London.

TAYLOR, C. M. A. (1991).
Forest fertilisation in Britain.
Forestry Commission Bulletin 95.
HMSO, London.

TITUS, B. D. and MALCOLM, D. C. (1991).
Nutrient changes in peaty gley soils after clearfelling of Sitka spruce stands. *Forestry* **64**, 251–270.

UKWAS (2000).
Certification Standard for the UK Woodland Assurance Scheme.
UKWAS steering group, Edinburgh.

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