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Foliar colour as indicator of nutrient status of Scots pine (*Pinus sylvestris* L.) on peatlands

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Abstract

Foliar colour of Scots pine was measured using a chromameter from 85 fresh, dried or dried and ground foliage samples. The colours obtained in the *XYZ* notation were transformed into the Munsell notation (Hue, Value, Chroma). Foliar nutrient concentrations (N, P, K, Mg, Ca, Mn, Fe, Zn and B) of the needle samples were analysed. Suitability of foliar colour in the evaluation of the nutritional status of Scots pine stands growing on unfertilized peatlands was investigated using correlation and discriminant analysis. An independent data set (41 samples) containing also PK-fertilized stands was used to test the discriminant functions. The correlations between colour attributes and foliar nutrient concentrations were at their highest when colour was measured from the tips of fresh needles. Then the Hue of the needle tip turned greener with increase in the concentration of foliar K. The indicative value of the colour of dried needles in estimating nutrient concentrations and deficiencies was lower than that of fresh or ground needles; this was attributed to decrease in the variation of the colour attributes following drying. The colour of fresh needle tips was the best indicator of simultaneous deficiency of P and K, while deficiencies of N and B were not successfully detected. The Hue of the fresh needle tips that was yellower than 1.5 GY indicated simultaneous deficiency of P and K. However, in the case of fertilized stands, foliar colour had low diagnostig value.

Keywords: Nutrient deficiency; Foliar analysis; Colourimetry; Munsell colour notation system

1. Introduction

In evaluation of the nutritional status of tree stands for diagnostic and monitoring purposes, chemical foliar analysis is a well established and widely used method based on the critical levels of concentrations of foliar nutrients (van den Driessche, 1974; Paarlahti et al., 1971). The nutritional status of tree stands can also be evaluated visually based on the morphological changes caused by nutrient deficiencies (Mengel and Kirkby, 1982; Reinikainen et al., 1998).

The most important general effect of nutrient deficiencies in trees is reduced growth, while leaves appear to be particularly sensitive indicators of nutrient deficiency (Kramer and Kozlowski, 1979). The symptoms of nutrient deficiencies are, however, not always specific and they can indicate a lack of more than one nutrient (Veijalainen et al., 1984; Reinikainen et al., 1998). For example, potassium deficiency in conifers is indicated by the yellow colour of the tips of needle or of the entire needles (chlorosis). Chlorosis is also a symptom of magnesium deficiency, but it differs from that caused by potassium deficiency in that the needle colour is yellower and the border between the yellow tip and the healthy part of the needle is sharp.

Visually estimated foliar colour has earlier been used in studies looking into the health and growth of trees, and the effects of fertilization or browsing damage (Viro, 1959; Luukkanen et al., 1971; Zimmermann et al., 1988; Berquist and Örlander, 1998; Weaver and Stipes, 1990). The visually assessed dark green colour of needles or the colour measured from photographs has been shown to correlate positively with foliar nitrogen concentrations and improved growth (Luukkanen et al., 1971; Thorn et al., 1995; Berquist and Örlander, 1998). Much of foliar nitrogen is incorporated in chlorophyll, which thus (together with colour) could be used as an indirect measure of plant nitrogen status (Viro, 1959, 1965; Richardson et al., 2002; Heiskanen, 2005). Reflectance spectroscopy, based on besides visible wavelengths also on other wavelengths such as near-infrared, has been used in ecological studies to predict nutrient concentrations of foliage (Gillon et al., 1999; Richardson and Reeves, 2005). Such data can be remotely

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sensed or sensed from dried and ground foliar samples (Martin and Aber, 1997; Foley et al., 1998).

The colour perception of the human eye depends on the stimulus produced by the interactions of the characteristics of the light source, the surface reflectance characteristics of the object, and the spectral response characteristics of the human eye (Melville and Atkinson, 1985). Thus, visual estimation of colour is subject to inaccuracies. The visual estimation of colour can be replaced by optical colourimetric measuring techniques directly from plant material or even from digital images (Thorn et al., 1995). A chromameter breaks the light down into its RGB components according to the amount of red, green, and blue light reflected from the object. The numeric value of the colour is then determined using the CIE (Comission Internationale de l'Eclairage) *XYZ* colour space or one of its derivative colour systems. One of the most widely used colour systems is the Munsell notation system. In this system, every colour has three qualities or attributes: Hue, Value and Chroma. The Hue notation is the attribute of the colour perception denoted by blue, green, red and so on. The Value represents the lightness, and the Chroma is the degree of difference from neutral colour. These attributes have numerical scales with visually uniform steps for each of these attributes.

Phosphorus and potassium deficiencies are common in Scots pine stands growing on drained peatlands in Finland (Moilanen et al., 2005). The peat of drained peatlands contains generally only small amount of mineral nutrients. Especially potassium stores in the root zone of trees are quite low compared with the amounts bound into tree stands (Kaunisto and Paavilainen, 1988; Laiho and Laine, 1994; Westman and Laiho, 2003). Potassium deficiency causes commonly leader changes and tree death, and can lead to rapid deterioration of the tree stand (Kaunisto and Tukeva, 1984; Reinikainen et al., 1998). Fertilization of potassium deficient stands has improved the nutrient status of trees and increased the growth of stands (Kaunisto and Tukeva, 1984; Kaunisto, 1989, 1992; Moilanen et al., 2005; Pietiläinen et al., 2005). Therefore, since conventional foliar nutrient analyses are rather expensive in large-scale monitoring of nutritional status of forest stands, a fast indirect method for detecting nutrient deficiencies would greatly help forest managers to identify potential deficiency areas in forest management plans (Saarinen, 1997).

In the present investigation, we tested the ability of foliar colour in detecting nutrient deficiencies of Scots pine trees growing on peatlands. Our aims were: (i) to investigate the general suitability of foliar colour in the evaluation of the nutritional status of Scots pine stands, (ii) to investigate which of the fresh, dried or dried and ground foliar samples are best suited for the colour-based evaluation of the nutritional status of trees, and (iii) to investigate if the colour of the foliar samples should be measured from the needle tips or from the middle part of the needles when evaluating nutritional status.

2. Materials and methods

2.1. Collecting of the material

The material consisted of two separate sets of data. The first data set (analysis sample) consisted of foliar samples collected from 85 Scots pine (*Pinus sylvestris* L.) stands growing on peatlands. These stands are located in western Finland (63–65°N and 22–26°E) and were sampled for foliar samples between December 2001 and March 2002. The second data set (test sample) consisted of 41 foliar samples collected between December 2004 and January 2005 from seven Scots pine fertilization experiments established on peatlands in different parts of the country. In each experiment, foliar samples were collected from unfertilized plots and plots fertilized with PK-fertilizer (P, 40 kg ha^{-1}; K, 72 kg ha^{-1}) 4–5 years before sampling. The mean height of the trees in the sampled stands varied from 3 to 15 m. All foliar samples were taken from at least five dominant or co-dominant trees from the sun-facing side of the tree to minimize variation among individual trees. Each tree was accessed by targeting on one lateral branch from each of the topmost three whorls. Only current year needles were sampled. The foliar samples were combined into one composite sample for each stand and in the case of fertilization experiments for each plot.

2.2. Foliar analyses

When the needle samples arrived at the laboratory they were separated into two parts. One part was placed in a freezer (−25 °C) to await colour analysis and the other part was used for nutrient analysis before which it was kept at room

Table 1
Descriptive statistics of the foliar nutrient concentrations for the study material

Nutrient	Analysis sample		Test sample			
			Unfertilized plots		PK-fertilized plots	
	Mean ± S.D.	Range	Mean ± S.D.	Range	Mean ± S.D.	Range
N (g kg^{-1})	14.0 ± 2.3	10.4–21.6	15.4 ± 3.0	11.5–23.7	14.3 ± 1.9	12.2–18.5
P (g kg^{-1})	1.4 ± 0.2	1.0–2.2	1.5 ± 0.3	1.0–2.1	1.8 ± 0.2	1.5–2.2
K (g kg^{-1})	4.3 ± 0.7	2.3–5.8	3.8 ± 0.5	3.1–4.9	4.9 ± 0.4	4.3–5.5
Ca (g kg^{-1})	2.3 ± 0.4	1.4–3.4	2.2 ± 0.4	1.6–2.9	2.3 ± 0.4	1.7–3.0
Mg (g kg^{-1})	1.3 ± 0.2	0.9–1.8	1.4 ± 0.1	1.1–1.7	1.3 ± 0.2	1.0–1.7
Mn (g kg^{-1})	0.4 ± 0.2	0.1–0.9	0.4 ± 0.2	0.1–0.8	0.3 ± 0.2	0.1–0.8
B (mg kg^{-1})	11.7 ± 5.2	2.0–26.0	12.1 ± 4.9	5.0–22.0	31.5 ± 4.0	25.4–38.3