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EFFECTS OF FERTILIZATION ON TREE SEEDLING ESTABLISHMENT AND GROWTH IN A LUPIN FIELD IN SOUTHERN ICELAND

Hreinn Óskarsson and Aðalsteinn Sigurgeirsson

Icelandic Forest Research, Mógilsá, IS-116 Reykjavík, Iceland

Corresponding author's e-mail: hreinn@skogur.is, adalsteinn@skogur.is

ABSTRACT

Large areas in southern Iceland are glacial outwash plains with soil composed of coarse gravel that contains only slight amounts of organic matter. Such barren and nutrient-deficient areas have been regarded as unsuitable for afforestation. Rehabilitation of such areas using Nootka lupin (*Lupinus nootkatensis*) has, however, been practiced in Iceland for several decades, and lupin-covered areas represent a potential forestland. The aims of the study were: (1) to test if fertilizer application had any effect on survival and growth of tree seedlings planted at a site previously rehabilitated with lupin, and (2) to examine the long-term vitality of downy birch (*Betula pubescens*), Sitka spruce (*Picea sitchensis*), and lodgepole pine (*Pinus contorta*) growing at the lupin site. The trial located in a 12-year-old Nootka lupin field at Markarfljótsaurar (N63°38'; W20°01') had previously been used for lupin seed harvesting. The field was ploughed and the trees were planted in the furrows in early July 1997. Ten fertilizer treatments were established for each species; five types of slow release fertilizer (SRF), two types of easily soluble fertilizer (ESF), two types of combined SRF and ESF, and a control treatment. Soil analyses revealed significant enrichment of soil organic matter, nitrogen, and available phosphorus in the top 5 cm of soil after 12 years of lupin growth. Survival at age 5 years was high for all tree species, with pine showing the lowest survival (91%). There was a significant fertilizer effect on the volume index for all species ($P < 0.05$). The SRF yielded on average the highest volume index, especially SRF with a high nitrogen ratio. ESF was intermediate and the control treatment (no fertilizer) yielded the poorest growth. A mixture of SRF and ESF yielded growth similar to SRF. Birch and spruce grew best when the density of lupin was high, while pine grew best at intermediate density. The results after five years suggest that afforestation of glacial outwash plains in southern Iceland is a feasible option when preceded by Nootka lupin establishment. Fertilization at planting, when combined with the facilitative effects of lupin at such sites, improves early seedling growth, but does not affect initial survival.

KEYWORDS

Lupinus nootkatensis, afforestation, fertilizer, glacial outwash plains

INTRODUCTION

Vast areas in Southern Iceland are glacial outwash plains, formed through a combination of frequent meltwater floods from ice-capped volcanoes, fluvial erosion, and slow plant succession on the nutrient-deficient soils. The glacio-fluvial soil deposits on these sites are generally extremely low in nitrogen (N) (Magnússon *et al.*, 2001). Rehabilitation of the glacial outwash plains using the Nootka lupin (*Lupinus nootkatensis*) has been practiced during the past decades in Iceland. Results of a survey of the succession of the Nootka lupin showed that the N and C content of soil increased considerably on lupin-covered sites (Magnússon *et al.*, 2001). Glacial outwash plains and other sandy deserts in Iceland have until recently been regarded as unsuitable for afforestation. Results of planting trials suggest, however, that such sites can represent a potential forestland through the facilitative effect of the Nootka lupin (Aradóttir, 2000). Some pilot studies have furthermore shown that early growth and survival of planted tree seedlings can be significantly improved by fertilization on such sites, especially by N and P fertilization at the time of planting (Óskarsson and Sigurgeirsson, 2001).

The aims of the present study were: (1) to test if fertilizer application at planting had any effect on the initial survival and growth of tree seedlings planted at Nootka lupin sites, and (2) to examine the long-term vitality of downy birch (*Betula pubescens*), Sitka spruce (*Picea sitchensis*), and lodgepole pine (*Pinus contorta*) growing on lupin sites.

Table 1. The initial height and diameter of the tree seedlings, that were used in the fertilizer trial at Markarfljótsaurar, Iceland.

Species	Scientific name	Origin	Seedling age	Seed no.	Root volume cm^3	Root collar diameter cm	Average height cm
Birch	*Betula pubescens*	Embla / Bæjarstaður	1/0	940007	150	4.1	21.0
Sitka spruce	*Picea sitchensis*	Tumastaðir	2/0	940021	100	4.0	22.6
Lodgepole pine	*Pinus contorta*	Tutshi Lake	1/0	930028	50	2.6	11.7

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Table 2. Results from soil analyses of samples collected in July 2001 at the experimental site within the lupin and on unvegetated gravel soil.

Site	Depth in cm	pH †	C ‡ %	N § %	C/N	P ¶ mg kg^{-1}	K^+ # cmol(+) kg^{-1}
Unvegetated gravel soil	0-15	5.9	0.10	0.010	10	0.52	0.29
12-year-old Lupin field	0-3	5.4	2.4	0.171	14.0	0.90	1.02
	10-25	5.5	0.17	0.011	15.4	0.36	0.16

† pH as measured in soil water-suspension using a combination calomel-electrode.
‡ Carbon determined by dry combustion at 1050°C using Leco CR-12 C-determinator.
§ Nitrogen was determined by the Kjeldahl-method.
¶ P soluble in 0.5 N $NaHCO_3$ (Olsen *et al.*, 1954).
# Exchangeable potassium extracted by 1.25% HAc and determined by flame emission spectrometry.

MATERIALS AND METHODS

The experimental site was located in a 12-year-old Nootka lupin field at Markarfljótsaurar (N63°38'; W20°01') that had previously been used for lupin seed harvesting. The site is on a flat and sparsely vegetated outwash plain in the middle of the 360 km^2 area of sand and gravel deposited during the past 10,000 years by the Markarfljót River (Haraldsson, 1981). The species composition outside the lupin field was indicative of extreme nutrient-deficiency, consisting of sparse islands of *Empetrum nigrum*, *Thymus praecox*, and some grass species. The soil was mostly a mixture of basaltic sand and coarse gravel and the nutritional status of the soil is poor (Table 2). In June 1997 the lupin field was ploughed by an agricultural plough and the tree seedlings were planted in the middle of the furrows later the same year (early July). The continuous furrows were 10-20 cm deep and 30-40 cm wide, and the surface layer formed a 20 cm high ridge. The furrows ran in a north-south direction with the ridges located at the eastern side of each furrow. The aim of this soil preparation was to create a favorable microclimate for seedlings by reducing the light competition, creating a shelter from the prevailing winds, and improving the soil temperature by creating a dark surface. The plants used were containerized seedlings raised at a nursery (Table 1). Ten fertilizer treatments were established for each species: five types of slow release fertilizer (SRF), two types of easily soluble fertilizer (ESF), two types of combined SRF and ESF, and an unfertilized control treatment (Table 3). The fertilizer was applied at planting and was either applied in a hole, five cm from the seedlings, or scattered by hand over a 15-20 cm area around the seedlings (Table 3).

Seedling total height and ground-level diameter were measured on four randomly selected seedlings from each treatment. Survival was registered for all seedlings. As the density of the lupin was not uniform at the site, it was classified into three

Table 3. Fertilization effects on the volume index ($diameter^2$ x height) of birch, spruce and pine after four growing seasons in a lupin field at the Markarfljótsaurar, Iceland. Means within columns followed by the same letter are not significantly different ($P < 0.05$) by Duncan's test.

Fertilizer treatment	Solubility	Application method	Total N (g $seedling^{-1}$)	Birch		Spruce		Pine	
RTI Silva-Pak	Slow release	hole	2.2	56.9	a	16.1	ab	10.2	a
RTI Bio-Pak	Slow release	hole	1.4	53.2	a	19.4	a	7.4	abcd
M&M	Easily s. & slow r. N	hole	1.0	33.0	b	16.5	ab	6.4	bcd
Osmocote	Slow release	hole	1.8	29.5	b	16.5	ab	7.0	abcd
Gróska	Easily s. & slow r. N	hole	1.8	28.6	b	20.4	a	7.9	ab
N1P15	Easily soluble	scattered	1.2	27.9	b	13.9	ab	8.4	ab
RTI Booster-Pak	Slow release	scattered	1.4	24.7	b	16.7	ab	7.8	abc
RTI Booster-Pak	Slow release	hole	1.2	24.0	b	12.6	b	6.5	abcd
Agriform	Slow release	hole	2.0	22.0	b	12.0	b	7.6	abcd
N1P15	Easily soluble	hole	1.2	20.4	b	11.4	b	4.6	cd
N1P3	Easily soluble	hole	1.2	18.5	b	13.9	b	5.6	bcd
Control			0	10.9	c	13.8	ab	4.6	d
Model R-square				0.54		0.48		0.46	
P-value				<0.0001		0.0135		0.0035	
N (observations)				601		590		600	

N = Fast release nitrogen (33-0-0 NH_4NH_3). N1 = 1.24 g N.
P = Triple phosphate (19% P as $Ca(H_2PO_4)_2$. P3 = 3 g $Ca(H_2PO_4)_2$, P15 = 15 g $Ca(H_2PO_4)_2$.
RTI Bio-Pak: N-P-K-S-Fe-Mn-Zn: 16-6-8-2.69-0.64-0.15-0.54: 9g pr. teabag.
RTI Booster-Pak: N-P-K-S-Ca-Mg-B: 18-6-6-5.7-8.5-0.71-0.18: 9g pr. teabag.
RTI Silva-Pak: N-P-K-S: 26.33-12.00-6.02-6.01): 9g pr. teabag.
Osmocote: N-P-K: 18-4.8-8.3 + micronutrients
Agriform: N-P-K-S-Ca-Fe-Mg-Mn-Zn-Cu-B: 20-10-5-2-2.8-0.50-0.50-0.05-0.05-0.05-0.02: 10 g tablet
Gróska-1 (Græðir 1b + Osmocote 38-0-0)
M&M (Triple phosphate (19% P as $Ca(H_2PO_4)_2$ + Osmocote 38-0-0)

classes. The first class, "low density", was used when no lupin was obscuring the seedling, "intermediate density" was used when lupin was obscuring one side of the seedling, and "high density" was used when lupin was growing at both sides of the seedling.

In July 2001, two soil profiles were dug at the experimental site, one in the lupin field and one at the glacial outwash plain outside. Soil samples were taken for chemical analyses at two depths in the lupin field, 0-3 and 10-25 cm, and at one depth, 0-15 cm, outside. The soil samples were dried (70°C, 48 h) and sieved through a 2-mm sieve before analysis. About half of the sample was coarser than 2 mm and was therefore not used for analysis. The methods used for soil analysis are shown in Table 1.

The volume index was calculated from the formula: (root collar diameter)^2 x height. The general linear model procedure of SAS 8 was used for statistical tests of fertilizer effects by ANOVA for randomized block design. To ensure a normal distribution of the data, the volume index was log-transformed before tests were done. Duncan's multiple range test was used for pair-vice comparisons, when the ANOVA yielded significant treatment effects ($P < 0.05$). The survival was analyzed with the GENMOD procedure in SAS 8.

RESULTS AND DISCUSSION

The survival was significantly affected by the fertilizer treatments at Markarfljótsaurar ($P = 0.045$) for pine, but not for birch and spruce (data not shown). There was, however, no clear positive or negative trend regarding the effect of fertilizer application, i.e. the control seedlings had sometimes a significantly higher survival rate than some of the fertilizer treatments and *vice versa* (data not shown). In year 2000, the overall survival at Markarfljótsaurar was 99%, 99%, and 91% for birch, spruce, and pine, respectively. This was a higher survival than earlier experiments with seedlings on a different substrate have shown in Iceland (Óskarsson and Sigurgeirsson, 2001; Óskarsson and Ottósson, 1990). The survival was also significantly different between the density classes for birch ($P < 0.001$) and pine ($P < 0.001$). For pine the survival was highest at 94% for the intermediate density, but survival rates for the lowest and highest densities were 90% and 75%, respectively (data not shown). For birch nearly all seedlings survived at low and intermediate densities, but the survival was 97% at the highest density.

There was a significant treatment effect on the volume index of all species: birch ($P < 0.001$), spruce ($P = 0.014$), and pine ($P = 0.004$). The Silva Pak fertilizer, which had the highest nitrogen ratio of the slow release fertilizers tested in this trial, gave the highest overall volume index. Bio Pak fertilizer mixture was also among the best treatments, but it contains, in addition to fertilizer, a microbiological mixture or Bio stimulants, which according to the manufacturer should assist the plant with nutrient assimilation in lieu of adequate microbial activity common to these types of sites. A mixture of both slow and easily soluble fertilizer gave similar growth as a slow release fertilizer (Table 3). Scattering the fertilizer gave higher volume index than putting the fertilizer in a hole. This difference was, however, in most cases not significant (Table 3). The density of the lupin had a significant effect on the volume index of birch ($P < 0.03$) and pine ($P < 0.03$), but not spruce (data not shown). The positive effects were in both cases found at the high and the intermediate densities.

The main conclusion of this study is that fertilization at planting with the proper amount and type of fertilizer improves the early growth rate of tree seedlings at lupin sites in South Iceland without adversely affecting their early survival. It is likely that the improvement of early growth rate, when combined with pre-treatment with Nootka lupin, will synergistically facilitate the long-term establishment of forest cover on nutrient-poor sites in Iceland.

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