Fertilization of Conifer Plantations[1]

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INTRODUCTION

Tree growth in old plantations on various soil types can often be increased by a temporary improvement of the nutrient economy of the soil (4, 7, 13, 14, 15, 20, 26, 28), but fertilization of young plantations is much more important. Appropriate fertilization can temporarily or permanently stimulate growth, resulting in earlier closure of canopy, reduced susceptibility to various influences and a decrease in the risks to which young trees are exposed (22, 26). Research in this field is not complete, but some general recommendations for practical use of fertilizers can nevertheless be made.

THE NUTRIENT REQUIREMENTS OF THE VARIOUS CONIFERS

Not alone do confers and broadleaf trees differ basically in their nutrient requirements, but conifers also vary among themselves. The most important nutrients are phosphorus, nitrogen and potassium. Phosphorus is of fundamental importance for root development (19, 25); nitrogen and potassium are important in photosynthesis (2, 9, 24). Nitrogen is the basis of all the protein compounds in the plant, and one of the functions of potassium is to regulate assimilation, respiration and transpiration.

The differences in nutrient requirements between coniferous species cannot be simply expressed in terms of the quantity present in the soil, but can be expressed in terms of the quantity that a certain species can extract from the soil. Pines and larches on nitrogen deficient soils —for example reclaimed heathland—can extract far more nitrogen from this type of soil than can Norway spruce or Douglas fir.

On the basis of our present knowledge we can divide the most important tree species, according to their nutrient requirements, as follows:

Species		Requirements of		
		N	P	K
Pinus spp.	......	low	low	high
Picea, spp.	......	high	high	low
Pseudotsuga	......	high	high	high
Larix spp.	......	low	high	low

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DETERMINATION OF FERTILIZER REQUIREMENTS

Investigation of nutrient requirements by means of soil analysis gives rise to difficulties in relation to sampling, extraction method and interpretation of results. In taking soil samples there are questions of location of sample, number of sub-samples of which each sample is composed, and depth of sampling. Answers to these questions were found through research carried out in co-operation with the Soil Survey Institute and the State Laboratory for Soil and Plant Research, and these findings serve as a basis for soil sampling recommendations. Each soil type should be sampled separately. The sample should be taken from the 0-25 cm layer and should consist of at least 25 sub-samples.

The extraction method depends on the amount of nutrients available for trees. It appears that trees can extract nitrogen, potassium and phosphorus from relatively insoluble compounds, and therefore total analysis is carried out where possible (1, 23, 29). But this also gives rise to difficulties which will not be discussed here. At present only phosphate determination appears to be useful in indicating which fertilizers are required. There is a relationship between tree growth and soil phosphate level, within certain soil types. No workable system of soil analysis has yet been developed for potassium or nitrogen.

Needle analysis is more promising for potassium and nitrogen. There is often a close correlation between growth and nitrogen content or the nitrogen/phosphorus ratio. It should therefore be possible to evolve a method for establishing the fertilizer requirement by means of soil and needle analysis. Needle analysis is only possible in the case of existing plantations (9, 17, 27, 29, 30), but this is not a great disadvantage since nitrogen and potassium should always be applied after and not before planting.

PRACTICAL USEFULNESS OF THE RESULTS OF SOIL AND FOLIAGE ANALYSIS

A large number of fertilizer experiments have been carried out to determine whether the use of combined results of soil and needle analysis to determine fertilizer requirements is of practical value.

The following is a summary of the results of these investigations:

1. Even with similar results from soil and foliage analysis the reaction of a tree crop to fertilization may vary greatly on similar soil types. A combination of the results of foliage analysis carried out before and after fertilization gives a better indication of the fertilizer requirement of a particular plantation, but at this stage the crop has already been fertilized.

2. Soil type is very important in interpreting the results of phosphate

analysis. It has been shown for example that for trees the availability of phosphate is higher on **holt**-podsols (humus iron podsols) than on **haar**-podsols (dry humus podsols) or **veld**-podsols (moist humus podsols). There will usually be no response to phosphate fertilization on a **holt**-podsol with a P content of 20 mg/100g, but there will be a response with the same P content on **haar**-podsols or on **veld**-podsols. An extraction method is now being developed which will give a better reflection of the inorganic soil phosphorus. Phosphate in inorganic form can be easily taken up by coniferous trees.

3. The nitrogen content of the needles gives a clear indication of the nitrogen supply. The optimum level lies between 1.7 and 2.0% of the dry matter. Fertilization with nitrogen increases the N content. The growth response, however, is determined not only by the increase in the level of nitrogen but also by the effect of the nitrogen fertilizer on the levels of other nutrients. In some cases, for instance, potassium deficiency occurs; in other similar cases the potassium level does not change. This is unpredictable.

4. The supply of potassium to the trees depends, among other things, on the potassium content and acidity of the soil. An increase in nitrogen supply usually causes a decrease in foliar potassium content, but the converse does not hold. In certain conditions the nitrogen content of Douglas fir and Scots pine needles can be increased by the application of potassium (9). Even if the potassium content of the needles is normal, this does not mean that potassium deficiency will not occur when nitrogen is added to the soil.

From the results summarised in the preceding four paragraphs we can conclude that soil and crop analyses by themselves do not give a complete picture of the fertilizer requirements of conifer plantations. Many other factors, such as soil type, history, etc., influence the response to fertilization to a degree which cannot yet be accurately estimated. This means that, as in agriculture and horticulture, forest fertilization practice must be based on soil and crop analyses combined with the results of fertilizer experiments on similar sites.

A large number of forest fertilizer experiments will need to be established on all soil types so that the influence of locality factors, so far unanalysed, on the response to fertilization can be determined. This research will take many years.

WORKING METHOD FOR FOREST PRACTICE

In order to be able to make use of fertilizers in practice it was necessary to devise a method by which the fertilizer requirements of a plantation could be roughly estimated. It should be remembered that the results obtained by this method may not always come up to expectations. The method that was developed is based on:

1. The tree species.
2. The average fertility of the soil type.
3. The result of soil analysis.
4. The symptoms observed in the needles and shoots.

Soil analysis and soil type will indicate whether phosphate content and acidity are satisfactory, the needle symptoms show whether there is a deficiency of certain nutrients or not. Fertilization based on these considerations will allow for possible interactions or antagonisms of nutrients in different tree species, and will avoid as far as possible any unexpected induced deficiencies (18).

DEFICIENCY SYMPTOMS

Deficiency symptoms for the most important nutrients are more or less similar in the different species of conifers.

1. **Nitrogen Deficiency**

Light-green to yellow-green discoloration of conifer needles indicates that the nitrogen supply is below optimum. The greater the deficiency the lighter and more yellow-green the colour, and the smaller the needles. The discoloration is uniform over the needles and over the whole tree. Nitrogen content of needles at the end of the growing season varies from about 1.0% (deficiency) to about 2.0% (optimum) of dry mater (6).

In all species of trees nitrogen deficiency is always accompanied by a decrease in growth.

2. **Phosphorus Deficiency**

A phosphorus deficiency severe enough to produce symptoms is rare. The needles have a typically dark greenish colour and are often covered with black algae. In severe cases the colour varies from a bronze-green to a brown purple and necrosis of the older needles occurs. In addition the needles are small. In spruces and in Douglas fir the foliage appears sparse. Growth is always poor. Deficiency symptoms appear when the phosphorus content drops below 0.10% of dry matter (6, 8).

3. **Potassium Deficiency**

Conifers suffering from a deficiency of potassium show a partial yellow discoloration of the needles, or a complete discoloration of the needles at the ends of the shoots. The latter only occurs in spruces, Douglas fir and larches, not in pines. In the needle discoloration the base of the needle remains green and the top is yellow. There is a gradual transition from the yellow to the green zone. A combination of the two above-mentioned symptoms occurs in spruces. Potassium deficiency symptoms become most pronounced towards the end of winter, particularly in pines. In larch the discoloration is mainly confined to the needles of the short shoots.

Deficiency symptoms occur when the K content at the end of the growing season drops below the following content of dry matter: pines 0.35%, larches 0.50%, spruces 0.40% and Douglas fir 0.45%.

4. **Magnesium Deficiency**

Although magnesium deficiency is less important in conifers, since no accompanying decrease in growth has so far been established, it is discussed here in order to prevent confusion with K deficiency symptoms. In pines, magnesium deficiency is indicated by a strong yellow discoloration of the needle ends (5). The transition from the yellow top to the green base is rather sharp. In spruces and in Douglas fir there is likewise a discoloration of the needle ends, but only in needles older than one year. Magnesium deficiency symptoms in larch are so far unknown in this country.

5. **Copper Deficiency**

Copper deficiency may cause serious growth disorders. In Douglas fir it shows in a contorted growth of the leader and side shoots (12, 21). Necrosis of the shoot tips occurs early in winter. Sometimes the needles at the lower ends of the shoots are yellow or even necrotic. In spruces the tips of the leaders and side shoots die back during autumn and winter resulting in a bushy form of growth (12). In larch also the deficiency symptoms consist of a dying back of the shoot tips and subsequent bushy growth. So far no deficiency symptoms have been found in pines. Deficiency symptoms occur when the copper content drops below 2.5 to 3 ppm of dry matter (12, 21).

GENERAL RECOMMENDATIONS FOR FERTILIZATION

The following general observations should be kept in mind:

1. The young trees must be in a suitable condition to respond to the nutrients supplied. This is possible only when the root system is fully intact and the above-ground parts have not been damaged in any way. Fertilization can only be effective in a viable plantation. Plantations of genetically inferior trees should not be fertilized.

2. Ground vegetation, particularly grasses, checks tree root development. Under these conditions the trees often show nitrogen

deficiency symptoms, due not so much to a poor soil nitrogen economy as to inadequate uptake by the underdeveloped root system. In such cases weed control is necessary before fertilizers are applied. If the ground vegetation consists of a not too heavy growth of heath, weed control is less important and fertilization can proceed without it.

3. When using individual fertilizers alone, phosphate and copper fertilizers can be applied at any time. They act slowly and therefore a winter application is preferable. Nitrogen fertilizers are more soluble, are not retained in the soil and are leached out relatively quickly. These fertilizers should therefore be applied in Spring so that the trees can benefit immediately.

   Potash fertilizers should preferably be applied in February/March. When mixed fertilizers are used the time of application is determined by the most soluble component. This means that all fertilizers containing nitrogen must be applied in April/May.

4. Phosphate, potassium and copper fertilizers are always broadcast. The method of application of nitrogen fertilizer depends on the age of the plantation. If canopy closure can be expected within two or three years the nitrogen may be broadcast. If the trees are smaller, nitrogen should be given to each plant separately over an area of about 1 sq. metre around the tree. An even distribution around the tree can be obtained by dropping the fertilizer from above the tree and then shaking it lightly with the foot, but for this the trees must be dry.

5. Phosphate should be applied before planting, or as soon as possible after, since it stimulates root development. Potassium and nitrogen are given after planting, nitrogen preferably not in the year of planting but rather in the following year.

   The fertilizers mainly used in forestry are: for phosphate, basic slag and ground rock phosphate; for potassium, sulphate of potash magnesia, muriate of potash and sulphate of potash; for nitrogen, calcium ammonium nitrate and sulphate of ammonia; and for copper, copper slag flour and copper sulphate. Mixed fertilizers should as far as possible be free of chloride and in granulated form.

6. If mixed fertilizers are used the phosphate and potassium dressings need not be repeated. These nutrients are retained in the soil to a greater or lesser degree and have long lasting residual effects. If nitrogen is required, the application must be repeated every year or every second year until the time of canopy closure.

RECOMMENDATIONS FOR FERTILIZING THE DIFFERENT CONIFERS

Pines

Species of **Pinus** do not make heavy demands on soil nutrients. Under certain circumstances, however, fertilization may be advisable:

1. In the afforestation of uncultivated ground where the vegetation consists of heath and grass, without Scots pine or other conifers, phosphate fertilizer may be necessary. Quantity: 300-500 kg of basic slag per ha (2.4-4.0 cwts per acre). No phosphate fertilization is necessary when replanting.

2. If potassium and/or magnesium deficiency symptoms appear in a plantation it is advisable to apply 150 to 300 kg of sulphate of potash magnesia per ha (1.2-2.4 cwt. per acre).

3. Nitrogen fertilization is not normally required for pines (10), except in serious cases of potassium deficiency when the base of the needle, in addition to the top, is discoloured. In such cases a light dressing of nitrogen, 200 kg (1.6 cwt per acre) of calcium amonium nitrate, is recommended in addition to the potassium.
   When only nitrogen deficiency symptoms are present it is better not to apply nitrogen.
   It should be noted that potassium deficiency symptoms in Scots pine can also be due to genetic factors (11). Continental provenances, particularly those from northern regions, always show potassium deficiency symptoms in winter. In such cases potassium fertilization may have disappointing results. If, however, a pine plantation of doubtful provenance growing on **veld**-podzol (moist humus podsol) or on **haar**-podsol (dry humus podsol) or on a sand dune soil shows signs of potassium deficiency, fertilization with potassium may be worth while.

Spruces

The nitrogen and phosphorus requirements of **Picea** species are generally high.

1. Soils with insufficient phosphate should be treated before or at the time of planting with 500 kg of basic slag per ha (4.0 cwt per acre). Such soils are **veld**-podsols or **haar**-podsols and **goor** earth soils (moist old arable land on sandy soils) with a total phosphate content of less than 40 mg P_2O_5 (18 mg P) per 100g of soil. If the content is higher, or if the planting is on **holt**-podsol (humus iron podsol) or **enk** earth ground (dry old arable land on sandy soils) or old farmland, then no phosphate fertilizer is required even if total phosphate content is below 40 mg P_2O_5 (18 mg P) per 100g of soil.

2. If nitrogen deficiency symptoms—small light-green to yellow-green needles—develop during the year after planting, or later, a dressing of calcium ammonium nitrate should be given. 50g ($1\frac{3}{4}$ oz) per plant or 400 kg per ha (3.2 cwt per acre) broadcast. If the dominant ground vegetation is grass, or anything other than heath, it must be controlled first.

   If nitrogen deficiency symptoms develop in a plantation on a soil which is low in phosphate, and where phosphate was not applied before or at the time of planting, the first nitrogen dressing can be given as phosphate ammonium nitrate rather than calcium ammonium nitrate. In this case the phosphate ammonium nitrate should be applied broadcast. If the plants are too small for broadcast fertilization it is more effective to treat each individual plant with calcium ammonium nitrate, and to broadcast phosphate instead of phosphate ammonium nitrate. Calcium ammonium nitrate can be given again later.

   On **veld**-podsols (moist humus podsols) and on poor moorland soils there is a danger of copper deficiency when nitrogen and phosphate are applied as fertilisers. On these soil types therefore it is advisable to use copper fertilizer in the form of 50 kg per ha (45 lb per acre) copper sulphate in addition to the other fertilizers.

3. Symptoms of potassium deficiency are either a yellow discoloration of the ends of the young needles or a discoloration of the needles at the ends of the shoots. When these appear the plantation should be treated with 150—300 kg of sulphate of potash-magnesia per ha (1.2-2.4 cwt per acre) combined if necessary with 50 gm ($1\frac{3}{4}$ oz) of calcium ammonium nitrate per plant or 400 kg per ha (3.2 cwt per acre) broadcast. The symptoms indicate whether the combination is required. If the trees are strongly discoloured and if the needle bases are also yellow-green then nitrogen is necessary. If the needle bases are green to dark green and discoloration limited to the very young needles at the end of the shoots then nitrogen need not be given. Potassium deficiency symptoms can be due not only to potassium deficiency in the soil, but also to excessively high pH (greater than 5.5 in water or 5.0 in KCl), for example in plantations on former arable land. If the pH is not much above this critical limit, and if the humus content is less than about 5%, fertilization with 400 Kg per ha (3.2 cwt per acre) of sulphate of ammonia and 200 kg per ha (1.6 cwt per acre) of sulphate of potash will give good results. If the pH and/or humus content are much higher than these limits then the dressing must be combined with 250 kg of flowers of sulphur per ha (2.0 cwt per acre). The latter can be given at the time of planting.

4. With phosphate deficiency symptoms—small green to blue-green needles pressed closely against the twig—500 kg of basic slag per ha (4.0 cwt per acre) should be given. In the following year this can be supplemented by nitrogen and potassium if foliar symptoms indicate that these are required. If phosphate deficiency symptoms are combined with those of nitrogen deficiency—in which case the ground vegetation is usually heathy and the needles are a dull greenish yellow—the nitrogen and phosphate can both be applied in the same year.

   For this phosphate ammonium nitrate (400 kg per ha, 3.2 cwt per acre) can be used.

Douglas fir

Douglas fir makes the highest demands on soil nutrients. The nitrogen, phosphorus and potassium requirements are all high.

1. Phosphate is applied in the same way and under the same circumstances as for spruces (No. 1).

2. When symptoms of nitrogen deficiency develop—light green to yellow-green needles—calcium ammonium nitrate should be applied at the rate of 50g (1¾ oz) per plant or 400 kg per ha 3.2 cwt per acre) broadcast. This should always be combined with 150-300 kg of sulphate of potash magnesia per ha (1.2-2.4 cwt per acre). Even in the absence of potassium deficiency symptoms it is possible that, because of the high potassium requirement of this species, the nitrogen dressing will result in a shortage of potassium. The nitrogen dressing would then be inefficient. In subsequent years the nitrogen should be repeated if necessary but without the potassium. If phosphate has not been given at the time of planting on soils where phosphate is necessary, phosphate ammonium nitrate is used instead of calcium ammonium nitrate. Alternatively in such cases an initial application of compound NPK fertilizer can be given. Once the phosphate ammonium nitrate or compound NPK fertilizers have been broadcast, calcium ammonium nitrate will suffice for later applications. The quantity of fertilizer to be applied to each plant is determined by the nitrogen content. A minimum of at least 10g (0.35 oz) of elemental N per plant should always be supplied.
   Douglas fir makes high demands on the supply of copper, and in all podsols, with the exception of **holt**-podsols (humus iron podsols) there is a danger of copper deficiency following the application of nitrogen and phosphate.

   It is advisable therefore to treat all Douglas fir plantations on such soils with copper sulphate at the rate of 50 kg/ha (45 lb/acre).

1. Nitrogen deficiency douglas fir

2. Phosphate deficiency douglas fir

3. Nitrogen deficiency Norway spruce

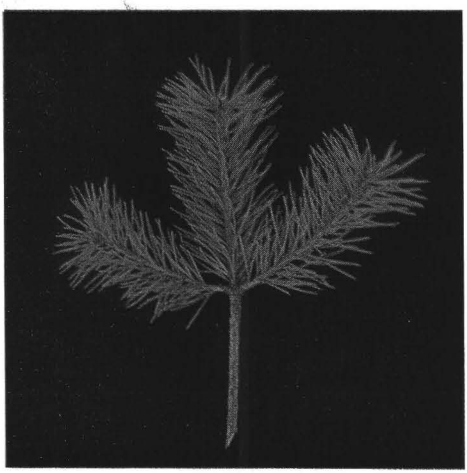
4. Phosphate deficiency Norway spruce

5. Potassium deficiency douglas fir at low nitrogen level

6. Potassium deficiency douglas fir at high nitrogen level

7. Potassium deficiency Norway spruce at low nitrogen level

8. Potassium deficiency Norway spruce at high nitrogen level



9. Nitrogen deficiency Scots pine

10. Phosphate deficiency Scots pine

11. Potassium deficiency Scots pine

12. Magnesium deficiency Scots pine

13. Copper deficiency douglas fir

3. Potassium deficiency symptoms are similar to those in spruce. When they appear a dressing of 150-300 kg of sulphate of potash magnesia should be given, combined with a normal nitrogen fertilization if necessary. The need for nitrogen is determined by the intensity of the deficiency symptoms. (See notes on **spruces**) Douglas fir is less sensitive than spruce to high pH values, so that potassium deficiency due to calcium antagonism is rare.

4. If symptoms of phosphate deficiency appear — small blueish green to brownish green needles — a dressing of 500 kg of basic slag per ha (4.0 cwt per acre) should be given. In the year following this application a supplementary dressing of nitrogen and/or potassium may be given as indicated by deficiency symptoms.

Larch

The only high nutritional demand of **Larix** species is on the soil phosphate supply. Their nitrogen and potassium requirements are low.

1. Phosphate is given in the same way and under the same circumstances as for spruces (No. 1).

2. Symptoms of nitrogen deficiency are rarely seen in larch unless the plantation is seriously infested with weeds. Here the first requirement is weed control. If nitrogen deficiency symptoms occur on soils without a strong growth of weeds, or with a heathy vegetation, calcium ammonium nitrate should be given at the rate of 20 gm ($\frac{3}{4}$ oz) to each plant, or 200 kg per ha (1.6 cwt per acre) broadcast. Nitrogen should be given cautiously since it is easy to give an overdose which will result in distorted growth.

3. When potassium deficiency symptoms occur—yellow-tip disease of the needles on the short shoots, and yellow needles at the ends of the long shoots—150-300 Kg of sulphate of potash magnesia per ha (1.2-2.4 cwt per acre) should be applied.
   Potash deficiency symptoms in larch are often due to moisture deficiency or high pH. In both cases the larch is on an unsuitable site and it is better not to fertilize but to replace the plantation.

4. Symptoms of phosphate deficiency occur sometimes in larch. The needles are blueish green, sometimes changing to yellow-brown, mauve-brown or violet. The plantation should be treated with basic slag at the rate of 500 kg per ha (4.0 cwt per acre), supplemented in the following year, if necessary, with nitrogen and potassium.

Other Conifers

Little is known about the other coniferous species, but remarks on Douglas fir apply also to **Abies grandis** and **Tsuga heterophylla.**

SUMMARY.

From the results obtained from fertilization research carried out so far it can be concluded that the need of nutrients and the effect of a fertilization cannot be forecast from the data of soil and needle analysis only. The data of complete fertilizer trials under comparable conditions must necessarily be combined with it. This means that a great many fertilizer trials have to be laid out, which take much time. In the meantime a directive for fertilization of young plantations for practical use has been drafted. This directive is based on the results of research concerning fertilization carried out until now, and further on tree species, soil type and soil analysis, and symptoms of needles. In this way it will be possible to obtain an appropriate improvement of growth in many plantations with insufficient growth although the effect cannot be forecast quantitatively. The present directive has been worked out for *Pinus, Picea, Pseudotsuga* and *Larix.*

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