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Long-term effect of fertilization on ^{137}Cs concentration in Scots pine needles

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Abstract. Long-term observations on the effects of a fertilization treatment on ^{137}Cs concentrations in forest vegetation are scarce. Needles of Scots pine were used as biological indicators of radionuclide uptake of trees. The fertilization experiments are located in western Finland in an area where radioactive contamination from the Chernobyl accident in 1986 was relatively high (22–75 kBq m^{-2}) compared to other parts of Finland. Fertilization treatments included different combinations of major nutrients, i.e. nitrogen, phosphorus, potassium and calcium. Needle ^{137}Cs concentrations of Scots pine were analyzed during 1991–2006. The effect of fertilization on ^{137}Cs concentration was tested 5 to 20 years after radioactive contamination from the Chernobyl accident in 1986. Fertilization clearly decreased ^{137}Cs concentration in Scots pine needles 1–21 growing seasons after application. Single K fertilization decreased significantly ^{137}Cs concentration 21 growing seasons after radioactive deposition on a drained mire. Mineral nutrients (application of commercial fertilizer or wood ash) can well be recommended for remediation of forests contaminated by accidental radionuclide deposition. The site conditions need to be taken into account in planning of remediation.

1. INTRODUCTION

In several field experiments significant decrease in uptake of radiocaesium by trees and understorey vegetation has followed soil preparation and fertilisation [1–9]. For example, the activity concentration of ^{137}Cs in certain compartments of trees has decreased to as low as ten per cent of the content in unfertilised stands, depending on dosage and time after the treatment. Availability of acceptable timber and wild food products can be substantially increased by such measures after an accidental contamination of forests. However, long-term observations on the effects of a fertilization treatment on ^{137}Cs concentrations in forest vegetation are scarce.

In this study we present preliminary results from fertilization experiments which have been monitored since 1991. Needles of Scots pine (*Pinus sylvestris*) were used as biological indicators of radionuclide uptake of trees.

2. MATERIAL AND METHODS

2.1 Study sites

The fertilization experiments are located in western Finland in an area where radioactive contamination from the Chernobyl accident in 1986 was relatively high (22–75 kBq m^{-2}) compared to other parts of Finland. Two Scots pine dominated stands were growing on xeric and sub-xeric heath forests and one stand on a drained pine mire (Table 1). Fertilization treatments included different combinations of major nutrients, i.e. nitrogen, phosphorus, potassium and calcium (Table 1). Site_H was established in a 45-year-old Scots pine stand in spring 1991 and site_S in a 50-year-old Scots pine stand in 1980. Site S was refertilised in 1985 with the same amount of nutrients as in 1980. Site_L is located in an

Table 1. Basic characteristics of the study sites.

Experiment	Site type	Fertilization Year	Fertilization: doses (kg/ha)	Replicates
Site_H	Xeric heath forest	1991	K: P31, K56	3
(Hämeenkangas)		1991	KNCa: N150, P31, K56, Ca395	3
Site_S (Siikakangas)	Sub-xeric heath	1980	NPK: N180, P80, K300	2
	forest	1985	NPK: N180, P80, K300	2
Site_L (Liesineva)	DsT[1]	1976	PK: P55, K96	2
		1989	K: K80	2

[1] Drained peatland forest, dwarf-shrub type in Finnish classification.

old experimental drainage area where fertilization experiment was set up in uneven-aged, 50-150-year-old Scots pine stand in 1976. The rates of applied nutrients in peatland forest were in accordance with practical guidelines, but the rates of P and K on mineral soils were quite high in terms of normal forest management. The experimental design of mineral soil sites was a completely randomised experiment, with a plot size of 800–900 m^2. Randomized block design was used on peatland site (plot size 1300 m^2). Experiments have been described in details in other papers [2, 10, 11]. Scots pine (*Pinus sylvestris*) was dominating tree species on all the sites with some mixture of downy birch (*Betula pubescens*) on drained peatland.

2.2 Sampling

Needles were sampled from 3–10 dominant trees per plot from southern and western aspects in the upper half section of the crown in the dormant season. The samples were collected using an extendable branch cutter, each sample branch of pines including at least two needle classes. The sample branches were stored in sealed plastic bags in a freezer until pre-treatment. Pre-treatment of the needle samples was performed separately for each sample tree.

2.3 Radiocaesium measurements and statistical analysis

Needle ^{137}Cs concentration of Scots pine were analyzed during 1991–2006. ^{137}Cs activity concentration in dried, homogenised samples was determined with a low-background, high-resolution (HPGe) gammaspectrometer at the radioanalytical laboratory of STUK[1]. A calibrated standard geometry was used for each sample type, and the results were corrected for the varying size and density of the samples with the software package developed at STUK [12].

The reference date for the radiocaesium concentrations was 1st of October, 1997, and 14th and 18th of December 2006 (Site_S and Site_L, respectively). For site_H the corresponding dates were 1st of October 1991 and 4th of January 2006.

The effect of fertilisation on ^{137}Cs concentration in current-year needles of Scots pine was tested 5 to 20 years after radioactive contamination from the Chernobyl accident in 1986 with t-test (Site_S and Site_L) or with ANOVA (Site_H; PASW Statistics 17.0).

3. RESULTS AND DISCUSSION

In general, fertilization clearly decreased ^{137}Cs concentration in Scots pine needles 1–21 growing seasons after application (Fig. 1). In 2005, in the xeric heath forest (site_H), ^{137}Cs concentrations were

[1] Research and Environmental Surveillance department (TKO) at STUK is a testing laboratory accredited by FINAS Finnish Accreditation Service under the registration number T167. The laboratory meets the requirements laid down in standard EN ISO/IEC 17025:2005.

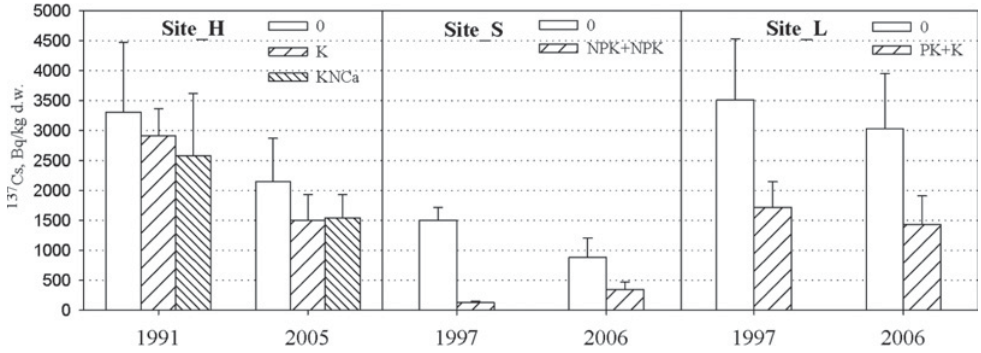

Figure 1. The effect of fertilization on ^{137}Cs concentration in current year needles of Scots pine in the study sites (see Table 1). The number of growing seasons after ^{137}Cs deposition was 6-12 (in 1991 and 1997) and 20–21 (during 2005–2006). Sites were fertilized in 1991 (Site_H), in 1980 and 1985 (Site_S), and in 1976 and 1989 (Site_L). Standard deviation is marked on top of the bars.

Table 2. The effect of fertilization on needle ^{137}Cs concentrations during study period: p values. (n.d. = not determined).

Exp.	Fertilization	1991	1997	2005–2006
Site_L	PK+K	n.d.	0.066	0.006
Site_S	NPK+NPK	n.d.	0.000	0.099
Site_H	K and KNCa	0.723	n.d.	0.062

Table 3. Remaining fraction of ^{137}Cs activity in Scots pine needles of fertilized trees compared to control trees during different years (n.d. = not determined).

Exp.	Fertilization	1991	1997	2005–2006
Site_L	PK+K	n.d.	0.488	0.472
Site_S	NPK+NPK	n.d.	0.087	0.350
Site_H	K	0.918	n.d.	0.698
	KNCa	0.843	n.d.	0.718

lower than could have been expected after radioactive decay. This reduction of activity concentration was probably caused by fertilization (Table 2), or, was a consequence of declined tree growth of control trees. In 1991, only one growing season after treatment, the effect of fertilization was not significant (Table 2).

In the sub-xeric forest (site_S), ^{137}Cs concentrations were still very low in fertilized pines in 2006, but concentrations were increased since last measurement in 1997 (Fig. 1, Tables 2 and 3). This may indicate that the effect of fertilization is slowly coming to the end. On the other hand, NPK refertilization clearly decreased the ^{137}Cs concentration in Scots pine needles both in 1997 and 2006. The application rate of potassium, 600 kg ha^{-1} during a 5-year period, was high compared to the potassium status of conifers in these conditions. Furthermore, as regards the timing of the treatments in relation to the Chernobyl fallout, the reduction in the uptake of ^{137}Cs may represent the near to maximum reduction that can be achieved with the doses used in this experiment, because the growth response of the trees to fertilization is normally observed during the second growing season following fertilization.

On a drained pine mire (site_L) the effect of fertilization was more stable than on two other sites. Very interesting observation was that single potassium fertilization, applicated three growing seasons after Chernobyl fallout, decreased significantly ^{137}Cs concentration in needles 21 growing seasons after deposition (Table 2). However, on all the sites the needle activities from different plots also showed

variation that revealed some inhomogeneity in growth conditions or differences in development stage of individual trees. The study material was also too limited for in-depth statistical analysis.

4. CONCLUSIONS

Mineral nutrients (application of commercial fertilizer or wood ash) can well be recommended for remediation of forests contaminated by accidental radionuclide deposition. The availability of acceptable timber to forest industry would be essentially increased with long term treatments of forests. However, there is no direct relationship between activity concentration in needles and the contamination level of stem wood, which integrates/accumulates radionuclides with varying intensity during rotation. The site conditions need to be taken into account in planning of remediation.

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