COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE 132



# SPECTRAL REFLECTANCE AS AN INDICATOR OF GROUND VEGETATION AND SOIL PROPERTIES IN NORTHERN FINLAND

AULIS RITARI & PEKKA SAUKKOLA

SELOSTE

SPEKTRINEN HEIJASTUSSÄTEILY PINTAKASVILLISUUDEN JA MAAN OMINAISUUKSIEN KUVAAJANA POHJOIS-SUOMESSA

HELSINKI 1985

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*Cover (front & back):* Scots pine (*Pinus sylvestris* L.) is the most important tree species in Finland. Pine dominated forest covers about 60 per cent of forest land and its total volume is nearly 700 mil. cu.m. The front cover shows a young Scots pine and the back cover a 30-metre-high, 140-year-old tree.

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*Approved on 30.5.1985*

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RITARI, A. & SAUKKOLA, P. 1985. Spectral reflectance as an indicator of ground vegetation and soil properties in northern Finland. Seloste: Spektrinen heijastussäteily pintakasvillisuuden ja maan ominaisuuksien kuvaajana Pohjois-Suomessa. Commun. Inst. For. Fenn. 132: 1—37.

The goal of the present study was to examine the degree to which four forest site types common in northern Finland (damp site, sub-dry site, dry site, barren site) can be distinguished from one another on the basis of the reflective properties of the ground vegetation and soil surface. The spectral distribution of the radiation from the site (wavelengths 0.5—1.0 μm) was measured using a spectroradiometer in mid-summer under various conditions: a) samples under normal moisture, artificial light, b) samples moistened, artificial light, c) samples in normal moisture, sunlight. Measurements were also made of the soil samples after they had been dried. A number of physical and chemical properties of the vegetation and soil samples were determined which were thought to have an effect on the reflected radiation. Further, the theoretical basis of the system of measurement and the properties of the objects upon which the empirical part of the study is based are examined.

Damp site *(Hylocomium-Myrtillus type)* was best distinguished from sub-dry site *(Empetrum-Myrtillus type)* in the infrared region; on the other hand, dry site *(Myrtillus-Calluna-Cladina type)* was distinguishable from barren site *(Cladina type)* in the region of green and red light. Both damp and sub-dry sites were distinguished from dry and barren in the red and infrared regions. The spectral ratios describing the spectral signature curve distinguished the site types under consideration with the greatest certainty. Moistening of the samples caused a diminution in the level of the reflectance factors (with the exception of the B horizon soil) but did not, in general, affect the distinguishability of the sites. Drying of the samples increased the average spectral signatures by 10—15 %.

Using correlation analysis, it was possible to achieve a breakdown of the variables describing a range of site characteristics (for both ground vegetation and soil) which in a given range of wavelengths correlate with the reflectance factor in a statistically significant fashion. The results may be adopted, e.g. in gathering multi-spectral material when it is necessary to evaluate the identifiability of the surfaces being interpreted, the best wavelengths from the standpoint of the interpretation, the relative lightness of the surfaces in relation to those with which they are being compared and the effects of imaging conditions on the results.

Tutkimuksen tavoitteena oli tarkastella neljän Pohjois-Suomessa yleisesti esiintyvän kasvupaikkatyypin (tuore kangas, kuivahko kangas, kuiva kangas, karukkokangas) erottuvuutta toisistaan pintakasvillisuuden ja pintamaan heijastusominaisuuksien perusteella. Kohteen heijastaman säteilyn spektrinen jakauma (aallonpituusalue 0.5—1.0 μm) mitattiin spektroradiometrillä keskikesällä erilaisissa olosuhteissa: a) näytteet normaalikosteudessa, keinovalo, b) näytteet kasteltuina, keinovalo sekä c) näytteet normaalikosteudessa, auringonvalo. Maanäytteet mitattiin myös kuivattuina. Sekä kasvi- että maanäytteistä määritettiin fysikaalisia ja kemiallisia ominaisuuksia, joiden oletettiin vaikuttavan kohteesta heijastuvaan säteilyyn. Lisäksi työssä tarkastellaan niitä mittausjärjestelmään ja kohteiden ominaisuuksiin liittyviä teoreettisia perusteita, joihin työn empiirinen osa perustuu.

Tuore kangas (metsätyyppi HMT) erottui kuivahkosta kankaasta (EMT) parhaiten infrapunan alueella, kuiva kangas (MCClT) sen sijaan erottui karukkokankaasta (ClT) parhaiten vihreän ja punaisen valon alueella. Sekä tuore että kuivahko kangas erottuivat kuivasta ja karukkokankaasta punaisen ja infrapunan alueella. Ominaissäteilykäyrän muotoa kuvaavat suhdekanavat erottivat tarkasteltavat kasvupaikkatyypit kaikkein varmimmin toisistaan. Näytteiden kastelu aiheutti heijastussuhteiden tason alenemisen (lukuunottamatta B-horisontin maata), mutta ei yleensä vaikuttanut kohteiden erottuvuuteen. Maanäytteiden kuivaus nosti niiden ominaissäteilykeskiarvoja 10—15 %.

Korrelaatioanalyysin avulla voitiin eritellä joukko kasvupaikan ominaisuuksia kuvaavia muuttujia (sekä pintakasvillisuuteen että maahan liittyviä), jotka määrätyllä aallonpituusalueella olivat kiinteässä riippuvuudessa heijastussuhteen kanssa. Tuloksia voidaan soveltaa mm. monikanava-aineistojen hankinnassa, jolloin tarvitaan tietoa tulkittavien pintojen tunnistettavuudesta, tulkinnan kannalta parhaista aallonpituusalueista, tulkittavien pintojen suhteellisesta vaaleudesta vertailupintoihin nähden sekä kuvausolosuhteiden vaikutuksesta tuloksiin.

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# 1. INTRODUCTION

The use of remote sensing in monitoring natural resources has been the focus of active interest in recent years. In addition to traditional aerial photographs, infrared pictures have been used in certain forestry applications. Scanner data transmitted by the American Landsat satellite has been available since 1972; the reduction in the size of the ground element will open new opportunites. Studies have also been done on the possible applications of multispectral scanners mounted on aircraft. On the basis of experiences both nationally (e.g. Kuusela & Poso 1975, Kilpelä et al. 1978, Saukkola 1982a, Saukkola 1982b, Häme & Saukkola 1982) and abroad (cf. literature in the Manual of Remote Sensing (Reeves et al. 1975), and the great number of other books and journals in the field), it can be supposed that an increase will occur in the forestry use of remote sensing methods which record both quantitative and qualitative data from an object.

The need for a basic understanding of and basic research on the reflectance properties of the objects is thus evident. The main objective of the present study was to ascertain the possibility of differentiating some common forest site types of northern Finland on the basis of the radiation reflected by the ground vegetation and soil surface. In addition, there was an interest in studying and singling out in greater detail the factors affecting spectral reflectance and the shape of the spectral signature curve.

As far as soil is concerned, the objective was to gain insight into the reflectance properties of the humus and the A and B horizons of the associated podzolic soils of the same forest sites, and the background factors affecting these. The measurements of radiation were made using a specially constructed telespectroradiometer.

The study is part of research on forest sites being carried out at the Rovaniemi Research Station of the Forest Research Institute as well as part of a study of the forestry applications of remote sensing at the Land Use Laboratory of the Technical Research Center of Finland. The planning of the experiments and analysis of the samples was handled by Aulis Ritari. Pekka Saukkola's contribution included the carrying out of radiometric measurements and preliminary processing of the spectral data. Both authors conducted the analysis of results and the report.

Ilkka Aro assisted in the field measurements, the collection of samples and laboratory analyses. Pekka Välikangas and Kimmo Melamies assisted in measuring site data and doing computer calculations. The manuscript was read by Professors Sipi Jaakkola, Eino Mälkönen and Simo Poso and Tuomas Häme, Lic. For., with constructive criticism. The English text was checked by Richard Foley, B.A.

We thank all those involved with this study for their invaluable assistance.

# 2. BASIC PRINCIPLES OF SPECTRAL SIGNATURE

## 21. The electromagnetic spectrum

The totality of wavelengths of electromagnetic radiation is called the spectrum (Fig. 1). Electromagnetic radiation can be expressed using both a wave and a particle model. They are related to each other through the definition for the energy of a photon:

$$E = \frac{h\ c}{\lambda} \tag{1}$$

where h = Planck's constant, c = the speed of light and λ = wavelength. Thus the energy of electromagnetic radiation is directly related to frequency (c/λ) and inversely related to wavelength.

Wavelengths in the spectrum range in theory from zero to infinity; however, the most important wavelength ranges frequently used for image interpretation are the following:

(1) ultraviolet radiation 0.30—0.38 μm, (2) the range of visible light 0.38—0.72 μm, (3) reflecting infrared radiation 0.72—3 μm, (near-infrared radiation 0.72—1.3 μm) and (4) thermal infrared radiation 3—14 μm.

Of the above, visible and near-infrared radiation are in general use in aerial photography, and it is not possible to record radiation of longer wavelength on film; entirely different imaging systems must be employed.

In image interpretation, the objective may be recognized with the aid of several factors registered on the image through electromagnetic radiation, e.g., form/shape, size, structure, tone, shadows, surroundings etc. The significance of tone increases when (1) the geometrical resolution of the imaging system diminishes, and (2) images of the objective are available from many wavelength ranges providing different types of information. This is always the case in practice when one uses multispectral aerial photography, color-infrared photography (case 2) or images which have been taken with multispectral scanners and are originally in numerical form (cases 1 and 2).

## 22. The concept of spectral signature

A basic concept of interpretation, which is based either wholly or partially on tone, is spectral signature. The ISP working group VII-9 (Spectral signatures of objects) recommends the following definition (Sievers & Kriebel 1980): "In remote sensing spectral signature is a relative spectral energy distribution s(λ) of the radiation reflected or emitted by an object". It is completed by the definition in the International Lighting Vocabulary (International . . . 1970): "Relative spectral energy distribution — description of the spectral character of a radiation by the relative spectral distribution of some radiometric quantity". Spectral signature is usually described as the average value of radiation on a graph in which the

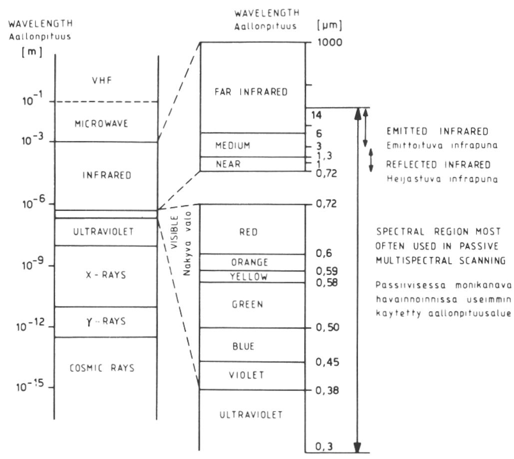



Fig. 1. The electromagnetic spectrum.
*Kuva 1. Sähkömagneettinen spektri.*

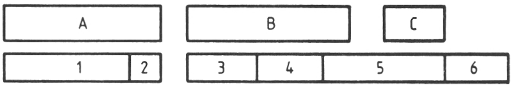



Fig. 2. Connection between field classes (letters indicate, for example, the site type) and the spectral classes (figures) obtained through the image interpreter.
*Kuva 2. Kuvatulkitsijan tavoittelemien informaatioluokkien, esimerkiksi kasvupaikkatyyppien (kirjaimet) ja spektristen luokkien (numerot), yhteys.*

x-axis is wavelength and the y-axis the reflectance factor. In normal image interpretation, the variation in spectral signatures for different surfaces is visible as a difference in the levels of the gray tones or colors. The key point for the spectral signature to be determined from the desired image surface is the radiation value or darkness vector of the image element, e.g.

— the darkness of the smallest distinguishable part of a pine crown in a black and white image (one wavelength channel)
— the radiation values for the stand of pines in one image element of the Landsat- satellite image (4 wavelength channels).

In order to determine the spectral signature from the individual reflectance values, the distribution of reflectance values representing the same surface is determined for each wavelength range. When the distribution is a normal one, the spectral signature of the surface can be represented as a matrix of averages and covariances for the reflectance values; this is generally used as an indicator of the spectral signature of a class in numerical pattern recognition methods (Jaakkola 1979). A condition for the use of the term "surface spectral signature" is that it represents all the image elements of a surface given with a moderate deviation. As a result, many field classes which are sufficiently informative for the user have no common spectral signature; rather, the field class is often divided into two or more spectral classes. On the other hand, different field classes may have identical spectral signatures, in which case they belong to the same spectral class (Fig. 2).

The possibility exists of using image interpretation based on spectral signature if (1) the spectral classes can be combined into field data classes adequate for the user or if (2) these spectral classes are in themselves sufficiently informative.

With a knowledge of the spectral signature for a given ground surface for as many points in time and as many wavelength channels as possible, one can

— determine whether the surface is distinguishable from certain other surfaces through image interpretation
— employ in imaging or in interpretation the wavelength ranges which either alone or combined best differentiate surfaces
— optimize the time for taking the images in order to maximize the distinguishability of a surface
— predict differences of tone for different types of surfaces in the images.

## 23. The measurement of spectral signature in the range of reflected radiation

The spectral signature can be measured with all imaging systems which record radiation from the ground objective on film or other material. In order to obtain spectral signature data under controlled conditions use is made of a spectroradiometer which is suitable for measurement of the properties of reflective radiation under both laboratory and field conditions. Fig. 3 presents the angles and terms connected with measurement work.

In remote sensing, the spectral signature is measured by determining the radiation departing into a cone tapering in a certain direction away from the the surface objective. As a result of this procedure, the measurement of the spectral signature in remote sensing is not measurement of total energy; the latter occurs when hemispherical reflectance from a surface is measured.

In order to take the irradiation circumstances into account, the reflected radiation is related to the incident radiation of the objective (this is not possible with emitted radiation). The incident radiation is determined with the aid of the reflection standard. An optimal reflection standard diffuses and reflects all radiation received in accordance with Lambert's cosine law. This type of theoretical standard is called the Lambert reflector (Monteith 1973, Bähr 1979). In practice, what is employed is a diffusing surface whose reflective properties are known; in this way incident radiation can be transformed into a perfect reflection using correction coefficients.

The reflectance factor R has been accepted as the unit of measure for the spectral signature in the cases of directed and conical reflection; this is adjusted for hemispherical reflectance. R is defined as follows (Radiometric . . . 1977): "Reflectance factor (at a representative element of a surface, for the part of the reflected radiation contained in a given cone with apex at the representative element of the surface, and for incident radiation of given spectral composition and geometrical distribution) is the ratio of the radiant (luminous) flux reflected in the directions delimited by the cone to that reflected in the same directions by a perfect diffuser identically irradiated (illuminated)." The reflectance factor is determined using the formula (parameters, see Fig. 3):

$$R(\lambda) = \frac{\int_{\Omega_r} L_{\lambda r}(\nu_r, \phi_r) \cos\nu_r d\Omega_r}{L_{\lambda w} \int_{\Omega_r} \cos\nu_r d\Omega_r} = \frac{\overline{L_{\lambda r}}(\Omega_r)}{L_{\lambda w}} \quad (2)$$

where $\nu_r$ and $\Phi_r$ denote the zenith angle and azimuth of reflection respectively. $L_r(\Omega_r)$ is the reflected radiance over the horizontal projection of the solid angle $\Omega_r$. $L_{\lambda w}$ is the reflected radiance of the perfect reflecting diffuser at wavelength $\lambda$. The reflectance factor is relative and thus dimensionless. Values in absolute units are not required of the measuring systems, but the response of the detector must be linear at different intensity levels. R is dependent on wavelength and it can be visualized on a graph in which the y-axis is reflectance and the x-axis wavelength.

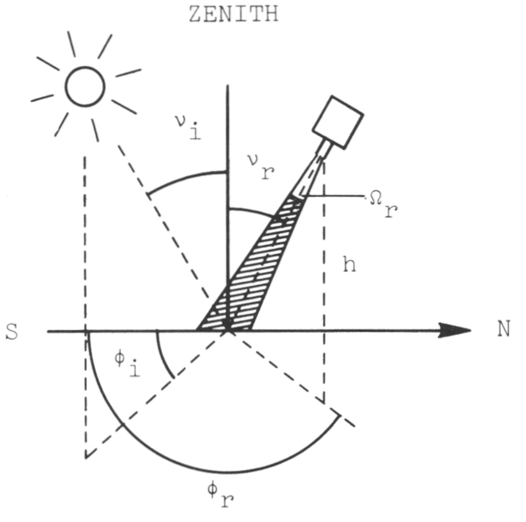



Fig. 3. The geometric parameters in the measurement of spectral signatures. Ω r is the viewing angle of the imaging system, h is the measurement height, νr is the zenith angle of reflected radiation, Φr is the azimuth angle of reflected radiation, νi is the zenith angle of the incoming radiation, Φi is the azimuth angle of the incoming radiation.

*Kuva 3. Ominaispektrimittauksen geometriset parametrit. Ω r on havainnointilaitteen avauskulma, h on mittauskorkeus, νr on heijastussäteilyn zeniittikulma, Φr on heijastussäteilyn atsimuuttikulma, νi on tulosäteilyn zeniittikulma, Φi on tulosäteilyn atsimuuttikulma.*

# 3. SPECTRAL PROPERTIES OF PLANTS AND SOIL

## 31. Plants

Transmission, reflection, absorption, emission and scattering of electromagnetic energy by any particular kind of matter are selective with regard to wavelength, and are specific for that particular kind of matter, depending primarily upon its atomic and molecular structure (Colwell 1969). Reflectance and transmittance of light from plants in the wavelength region 0,5—2,5 μm is influenced by at least three phenomena. At visible wavelengths to about 0,7 μm, chlorophyll and carotene absorption most strongly influence the magnitude of reflectance. The photosynthetic activity also uses energy absorbed in this part of the spectrum. At near-infrared wavelengths to 1,3 μm, in the absence of chlorophyll and carotene absorption, the physiological structure of plants (the number and structure of the cell walls and cavities in the leaf blades) results in high values of reflectance and transmittance. Beyond 1,3 μm absorption of electromagnetic radiation by water contained in plant tissue influences the magnitude of reflectance and transmittance and the internal leaf structure appears to be less important. Also, the presence of cellulose probably influences reflectance in the wavelengths (Myers 1970). The morphological characteristics of the leaves have been correlated, however, with the reflectance in the whole 0,5—2,5 μm spectral region (Gates 1970, Goillot 1980).

According to Gates (1970), scattering within the mesophyll cells produces nearly complete absorption over a narrow wavelength region in the red, although the absorption coefficients in the red are substantially less than in the blue. In addition, scattering closes the transmission gap in the green and broadens the absorption. The reflection of the green is generally relatively low (10 to 20 percent), but because of the enormous sensitivity of the human eye for green the eye sees light of this wavelength reflected with great contrast (Fig. 4).

The pigment and liquid-water absorption bands are physically very different. The pigment absorptions are caused by electron transition within the pigment molecular complexes. The liquid water absorptions are caused by transition of the vibrational and rotational states of the water molecules. Electron transitions require substantially higher energies than the vibrational-rotational transitions. Therefore the electronic absorption bands are in the ultraviolet and visible regions, and the vibrational-rotational absorption bands are in the long-wave infrared (Gates 1970).

The spectral reflectance of the leaves undergoes changes with the growth, maturation and senescence of the plants in the growing season. This can be seen as a change in the color caused by different internal or external factors. The change in the reflective properties can be affected by (1) a change in pigmentation, (2) a change in mesophyll cell structure, (3) a change in water content, and (4) a change in the surface coat of the leaf (Gates 1970). When studying the spectral signature of a mixed vegetation instead that of an individual leaf it is more difficult to estimate the amount of reflected radiation, although the basic form of the spectral signature still follows that of an individual leaf. The following factors, among others, affect the spectral signature of a mixed vegetation: imaging and illuminating angle, the number and configuration of leaves, other parts of the plants, the texture and coverage of plants, shadows and the background. The effect of these varies in the different wavelength ranges and has to be considered when discriminating different vegetation surfaces by their spectral signature (Goillot 1980, Hildebrandt 1976).

## 32. Mineral soil

As with the individual parts of plants and vegetation, one can enumerate for mineral soils a number of factors which affect the

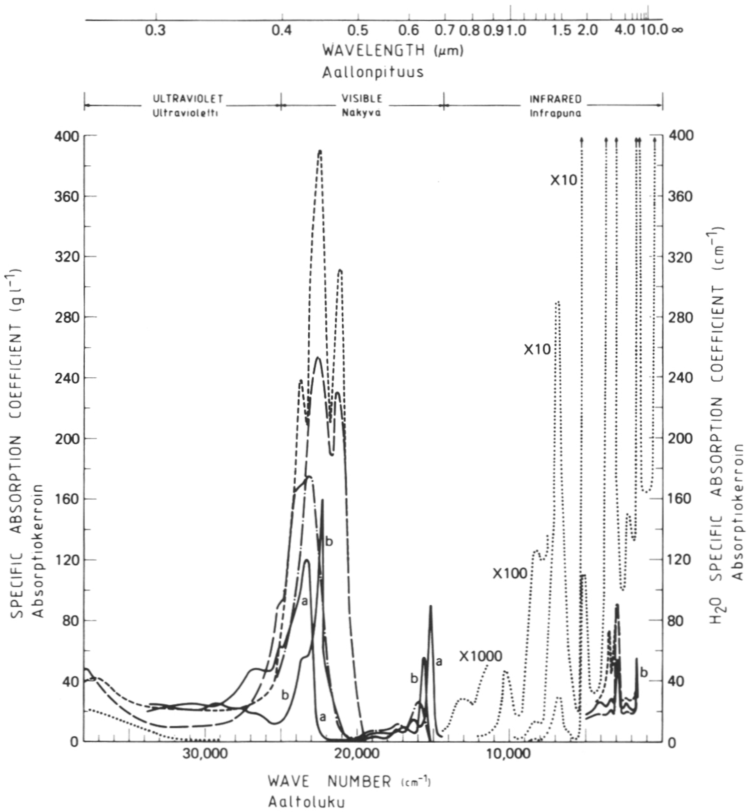



Fig. 4. Spectral absorption of some plant pigments and liquid water according to Gates (1970).
*Kuva 4. Eräiden kasvipigmenttien ja nestemuodossa olevan veden aiheuttama säteilyn absorptio Gates'in (1970) mukaan.*

spectral reflectance. The most important of these are: (1) the physical structure of the soil, (2) the amount and quality of the organic matter, (3) soil moisture, (4) mineralogy, (5) intensity and direction of incoming radiation and (6) the spectral band under inspection (cf. Crown 1977, Hunt 1977, Gerbermann & Neher 1979, Peterson et al. 1979, Stoner et al. 1980).

Reflected radiation is crucially dependent on the angle of incidence; this circumstance can be seen in Table 1. According to Coulson (1966) the intensity of radiation reflected by the vegetation in the range of visible light changes only slightly with a change in the angle of incidence. However, radiation reflected by mineral soil decreases more sharply when the angle of incidence departs from a vertical position with respect to the surface (cf. Kondratyev 1977, Boehnel et al. 1978).

When wetting a soil one can visually notice its darkening. This is caused by the increasing scatter of the light inside a water-film on a soil particle (Planet 1970). In moist soil the intensity of reflected radiation decreases most noticeably in the near infrared part of the spectrum and in the wavelengths where the energy of the incoming radiation equals the demands of vibrational-rotational transitions of the water molecules (cf. Fig. 4). Due to many interactions the physical explanation of the correlation between the reflected radiation and the properties of the reflective surface meets with several difficulties and the standardization of study conditions is needed.

Often the organic matter in the soil most

Table 1. Short-wavelength albedo as a function of solar zenith angle (Sellers 1965).
*Taulukko 1. Lyhytaaltoisen säteilyn albedo auringon zeniittikulman funktiona (Sellers 1965).*

| Surface — *Pinta* | 40° | 50° | 60° | 70° | 80° | 90° |
|---|---|---|---|---|---|---|
| Dry sand — *Kuiva hiekka* | 35 | 41 | 51 | 63 | 81 | 100 |
| Wet sand — *Märkä hiekka* | 26 | 28 | 33 | 43 | 60 | 100 |
| Moving water — *Liikkuva vesi* | 7 | 10 | 16 | 26 | 47 | 100 |

strongly affects the reflected radiation in the region of visible light. The quality of the organic matter, however, is most important. Organic matter can also mask the effect of other substances, e.g. ferroxides (Shields et al. 1968, Crown 1977, Krishnan et al. 1982).

The height of the surface, size of particles, impurities, dust and dew on particles, etc. have an effect on the intensity of the reflected radiation. The brightness of small shaded areas may, for example, be only one tenth that of the radiation intensity for objectives in sunlight. Deep cracks in the surface reflect radiation even less (Idso et al. 1975, Myers 1975). In general, the addition of fine particles causes an increase in the intensity of radiation reflected by the soil (Orlov 1966, Gerbermann & Neher 1979).

The influence of clay minerals on the nature of reflected radiation in the area of visible light is dependent on their specific absorption. The optimal wavelength range for detecting the presence of minerals is 0.8—1.4 μm, the characteristic range of vibration for Si-0 minerals (Coblenz 1962, Stepanov 1974, Hunt 1977). Different forms of iron oxides may impart red and yellow colors to soils as a result of absorption taking place in the near infrared range of the spectrum (Stepanov 1974, Stoner et al. 1980). Of the chemical indicators of soil fertility the cation exchange capacity has been observed in some studies as correlating with spectral reflectance. In fact a hypothesis has been advanced that, in a sense, cation exchange capacity integrates the effect of the factors which comprise it (Ca, Mg, K, Na, exhangeable acidity) (Montgomery & Baumgardner 1974, Stoner et al. 1980).

The information contained in reflected radiation has been used for a long time, e.g., in the X-ray and IR-analytic studies of clay minerals. However, there is still work to be done on the utilization of the entire electromagnetic spectrum inasmuch as we are dealing with a material as diverse as soil.

# 4. MATERIAL AND METHODS

## 41. Test area and procedures

The study material was collected at the end of July from experiment areas located within 50 km of the city of Rovaniemi (Fig. 5). The goal was to obtain representative samples of the forest floor and topsoil for four forest site types common in northern Finland, samples which would also represent midsummer conditions. The site types were the following: (1) damp site, (2) sub-dry site, (3) dry site and (4) barren site. The forest site types were named using terminology defined by the forest vegetation zone in question (cf. Lehto 1978) (Table 2).

Table 3 presents the frequencies of plant species in the ground vegetation as based on the sample material; it also shows the average coverage values for different sites and the most common colors of different plant species.

The sample material was removed in 25 × 40 cm patches such that the surface vegetation and humus samples of each site were taken systematically from four experimental plots established in each stand. The sample plots were located in the corners and the center of a 10 × 10 meter square. Soil samples (8 per site) were taken from the center of the experimental plot from the A and B horizons of the podzol solum.

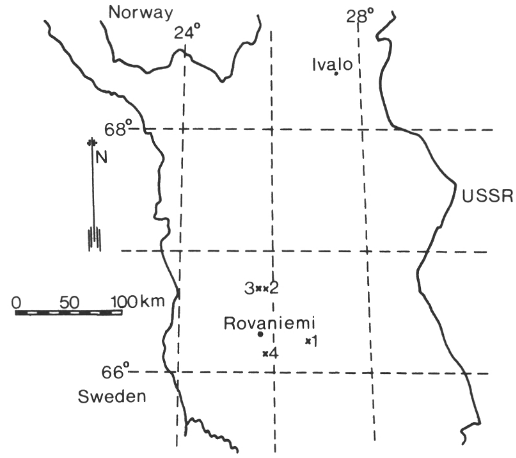



Fig. 5. Location of the experimental areas.
*Kuva 5. Koealueiden sijainti.*

Table 2. General data on the experiment areas and corresponding forest site types.
*Taulukko 2. Koealueiden yleistietoja sekä vastaavat metsätyypit.*

| General data<br>*Yleistietoja* | Experiment area — *Koealue*<br>1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Location<br>*Sijainti* | 26°42′ E<br>66°19′ N | 25°53′ E<br>66°56′ N | 25°44′ E<br>66°56′ N | 26°03′ E<br>66°15′ N |
| Height, m asl.<br>*Korkeus, m mpy.* | 260 | 250 | 230 | 180 |
| Slope<br>*Kaltevuus°* | 10 | 3 | 4 | 0 |
| Species composition<br>*Puulajisuhteet* (1/10) | | | | |
| Scots pine — *mänty* | — | 6 | 10 | 10 |
| Norway spruce — *kuusi* | 9 | 2 | — | — |
| Birch — *koivu* | 1 | 2 | — | — |
| Basal area<br>*ppa $m^2/ha$* | 18 | 19 | 13 | 10 |
| Mean height<br>*Keskipituus, m* | 15 | 15 | 16 | 13 |
| Timber volume<br>*Kuutiomäärä, $m^3/ha$* | 130 | 120 | 110 | 80 |
| Age of stand<br>*Puuston ikä, v* | 150 | 200 | 200 | 170 |
| Crown cover<br>*Latvuston peittäv. %* | 30 | 30 | 25 | 20 |
| Site<br>*Kasvupaikka* | Damp site | Sub-dry site | Dry site | Barren site |
| Forest site type<br>*Metsätyyppi* | *Hylocomium-Myrtillus*<br>(HMT) | *Empetrum-Myrtillus*<br>(EMT) | *Myrtillus-Calluna-Cladina*<br>(MCClT) | *Cladina*<br>(ClT) |

Table 3. The frequency and the mean coverages of plant species in the ground vegetation and litter with their standard errors on different sites. The table also includes the dominating colors for different plant species and litter; these were determined visually employing the Munsell-scale.

*Taulukko 3. Pintakasvillisuuden kasvilajien sekä karikkeen frekvenssit ja keskimääräiset peittävyysarvot keskivirheineen eri kasvupaikoilla. Taulukkoon on merkitty myös eri kasvilajien ja karikkeen yleisimmät silmävaraisesti määritetyt värit Munsell-asteikkoa käyttäen.*

| Plant species and litter — *Kasvilaji ja karike* | Site 1 (HMT) Frequency *Frekvenssi* | Site 1 (HMT) Coverage *Peittävyys* | Site 2 (EMT) Frequency *Frekvenssi* | Site 2 (EMT) Coverage *Peittävyys* | Site 3 (MCCIT) Frequency *Frekvenssi* | Site 3 (MCCIT) Coverage *Peittävyys* | Site 4 (CIT) Frequency *Frekvenssi* | Site 4 (CIT) Coverage *Peittävyys* | Munsell color (most common) *Yleisin väri* |
|---|---|---|---|---|---|---|---|---|---|
| *Pinus sylvestris* | — | — | — | — | 25 | 0,9 ± 0,4 | 28 | 0,03 ± 0,03 | 7,5 GY 5/6 |
| *Calluna vulgaris* | — | — | 43 | 3,6 ± 1,0 | 90 | 25,6 ± 2,9 | 20 | 1,2 ± 0,8 | 5 GY 6/8 |
| *Empetrum nigrum* | 20 | 2,4 ± 1,0 | 95 | 12,3 ± 1,2 | — | — | — | — | 5 GY 5/8 |
| *Vaccinium myrtillus* | 100 | 31,9 ± 1,9 | 98 | 18,2 ± 1,4 | 30 | 0,7 ± 0,3 | — | — | 5 GY 5/8 |
| *Vaccinium vitis-idaea* | 45 | 0,7 ± 0,3 | 95 | 8,2 ± 0,9 | 70 | 3,0 ± 0,7 | 50 | 2,9 ± 0,9 | 7,5 GY 4/6 |
| *Vaccinium uliginosum* | — | — | 13 | 0,6 ± 0,3 | — | — | — | — | |
| *Deschhampsia flexuosa* | 83 | 1,9 ± 0,6 | 28 | 0,03 ± 0,03 | — | — | — | — | 5 GY 5/8 |
| *Trientalis europaea* | 5 | 0,03 ± 0,03 | — | — | — | — | — | — | |
| *Maianthemum bifolium* | 15 | 0,03 ± 0,13 | — | — | — | — | — | — | 5 GY 6/8 |
| *Lycopodium annotinum* | 3 | 0,03 ± 0,03 | 3 | 0,03 ± 0,03 | — | — | — | — | |
| *Melampyrum pratense* | 10 | 0,10 ± 0,05 | — | — | — | — | — | — | |
| *Polytrichum commune* | 18 | 0,5 ± 0,4 | 35 | 0,5 ± 0,2 | 70 | 0,4 ± 0,1 | 75 | 0,6 ± 0,3 | 5 GY 6/8 |
| *Pleurozium schreberi* | 100 | 30,5 ± 3,6 | 100 | 27,9 ± 2,4 | 35 | 1,9 ± 1,0 | — | — | 5 GY 6/8 |
| *Hylocomium splendens* | 58 | 3,9 ± 0,8 | 3 | 0,02 ± 0,03 | — | — | — | — | 5 GY 5/6 |
| *Hepaticae sp.* | 20 | 2,1 ± 0,9 | 13 | 0,5 ± 0,2 | — | — | — | — | 5 GY 6/6 |
| *Peltigera aphthosa* | — | — | 8 | 0,1 ± 0,07 | — | — | — | — | 5 GY 7/6 |
| *Cetraria islandica* | — | — | 3 | 0,03 ± 0,03 | — | — | 13 | 0,1 ± 0,1 | 2,5 GY 2/8 |
| *Cladonia alpestris* | — | — | 35 | 0,4 ± 0,2 | 100 | 20,5 ± 1,6 | 100 | 27,4 ± 1,7 | 2,5 GY 2/8 |
| *Cladonia sp.* | — | — | — | — | 68 | 0,03 ± 0,03 | 43 | 0,1 ± 0,1 | 2,5 GY 2/8 |
| Calluna's brown steam *Kanervan ruskea varsi* | — | — | 5 | 0,08 ± 0,06 | 60 | 6,9 ± 1,3 | 38 | 4,4 ± 1,2 | 5 YR 3/2 |
| Empetrum's brown stem *Variksenmarjan ruskea varsi* | 3 | 0,05 ± 0,05 | 40 | 1,8 ± 0,5 | — | — | — | — | 5 YR 3/2 |
| Needles (litter) — *Neulaset (karike)* | 40 | 1,7 ± 0,5 | 68 | 1,8 ± 0,5 | 95 | 12,9 ± 1,5 | 95 | 30,9 ± 1,4 | 5 YR 4/6 |
| Leaves (litter) — *Lehdet (karike)* | 98 | 14,0 ± 2,2 | 100 | 10,9 ± 1,7 | 53 | 3,5 ± 0,5 | 8 | 1,6 ± 0,3 | 7,5 YR 5/4 |
| Other (branches, bark, cones) *Muu (oksat, kuoret, kävyt)* | 30 | 1,4 ± 0,5 | 63 | 4,0 ± 1,1 | 70 | 5,3 ± 0,8 | 100 | 23,6 ± 1,5 | 5 YR 3/2 |

Table 4. The measured properties related to soil horizons.
*Taulukko 4. Maan ominaisuuksia horisonteittain.*

| Site *Alue* | Horizon *Hori-sontti* | Thickness (cm) *Paksuus (cm)* x̄ | ± | Moisture (%) (field capacity) *Kosteus (%) (kenttäkapasiteetti)* x̄ | ± | pH ($H_2O$) x̄ | ± | pH ($CaCl_2$) x̄ | ± | E.C. x 10 μS x̄ | ± | Color, moist *Väri, kostea* Hue *Värisävy* | Value *Varj.* | Chroma *Tiheys* | Color, dry *Väri, kuiva* Hue *Värisävy* | Value *Varj.* | Chroma *Tiheys* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | L | 0,6 | 0,03 | | | | | | | | | | | | | | |
| | FH | 2,4 | 0,1 | | | 4,3 | 0,2 | 3,4 | 0,2 | 5,3 | 0,6 | | | | | | |
| | A | 11,0 | 1,8 | 12,2 | 1,2 | 4,7 | 0,6 | 3,7 | 0,4 | 2,0 | 0,3 | 10 YR-5 Y | 5—6 | 1—2 | 10 YR-2,5 Y | 7—8 | 1 |
| | B | 10,5 | 3,6 | 25,1 | 5,1 | 5,3 | 0,4 | 4,6 | 0,7 | 1,6 | 0,1 | 5 YR-10 YR | 4—5 | 4—6 | 10 YR | 6—7 | 6 |
| 2 | L | 0,6 | 0,04 | | | | | | | | | | | | | | |
| | FH | 4,0 | 0,1 | | | 4,2 | 0,3 | 3,3 | 0,2 | 5,0 | 0,5 | | | | | | |
| | A | 9,5 | 2,2 | 11,2 | 2,5 | 4,6 | 0,6 | 3,7 | 0,8 | 2,0 | 0,5 | 10 YR-5 Y | 5—7 | 1—2 | 7,5 YR-10 YR | 7—8 | 1 |
| | B | 8,5 | 0,5 | 7,5 | 2,0 | 5,3 | 1,3 | 4,7 | 1,0 | 1,2 | 0,2 | 10 YR | 4—5 | 6—8 | 10 YR | 6—7 | 4—6 |
| 3 | L | 0,5 | 0,03 | | | | | | | | | | | | | | |
| | FH | 1,1 | 0,1 | | | 4,3 | 0,3 | 3,4 | 0,3 | 4,2 | 0,4 | | | | | | |
| | A | 3,8 | 0,9 | 10,4 | 1,7 | 4,8 | 2,2 | 3,8 | 1,9 | 2,1 | 0,8 | 10 YR-2,5 Y | 6—7 | 1 | 10 YR-2,5 Y | 7 | 1 |
| | B | 8,5 | 1,3 | 21,6 | 4,3 | 5,0 | 2,1 | 4,1 | 3,6 | 1,1 | 0,1 | 7,5 YR-10 YR | 4 | 4—6 | 10 YR | 6 | 4—6 |
| 4 | L | 0,7 | 0,1 | | | | | | | | | | | | | | |
| | FH | 1,3 | 0,1 | | | 4,2 | 0,3 | 3,3 | 0,2 | 5,4 | 0,4 | | | | | | |
| | A | 6,5 | 0,9 | 5,2 | 0,6 | 4,8 | 0,8 | 3,5 | 0,8 | 1,6 | 0,4 | 10 YR-2,5 Y | 7 | 1 | 5 Y | 7 | 1 |
| | B | 22,3 | 1,9 | 11,0 | 2,6 | 5,1 | 0,7 | 4,7 | 0,8 | 1,5 | 0,1 | 10 YR | 5 | 4—8 | 10 YR-2,5 Y | 6 | 2—4 |

| Site *Alue* | Horizon *Horisontti* | L.I.% x̄ | ± | N% x̄ | ± | Ca%×$10^{-1}$ x̄ | ± | K%×$10^{-1}$ x̄ | ± | Mg%×$10^{-1}$ x̄ | ± | P%×$10^{-1}$ x̄ | ± | Fe%×$10^{-1}$ x̄ | ± | Al%×$10^{-1}$ x̄ | ± | Mn%×$10^{-1}$ x̄ | ± | Si%×$10^{-1}$ x̄ | ± |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | L | 92,8 | 0,5 | 1,16 | 0,04 | 4,32 | 0,28 | 2,34 | 0,06 | 0,74 | 0,03 | 0,66 | 0,02 | 0,47 | 0,03 | 0,42 | 0,05 | | | | |
| | FH | 88,9 | 1,6 | 1,12 | 0,05 | 3,07 | 0,17 | 0,90 | 0,05 | 0,56 | 0,02 | 0,52 | 0,02 | 0,89 | 0,10 | 1,39 | 0,49 | | | | |
| | A | 3,0 | 0,4 | 0,04 | 0,00 | 0,23 | 0,09 | 0,18 | 0,02 | 0,31 | 0,09 | 0,03 | 0,00 | 2,75 | 0,15 | 2,84 | 1,64 | 0,14 | 0,02 | 1,28 | 0,12 |
| | B | 11,6 | 1,6 | 0,07 | 0,01 | 0,63 | 0,06 | 0,19 | 0,02 | 1,79 | 0,08 | 0,26 | 0,05 | 13,31 | 0,11 | 13,66 | 1,24 | 0,71 | 0,15 | 3,91 | 0,36 |
| 2 | L | 95,1 | 0,4 | 0,88 | 0,05 | 3,64 | 0,27 | 2,15 | 0,11 | 0,81 | 0,02 | 0,47 | 0,03 | 0,35 | 0,04 | 0,79 | 0,49 | | | | |
| | FH | 93,6 | 0,6 | 1,11 | 0,03 | 2,71 | 0,17 | 0,95 | 0,06 | 0,57 | 0,02 | 0,48 | 0,02 | 0,67 | 0,06 | 0,70 | 0,04 | | | | |
| | A | 2,6 | 0,2 | 0,03 | 0,00 | 0,22 | 0,02 | 0,14 | 0,01 | 0,17 | 0,02 | 0,01 | 0,00 | 5,91 | 3,57 | 5,32 | 2,56 | 0,06 | 0,02 | 0,95 | 0,06 |
| | B | 7,2 | 1,2 | 0,05 | 0,01 | 0,53 | 0,05 | 0,22 | 0,04 | 1,28 | 0,11 | 0,33 | 0,06 | 14,31 | 1,89 | 13,50 | 1,00 | 0,37 | 0,03 | 4,13 | 0,11 |
| 3 | L | 87,9 | 1,2 | 0,81 | 0,04 | 2,74 | 0,09 | 1,23 | 0,06 | 0,52 | 0,02 | 0,36 | 0,01 | 1,14 | 0,13 | 0,94 | 0,09 | | | | |
| | FH | 48,3 | 2,7 | 0,65 | 0,04 | 1,32 | 0,08 | 0,48 | 0,03 | 0,46 | 0,05 | 0,25 | 0,01 | 3,05 | 0,29 | 2,10 | 0,15 | | | | |
| | A | 5,6 | 1,2 | 0,30 | 0,00 | 0,23 | 0,04 | 0,13 | 0,01 | 0,16 | 0,03 | 0,01 | 0,01 | 2,31 | 0,36 | 2,86 | 1,72 | 0,10 | 0,10 | 1,10 | 0,09 |
| | B | 5,0 | 0,4 | 0,03 | 0,00 | 0,66 | 0,12 | 0,42 | 0,05 | 1,78 | 0,11 | 0,77 | 0,12 | 13,56 | 0,74 | 10,13 | 0,63 | 0,72 | 0,04 | 3,26 | 0,06 |
| 4 | L | 84,1 | 1,8 | 0,81 | 0,02 | 2,44 | 0,12 | 0,85 | 0,04 | 0,36 | 0,02 | 0,25 | 0,01 | 1,02 | 0,10 | 0,86 | 0,11 | | | | |
| | FH | 57,0 | 3,3 | 0,71 | 0,04 | 1,62 | 0,10 | 0,41 | 0,02 | 0,29 | 0,03 | 0,22 | 0,01 | 1,41 | 0,12 | 1,20 | 0,06 | | | | |
| | A | 2,2 | 0,2 | 0,02 | 0,00 | 0,24 | 0,02 | 0,10 | 0,02 | 0,20 | 0,05 | 0,01 | 0,00 | 1,54 | 0,17 | 0,80 | 0,09 | 0,10 | 0,01 | 0,93 | 0,06 |
| | B | 3,2 | 0,8 | 0,02 | 0,01 | 0,48 | 0,02 | 0,16 | 0,05 | 2,23 | 0,33 | 0,30 | 0,05 | 9,69 | 1,18 | 8,06 | 0,99 | 0,98 | 0,17 | 3,12 | 0,24 |

Table 4 presents site-by-site averages for the measured physical and chemical properties of the podsolic soil horizons. The particle size distribution determined from the A and B horizons of mineral soil is presented in Fig. 6.

The goal of the experimental layout was not to study any wider areal variation in the characteristics being measured; for this reason, the experiment plots were placed in locations subjectively chosen with representative surface vegetation in experimental stands, taking care that there were no crown projections of trees on the plot. In Fig. 7 examples of vegetation and humus samples taken from different sites can be seen.

Measurements with the spectroradiometer were made at Rovaniemi shortly after the collection of samples. Measurements were taken both in the laboratory under artificial light and outdoors in sunlight. Vegetation and humus samples were measured with their surfaces both dry and wet and soil samples at field moisture capacity as well as moistened and oven dried (105° C).

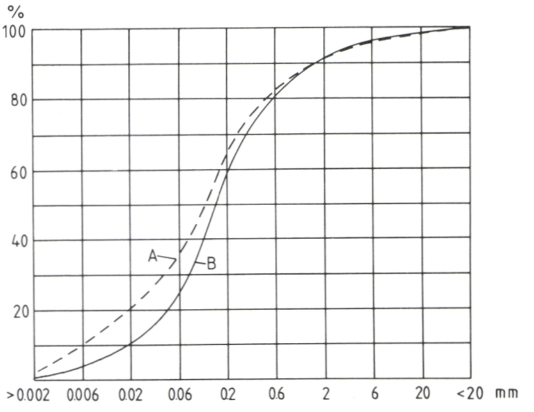



Fig. 6. The particle size distribution for the mineral soil of the A and B horizons.
*Kuva 6. Kivennäismaan A- ja B-horisonttien lajitekoostumus.*

## 42. The telespectroradiometer and its use

The spectroradiometer system used for measuring the reflected radiation from the sample material is composed of parts from several manufacturers (Fig. 8). The operational principle of the system is as follows:

1. The lens collects the incoming radiation and directs it into the aperture of the monochromator.
2. The diffraction grating serving as a monochromator disperses the incoming radiation into different wavelengths.
3. The radiation at the wavelength channel (20 nm) delimited by the aperture of the monochromator is directed to a detector in which the incident radiation is converted to a corresponding electrical signal.
4. From the detector, the electrical signal is fed into the radiometer, which converts it into a digital one. (The change of wavelength takes place in that the stepping motor in the monochromator is continuously turning a grating; the radiation being measured is thus a moving average of the 20 nm channel).
5. As the stepping motor turns the grating over the selected wavelength range the cassette recorder in the radiometer takes samples of the digital radiation values at the desired intervals (10 nm) and records these on a C cassette when the measurement ends along with manually coded data. (For example, for the wavelength range 400—1000 nm, 60 radiation measurements are obtained at 10 nm intervals. The spectral measurement of the range and the recording thereof takes 16.5 sec.).

The system measures the radiation reflected from the area surface at a spherical angle tapering in the direction of the optical element; it is sensitized for wavelengths of visible light and reflected infrared (400—1200 nm). The configuration of the measurement system is presented in Fig. 9.

The geometrical parameters in the measurement were the following (see Fig. 3): viewing angle of the device 0,18 (radians), the zenith angle of the reflected radiation 0°, the zenith angle of incoming radiation 45°, length of a side of a square field element 16 cm, and measurement height 90 cm.

The properties of the central sections of the field element to be measured affect the radiation flux into the detector more than do the properties of the edges; this is due the diffraction and absorption which takes place on the edges of the monochromator aperture. The spectral distribution of the intensity of the radiation of the light source used in laboratory measurements is presented in Table 5. From the standpoint of the light source the least reliable range is that of short wavelengths, one in which the radiation intensity of the lamp is weakest.

In measurements both outdoors and indoors, the proportion of direct, focused illumination in the total irradiation was 85—88 %. The diffuse light outdoors was the result of the normal scattering caused by clouds and the atmosphere and indoors the effect of radiation reflected from walls and ceilings.

Barium sulfate was used as the reflection standard; its properties are quite close to those of an ideal Lambert reflector. It reflects approx. 97.5 % of incident radiation over the wavelength range of 400—1000 nm.

The order of measurement of samples and reflection standard was the following both outdoors and indoors:

.
.
.
sample n
reflection standard
sample n+1
sample n+2
reflection standard
sample n+3
.
.
.

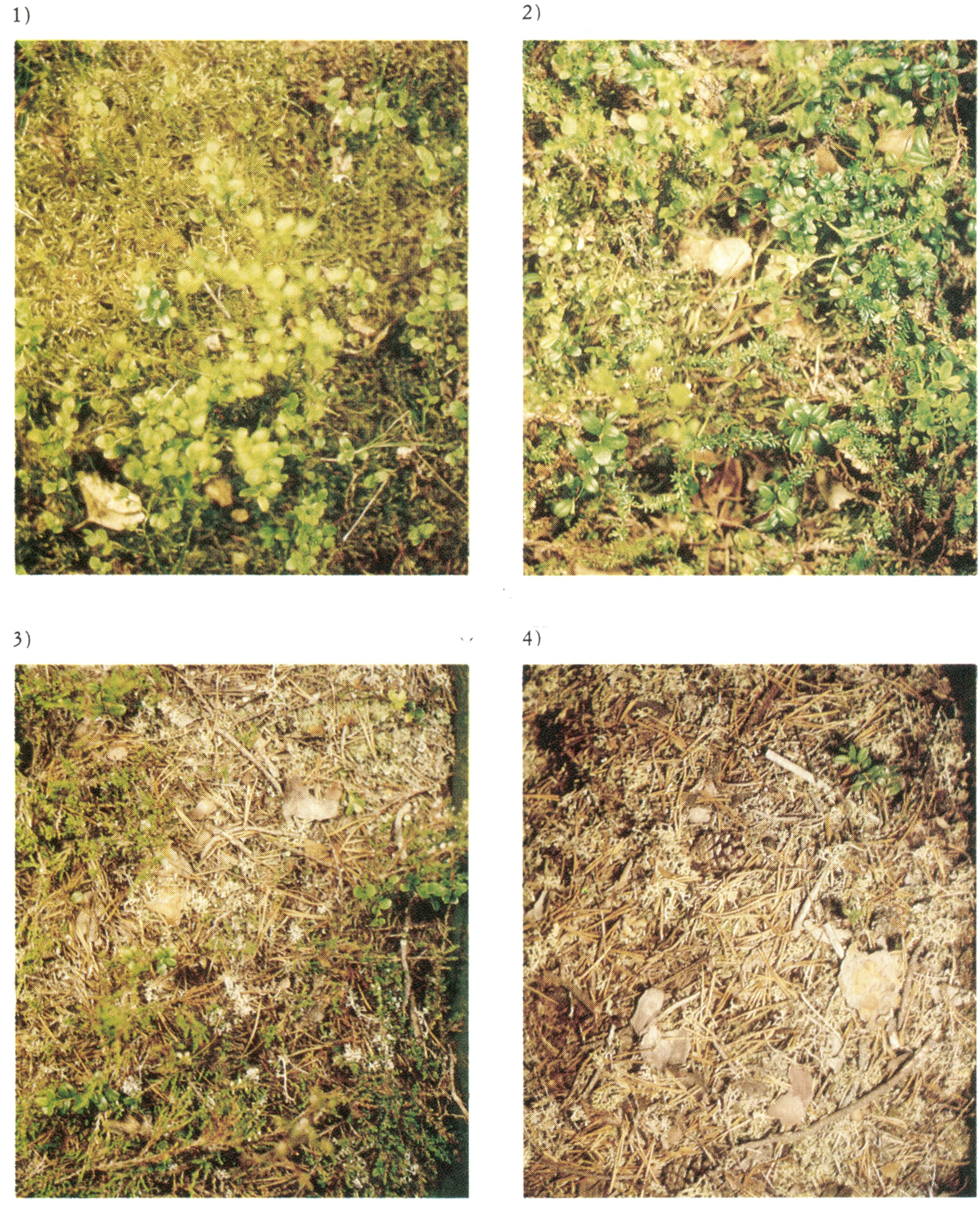



Fig. 7. Samples from different sites (1=HMT, 2= EMT, 3=MCClT, 4=ClT).
*Kuva 7. Eri kasvupaikoilta otettuja näytteitä (1=HMT, 2=EMT, 3=MCClT, 4=ClT).*

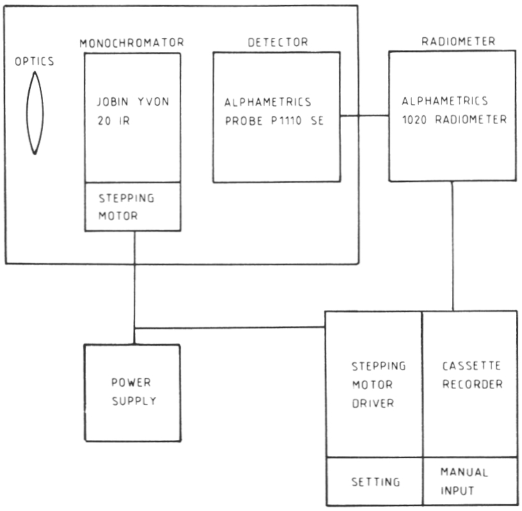



Fig. 8. Block diagram of the telespectroradiometer system used in the study. The system is both AC- and DC-compatible.
*Kuva 8. Kaavio spektroradiometrilaitteesta. Laite toimii sekä vaihto- että tasavirralla.*

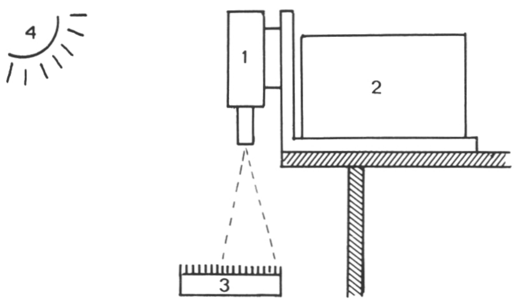



Fig. 9. Carrying out measurements: 1) the optics of the system, monocromator and detector, 2) the radiometer and cassette redorder, 3) objective (sample or reflection standard), 4) light source.
*Kuva 9. Mittauksen toteutus: 1) laitteiston optiikka, monokromaattori ja ilmaisin, 2) radiometriyksikkö ja spektritallennin, 3) kohde (näyte tai heijastusstandardi), 4) valonlähde.*

Table 5. The relative distribution of the intensity of radiation for the lamp (Photolita 220 V 500 W-227, type PF 2182/49) used as light source in the wavelength range under study.
*Taulukko 5. Valonlähdelampun (Photolita 220 V 500 W-227, type PF 2182/49) säteilyn intensiteetin suhteellinen jakauma käytetyllä aallonpituusalueella.*

| **Wavelength** — *Aallonpituus, (nm)* | Relative intensity — *Suhteellinen intensiteetti* |
|---|---|
| 400 | 5 |
| 500 | 38 |
| 600 | 75 |
| 700 | 100 |
| 800 | 88 |
| 900 | 84 |
| 1000 | 76 |

The radiance of the standard for the exact time of the sample measurement was interpolated from the standard measurements before and after each sample measurement.

## 43. Analyses in the laboratory

### *431. Vegetation and humus*

The frequencies and coverage values of different plant species were determined from radiation measurement elements 14 × 14 cm in size; there were 40 such elements per site altogether. Coverages were recorded with an accuracy of 1 %. The same determinations were made for needle and leaf litter, bare mineral soil and other material (branches, cones and bark). In addition, measurements were taken of the height of dwarf shrubs and the thickness of the moss and lichen layer. Visual determination using a color chart was made of the most common color of different plant species (Munsell . . . 1963).

Chemical nutrient analyses were made separately for the ground vegetation and litter (L horizon) as well as for the humus layer (FH horizon); the total number of samples per site was 20. The analysis included the following: pH (water and 0,1 N $CaCl_2$ suspensions), electrical conductivity ($\mu S/cm$), loss on ignition (L. I., 550° C), total nitrogen (Kjeldahl method), potassium, calcium and magnesium, iron and aluminium (extraction with 2 N HCl, analysis by AAS), phosphorus (extraction with 2 N HCl, analysis by the molybdate-hydrazine method) (For details, see Kungl . . . 1965, Halonen et al. 1983). Concentrations of different elements were reported as percentages of dry weight.

### *432. Mineral soil*

The mineral soil samples comprised the eluviated light A horizon and the reddish brown illuviated B horizon of the podsolic soils. For each sample (32 in all), color was determined visually both moist and dry using a color chart (Munsell . . . 1954). The particle size distribution was determined by sieving and by the pipette method (for particles smaller than 0.06 mm) (Elonen 1971). Gravimetric soil moisture content at field capacity (—0.33 bar) was measured using a pressure plate extractor (Richards 1948). The pH, electrical conductivity, loss on ignition, total nitrogen, potassium, calsium, magnesium, manganese, phosphorus, iron and aluminium contents were determined employing the same methods as for the plant and humus samples. In addition manganese and silicon-contents were determined from 2 N HCl extract by AAS.

## 44. Data analysis

The radiation and field data were treated as shown in Fig. 10. The observations were transferred to the disk memory of a computer from a cassette recorder. The data in the disk file were corrected using a program written for checking. The procedure included thinning the data from 60 reflectance values to 30 in the range 400 to 1000 nm to correspond to the 20 nm resolution of the original measuring device. The so-called second order effect was eliminated as well.

At the same time, reflectance factors for 20 nm and 100 nm-wide channels were calculated. These were in the form of the ratio between the spectral reflectance of the object and the interpolated spectral reflectance of the reflectance standard at the time of measurement (cf. 23.). Observations could be checked by a visual examination of the curves drawn by a drum plotter.

The statistical analysis comprised the following steps:

— the statistics of the stratified data were calculated
— tests were made as to whether the observations in the strata belonged to the same populations using the parameter-free Mann-Whitney U-test (Wenderoth et al. 1965)
— the linear correlations of the reflectance factors with the various data from the samples were calculated
— the dependency between reflectance factors and certain site characteristics was studied using a multiple regression analysis (Snedecor & Cochran 1968).

The significance of the statistical test values (p= probability that the value is 0) was indicated as follows:

*** probability level 0,001
** „ „ 0,01
* „ „ 0,05.

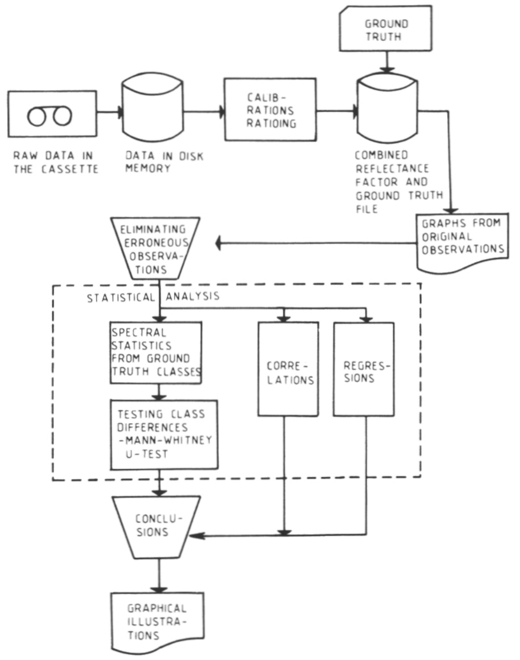



Fig. 10. Block diagram of the preprocessing, statistical analysis and plotting of the spectral measurements.

*Kuva 10. Kaavio spektrihavaintojen esikäsittelystä, tilastollisesta analyysista ja tulosten esittämisestä.*

The results were represented graphically as spectral signature curves and figures in which the correlation coefficients were presented, arranged according to wavelength, for each variable pair showing a statistically significant correlation. In calculations the antilog values of pH, i.e. the H+ ion concentrations (cH), were used.

# 5. RESULTS

## 51. Spectral signature of the ground vegetation and ground surface of the forest sites

Fig. 11 presents the spectral signature averages in 20 nm channels over the 500—1000 nm wavelength range for the surface vegetation and the soil surface of the four different forest sites examined in this study. The measurements in Fig. 11a were made under artificial light with the samples in normal moisture (dry surface); Fig. 11b under artificial light after moistening; Fig. 11c in sunlight with the samples in normal moisture. The high reflectance factor value (R) reveals the relative lightness of the objective as compared with surfaces having low reflectance; these appear darker in the image.

The site types ClT and MCClT (see Table 2) were clearly distinguished from HMT and EMT in the wavelength range 750—1000 nm. HMT and EMT were also different as to spectral signature in this range. In the same range the differences between ClT and MCClT were at their smallest. The standard deviations presented in Fig. 12 are rather large, a circumstance arising mainly from variation in the texture of the vegetation surfaces and from shadows. Each site type had its own characteristic spectral signature curve which recurred in all measurements. ClT and MCClT differed from each other most in the range of green and red light (550—700 nm).

The results of measurements taken under artificial light (Fig. 11a) and in sunlight (Fig. 11c) turned out to be very similar. In the values obtained in measurements made in sunlight, however, some systematic instability can be seen in the infrared range (800—1000 nm), obviously a result of the

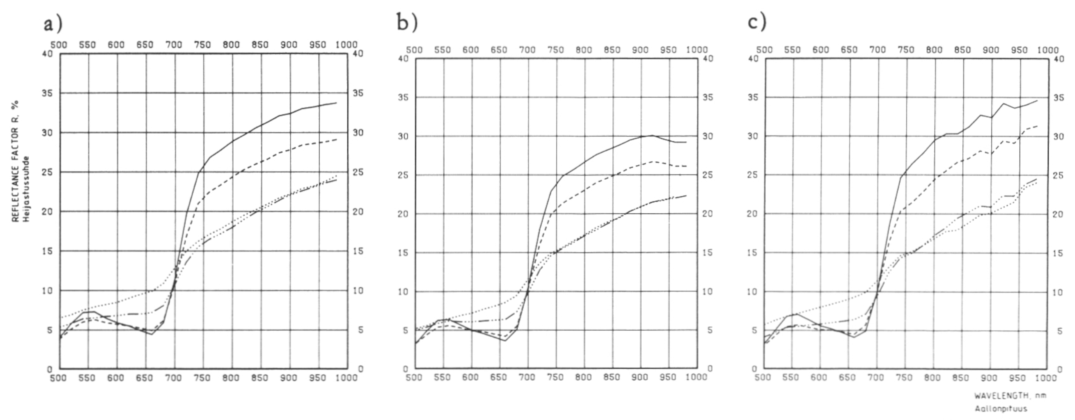



Fig. 11. Averaged spectral signatures of ground vegetation and ground surface of four mineral soil sites in northern Finland. The measurements were carried out in midsummer (a) in artificial light and samples in normal moisture conditions, (b) in artificial light, samples moistened and (c) in sunlight in normal moisture conditions.

*Kuva 11. Neljän Pohjois-Suomen kangasmaan kasvupaikan pohjakasvillisuuden ja maanpinnan ominaissäteilykeskiarvot aallonpituuden funktiona. Mittaukset suoritettu keskikesällä (a) keinovalossa näytteet normaalikosteudessa, (b) keinovalossa näytteet kasteltuina ja (c) auringonvalossa näytteet normaalikosteudessa.*

absorption of the atmosphere.

Irrigation (comparable with the effect of rain or dew) caused a 2—3 % systematic drop in the reflectance values, primarily in the infrared range. At a wavelength of approx. 920 nm, the rise in the spectral signature curve slowed or the curve began to turn downward. The phenomenon was the result of the absorption of radiation by the water film and it has relatively more significance for the spectral signature values of moist upland sites than for drier ones.

The determination of whether the samples collected from the different sites belong to the same population was made using the Mann-Whitney U-test. Corresponding calculations were made for certain ratios of wavelength channels as well. The wavelength ranges of the channels correspond to the wavelengths of the Landsat satellite scanner data (Table 6).

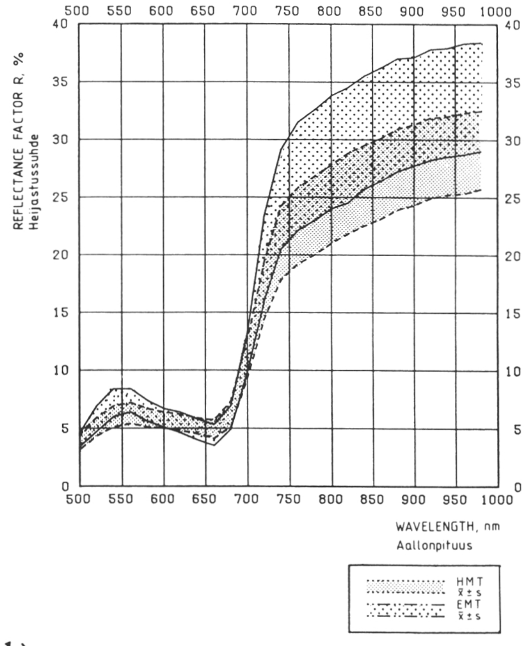
MCClT and ClT formed their own spectral group in the infrared range (700—1000 nm); this group clearly reflects less infrared radiation than that comprising EMT and HMT, which has a greater variation (darker on the image). Under red light, (600—700 nm) HMT and EMT were clearly of lower reflectance than the drier types; the vegetation of the lichen type (ClT) does not absorb red light, and indeed it is distinguished from the others in this wavelength range. Also, MCClT under red light was clearly lighter than HMT and EMT. The differences were statistically very significant ($p \leq 0.001$).

The channel ratios which describe the form of the spectral signature curves distinguished the site types from one another. Indeed, by making use of these channels, it is possible to achieve the most reproducible differentiation of the sites.

## 52. Correlation between reflectance factors and properties of the vegetation and humus

In Figures 13, 14 and 15 the dependence between the reflectance factors and the properties of living plants and humus is presented (in 20 nm channels) arranged according to wavelength on a site-by-site basis. The high value of the correlation coefficient relative to low probability level is an indication of a definite rectilinear dependence

a)




b)

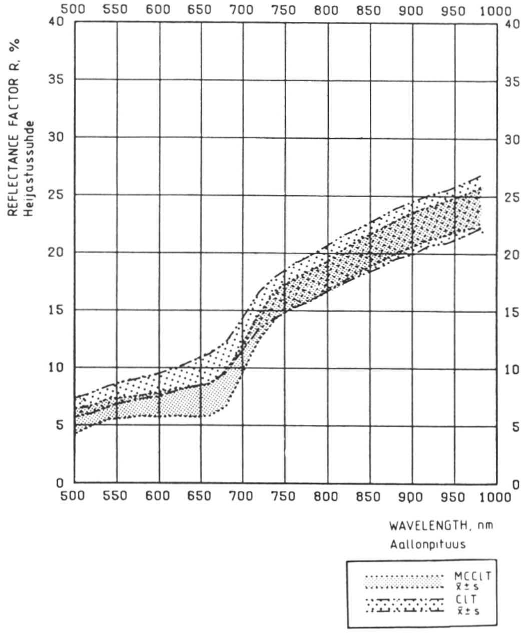



Fig. 12. Standard deviation belts ($x \pm s$) of spectral signature for site type vegetation. Measurements under sunlight with samples at normal moisture conditions. (a=HMT—EMT, b=MCClT—ClT).

*Kuva 12. Tyyppikasvustojen ominaissäteilyn hajontavyöt ($x \pm s$). Mittaus auringonvalossa, näytteet normaalikosteudessa (a=HMT—EMT, b=MCClT—ClT).*

Table 6. Mean values and standard deviations for the reflectance factors calculated by site type and selected wavelength channels for the ground vegetation and ground surface. Significance of the differences in distributions is determined according to the Mann-Whitney U-test. Measurements were carried out under sunlight with samples in normal moisture conditions (see Figures 11 and 12).

*Taulukko 6. Pintakasvillisuuden ja maanpinnan aallonpituuskanavittain ja kasvupaikoittain lasketut ominaissäteilykeskiarvot keskihajontoineen sekä Mann-Whitneyn U-testin mukaiset jakaumien mediaanien erojen merkitsevyydet. Mittaus suoritettu auringonvalossa näytteet normaalikosteudessa (vrt. kuvat 11 ja 12).*

| | Variable — *Muuttuja*<br>Site type — *Kasvup. t.* | | R 410—490 nm | R 510—590 nm | R 610—690 nm | R 730—790 nm | R 810—990 nm | R(550 nm) / R(660 nm) | R(510—590 nm) / R(610—690 nm) | R(730—790 nm) / R(610—690 nm) | R(810—990 nm) / R(610—690 nm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (x) *Keskiarvo* | HMT | $\bar{x}$ | 2.09 | 6.37 | 4.75 | 26.25 | 32.13 | 1.74 | 1.34 | 5.57 | 6.85 |
| | | s | 0.43 | 1.42 | 0.93 | 6.03 | 6.79 | 0.28 | 0.16 | 0.94 | 1.13 |
| Standard deviation (s) *Hajonta* | EMT | $\bar{x}$ | 2.06 | 5.22 | 4.99 | 21.49 | 27.93 | 1.30 | 1.06 | 4.36 | 5.67 |
| | | s | 0.32 | 0.79 | 0.78 | 3.58 | 4.24 | 0.22 | 0.13 | 0.70 | 0.67 |
| | MCCIT | $\bar{x}$ | 3.37 | 5.33 | 6.41 | 15.03 | 20.87 | 0.87 | 0.84 | 2.43 | 3.38 |
| | | s | 0.78 | 0.90 | 1.30 | 1.84 | 2.28 | 0.13 | 0.07 | 0.56 | 0.75 |
| | CIT | $\bar{x}$ | 4.78 | 6.96 | 9.08 | 15.16 | 19.78 | 0.78 | 0.77 | 1.68 | 2.19 |
| | | s | 0.60 | 0.82 | 1.19 | 2.21 | 2.73 | 0.04 | 0.03 | 0.20 | 0.27 |
| Statistical significance of the difference of median *Jakaumien mediaanien eron merkitsevyys* | HMT—EMT | | — | xxx | — | xxx | xx | xxx | xxx | xxx | xxx |
| | HMT—MCCIT | | xxx | xxx | xxx | xxx | xxx | xxx | xxx | xxx | xxx |
| | HMT—CIT | | xxx | x | xxx | xxx | xxx | xxx | xxx | xxx | xxx |
| | EMT—MCCIT | | xxx | — | xxx | xxx | xxx | xxx | xxx | xxx | xxx |
| | EMT—CIT | | xxx | xxx | xxx | xxx | xxx | xxx | xxx | xxx | xxx |
| | MCCIT—CIT | | xxx | xxx | xxx | — | x | xxx | xxx | xxx | xxx |

between the two variables. The stability of the curve shows the slight change of the dependency in the wavelength range being examined. The figures show only those correlation coefficients which deviate from zero at the probability level 0.05. The number of observations varied from variable to variable because 0 observations were not included when calculating the results. Owing to this, it is not possible to make direct comparisons among coefficients other than in cases where variables have the same number of observations. As regards correlation coefficients, levels of significance vary as a function of the number of observations as well. This fact can be ascertained from the line on the left of the curves which joins the probability level corresponding to the largest and smallest number of observations.

Fig. 13 indicates the plant species characteristic to different sites as well as the wavelengths on which variations in the measured properties of the individual species were best reflected in the reflectance values. In all there were on HMT four, on EMT six, on MCClT two and on ClT two species for which the correlation between the coverage and reflectance factor was statistically significant ($p < 0.05$). In the combined data the figure was six. The highest correlation coefficients were frequently found, not for the coverages of the living plants, but for the coverages of litter and the height of dwarf schrubs, mosses and lichens.

Furthermore, it can be seen how, for example, the coverage of *Vaccinium myrtillus* on HMT appeared in the reflectance factor values in the range of red light as a negative correlation; in the infrared range, on the other hand, the correlation was positive. In the combined material including all sites, the situation is more or less the same, but the dependence is even stronger. An examination of the correlation diagrams in which individual observations are visible reveals that the rise in the value of the coefficient is, in addition to the increase in the number of observations, mainly the result of one directional expansion of the total variation relative to variation within each strata, but is also due in some measure to an increase in the number of observations. In some instances in the combined material (e.g. when a certain species has varying coverage values on two sites) there can be a double-peak distribution. In such cases, the correlation coefficients cannot be directly compared, for the procedure used in calculating them presupposes a normal distribution.

In the combined data the correlations between the variables being studied and the reflectance factors were generally smallest near the wavelengths 540 nm and 700 nm. It ought to be noted, however, that the direction of the dependency changed only in the case of the latter wavelength. How definite the dependence is between coverage and the reflectance factor is determined primarily by the reflective properties of the surface of the species in question on each wavelength range and by the relative reflecting surface area in the direction of the sensing instrument, i.e. in which the observation is made.

In examining the vegetation cover from above, it was ascertained that, particularly in the case of poorer sites, a significant portion of the surface consisted of other than living vegetation. For example, on ClT needle litter accounted on average for 30.9 % of the coverage values, and other material (branches, barks, cones) for 23.6 % (cf. Table 2). As was assumed, this could have had an effect on reflectance factors according to the color of the material. The correlation between the height of the vegetation and reflectance factor was in most cases a negative one in the visible light owing to the fact that an increased amount of shade and biomass (cf. L.I. in Table 4) reduces the reflection of radiation.

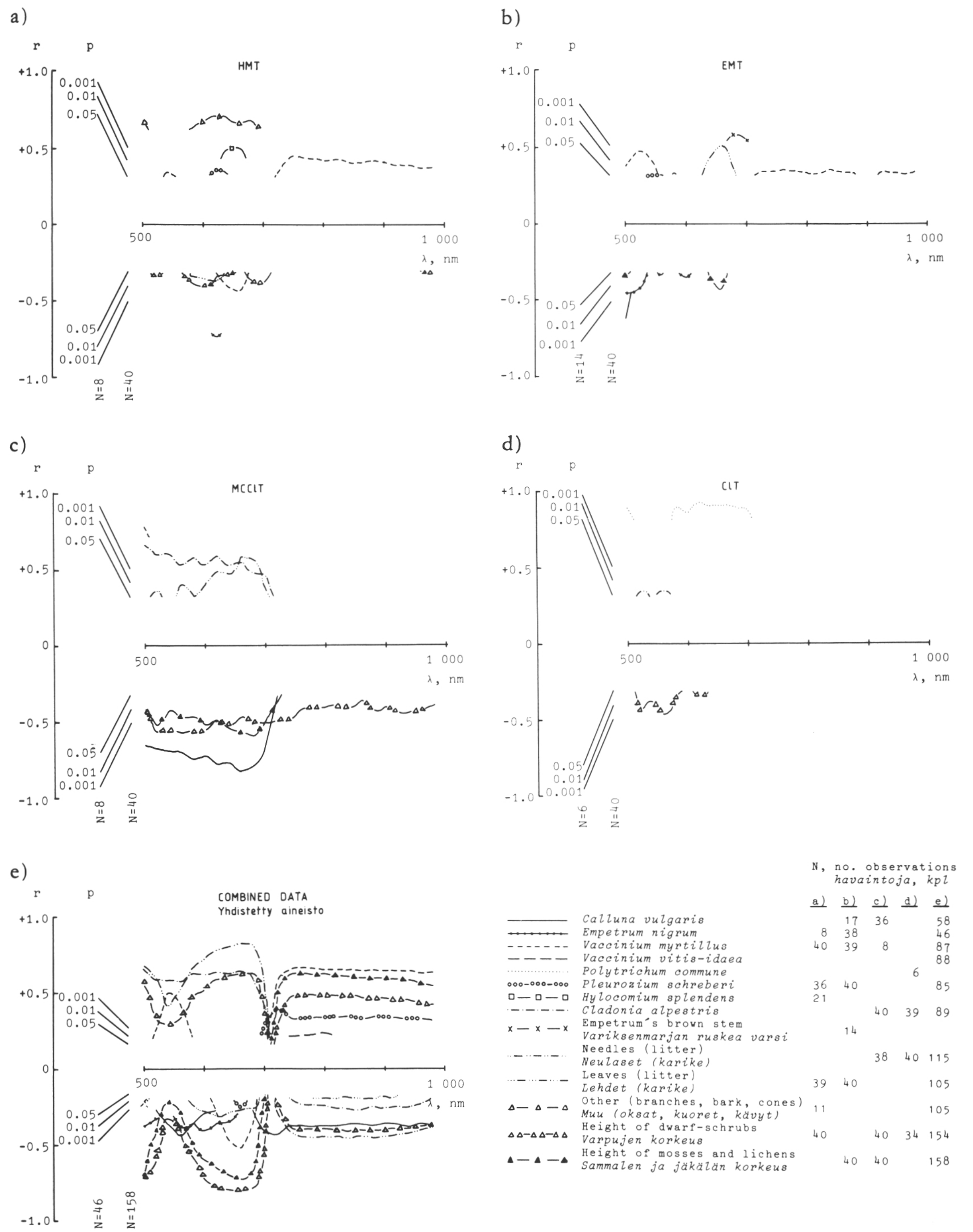
When choosing the 1 to 3 best predictors of the measured properties for the red light channel ($\lambda = 650$—$670$ nm) having the highest correlation coefficients in the combined data, the multiple regression analysis produced the following formulas to explain the variation of the reflectance factor (Y):

$$Y = 49.8 + 1.4\,x_1 \quad (3)$$
$$r^2 = 0.68$$
$$F = 237.9 \text{ (d.f. 1;113) ***}$$

$$Y = 45.9 + 1.0\,x_1 + 0.7\,x_2 \quad (4)$$
$$r^2 = 0.73$$
$$F = 112.1 \text{ (d.f. 2;82) ***}$$

$$Y = 54.1 + 0.9\,x_1 + 0.6\,x_2 - 0.5\,x_3 \quad (5)$$
$$r^2 = 0.75$$
$$F = 77.5 \text{ (d.f. 3;75) ***}$$

where $x_1$ = coverage of needles, $x_2$ = coverage of *Cladonia sp.* and $x_3$ = height of dwarf schrubs.




| | N, no. observations<br>*havaintoja, kpl* a) | b) | c) | d) | e) |
|---|---|---|---|---|---|
| *Calluna vulgaris* | | 17 | 36 | | 58 |
| *Empetrum nigrum* | 8 | 38 | | | 46 |
| *Vaccinium myrtillus* | 40 | 39 | 8 | | 87 |
| *Vaccinium vitis-idaea* | | | | | 88 |
| *Polytrichum commune* | | | | 6 | |
| *Pleurozium schreberi* | 36 | 40 | | | 85 |
| *Hylocomium splendens* | 21 | | | | |
| *Cladonia alpestris* | | | 40 | 39 | 89 |
| Empetrum´s brown stem<br>*Variksenmarjan ruskea varsi* | | 14 | | | |
| Needles (litter)<br>*Neulaset (karike)* | | | 38 | 40 | 115 |
| Leaves (litter)<br>*Lehdet (karike)* | 39 | 40 | | | 105 |
| Other (branches, bark, cones)<br>*Muu (oksat, kuoret, kävyt)* | 11 | | | | 105 |
| Height of dwarf-schrubs<br>*Varpujen korkeus* | 40 | | 40 | 34 | 154 |
| Height of mosses and lichens<br>*Sammalen ja jäkälän korkeus* | | 40 | 40 | | 158 |

Fig. 13. The linear correlation between reflectance factors (in 20 nm channels) and coverages of ground vegetation species and litter by site type and the site types combined according to wavelength; p is the probability that the coefficient r is zero. Reflectance factors have been determined under artificial light with samples in normal moisture conditions.

*Kuva 13. Heijastussuhteiden (laskettu 20 nm:n kanavissa) sekä pintakasvillisuuden lajien ja karikkeen peittävyyksien välinen lineaarinen korrelaatio kasvupaikoittain ja yhdistetyssä aineistossa aallonpituuden mukaan järjestettynä. p = todennäköisyys sille, että kerroin r on nolla. Heijastussuhteet on määritetty keinovalossa normaalikosteudessa olleista näytteistä.*

Similarily, in the range of infrared light ($\lambda = 790—810$ nm) the variation of the reflectance factor could be described by the formulas:

$$Y = 198.7 + 2.6\ x_4 \qquad (6)$$
$$r^2 = 0.42$$
$$F = 61.62\ (d.f.\ 1;85)\ ^{***}$$

$$Y = 167.2 + 1.3\ x_3 + 13.2\ x_5 \qquad (7)$$
$$r^2 = 0.39$$
$$F = 47.99\ (d.f.\ 2;149)\ ^{***}$$

$$Y = 194.9 - 3.2\ x_3 + 2.9\ x_4 + 9.3\ x_5 \qquad (8)$$
$$r^2 = 0.54$$
$$F = 31.90\ (d.f.\ 3;81)\ ^{***}$$

where $x_3$ = height of dwarf schrubs, $x_4$ = coverage of *Vaccinium myrtillus* and $x_5$ = height of mosses and lichens.

The observations which could be seen by screening the regression residuals and the calculated F-values gave reason to use linear models. The models, however, still left a considerable amount of variation in the reflectance factor unexplained.

In the present study, there was an aim to examine more closely some chemical and physical factors which were assumed to be ”visible” in the reflectance factors measured. Fig. 14 presents in the manner described above the values of the correlation coefficients between reflectance factors and the measured properties of the combined ground vegetation and litter samples (L horizon). The K content reached a statistically significant correlation ($p \leq 0.05$) on HMT and MCClT. The Fe, Al and Mg contents of the samples correlated in a statistically significant way only on MCClT (Fe also on EMT). On ClT only did the thickness of the litter layer and the loss on ignition produce significant correlation. Of the properties analyzed, the following showed no correlation at the probability level 0.05: cH (water and $CaCl_2$ suspensions), electrical conductivity and P, Ca and N contents. In the combined data K, Mg, Fe and Al contents correlated most strongly with reflectance factors.

Fig. 15 shows corresponding correlations in the humus FH horizons. On HMT there were significant correlations between K and P contents and the reflectance factor, on EMT with Ca, K, P, Fe and Al contents, on MCClT with cH (water suspension), Mg and Al contents, and on ClT with Fe and N-contents, the loss on ignition and the thickness of the FH horizon. Of the properties analyzed cH ($CaCl_2$-suspension) and electrical conductivity showed no correlations at the probability level 0.05. In the combined data cH (water suspension) and Ca, N and P contents also showed a statistically significant correlation with reflectance factors when compared to Fig. 14e. As with the combined data in Fig. 13 the data in Fig. 14 and 15 displayed the same diminution in the correlation coefficients near wavelengths 540 nm and 700 nm.

### 53. Spectral signature of the A and B horizons of the podzolic soils

Figures 16 and 17 present the average values of the spectral signatures for the mineral soil of the four sites as a function of wavelength separately defined for the A and B horizons of the podzol sola. In figures 16a and 17a appear the average values of the spectral signatures of the A and B horizons under artificial light and soil moisture at field capacity (average moisture contents: A horizon 9,7 %, B horizon 16,3 %). In samples from the A horizon, the spectral signature values begin to rise at 540 nm in linear fashion all the way up to 1000 nm. The spectral signatures determined from the samples of the darker B horizon, on the other hand, were clearly lower and the rise in curves slowed after 700 nm.

The results obtained in sunlight (Fig. 16b and 17b) correspond in the main to those obtained under artificial light. In sunlight the deviation of the spectral signature of the A horizon increased. In the reflectances for both horizons there was a recurrence in the infra range ($\lambda > 850$ nm) of the instability caused by atmospheric absorption recorded also in connection with vegetation samples. The result of wetting was a 2—3 % drop in the spectral signature averages of the A horizon samples in the range > 500 nm. In the case of the B horizon, no such change was recorded (Fig. 16c and 17c). Drying of the samples caused a clear 10—15 % increase in the average values for the spectral signature of both the A and B horizons (Fig. 16d and 17d, cf. Fig. 16a and 17a). The differences in the values for samples measured dried and at field capacity increased somewhat towards longer-wave radiation. Likewise, deviation in the reflectance factors increased.

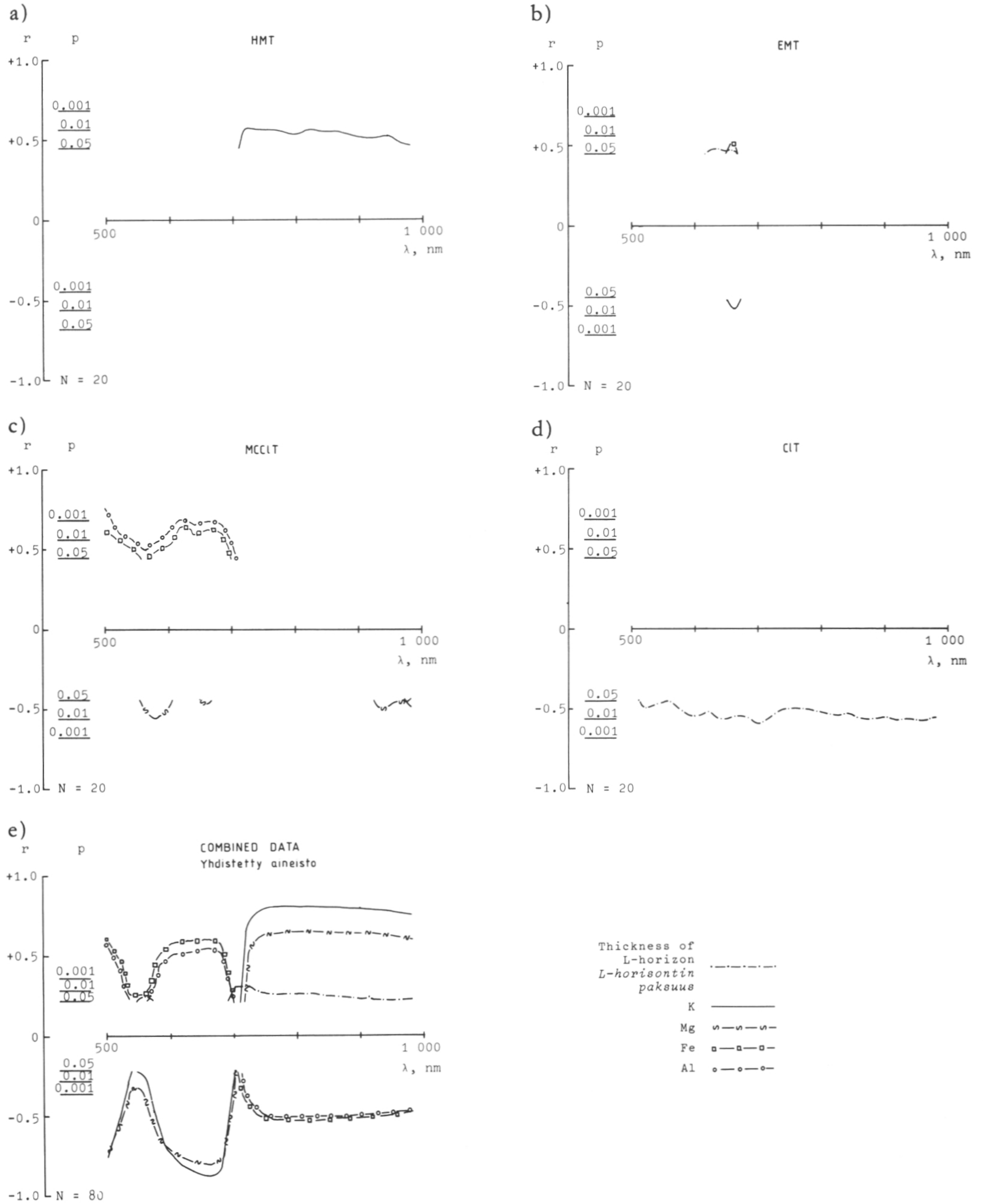



Fig. 14. The linear correlation by site type according to wavelength (in 20 nm channels) between reflectance factors and certain properties of the ground vegetation and litter. Reflectance factors have been determined under artificial light with samples in normal moisture conditions.

*Kuva 14. Heijastussuhteiden (laskettu 20 nm:n kanavissa) sekä pintakasvillisuuden ja karikkeiden eräiden ominaisuuksien välinen lineaarinen korrelaatio kasvupaikoittain aallonpituuden mukaan järjestettynä. Heijastussuhteet on määritetty keinovalossa normaalikosteudessa olleista näytteistä.*

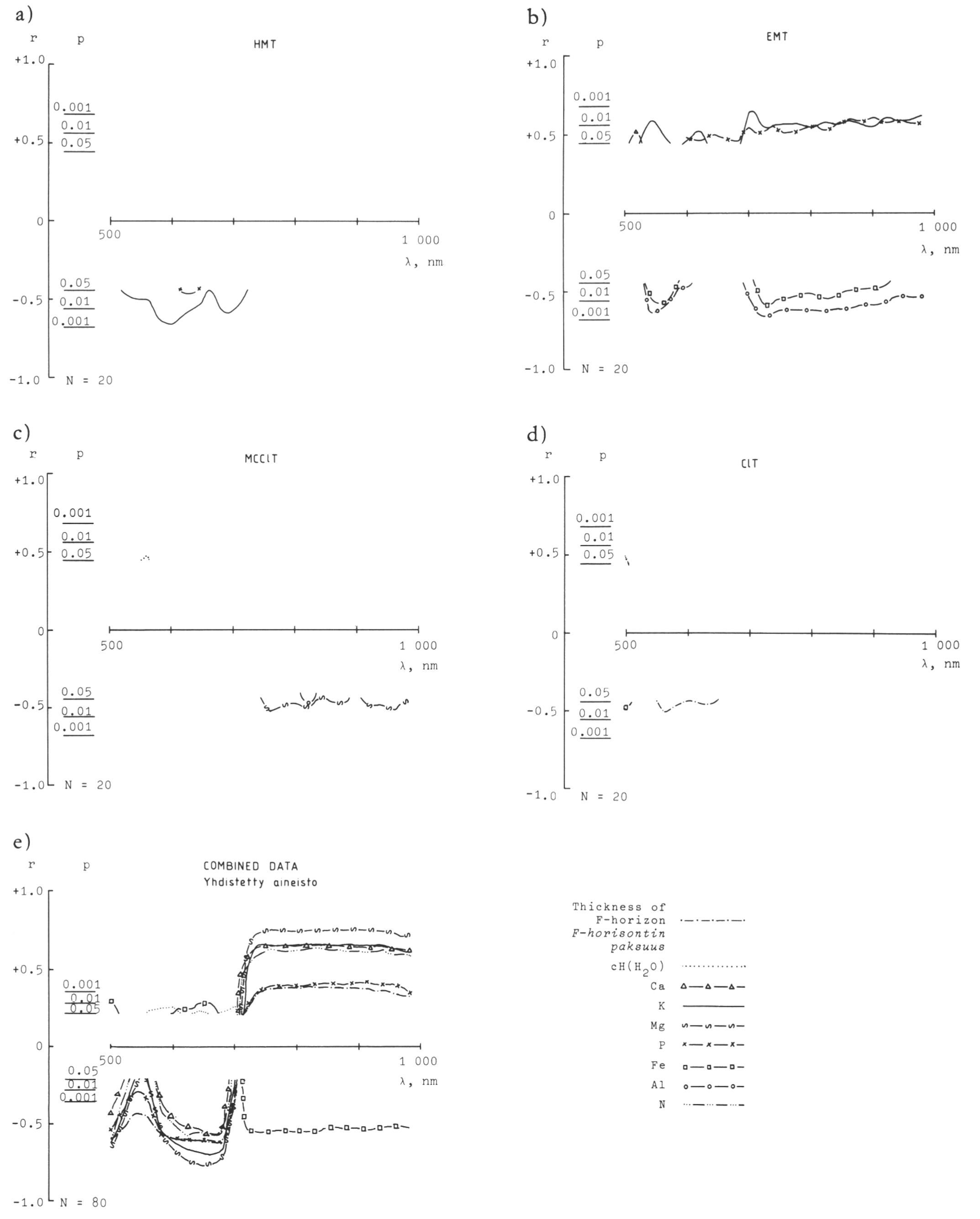



Fig. 15. The linear correlation between the reflectance factors (in 20 nm channels) and certain properties of the FH horizons of the humus layer by site type according to wavelength. Reflectances have been determined under artificial light with samples in normal moisture conditions.

*Kuva 15. Heijastussuhteiden (laskettu 20 nm:n kanavissa) ja humuskerroksen FH horisonttien eräiden ominaisuuksien välinen lineaarinen korrelaatio kasvupaikoittain aallonpituuden mukaan järjestettynä. Heijastussuhteet on määritetty keinovalossa normaalikosteudessa olleista näytteistä.*

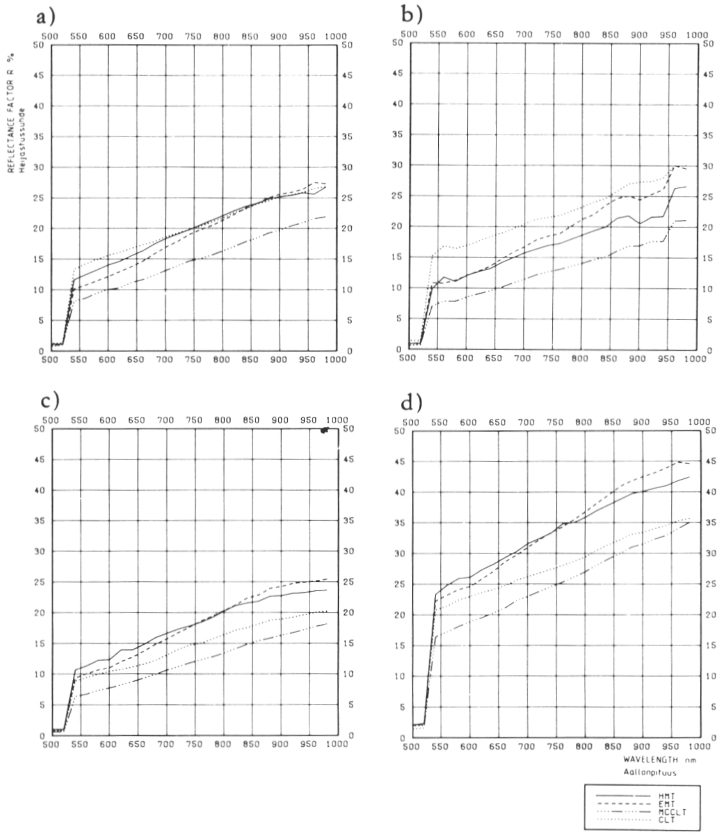



Fig. 16. Averaged spectral signatures as determined from the A horizon of the soil for the four mineral soil sites. The measurement conditions were as follows: (a) measurement under artificial light, soil moisture at field capacity, (b) measurement in sunlight, soil moisture at field capacity, (c) measurement in artificial light, soil moistened, (d) measurement in artificial light, soil ovendried.

*Kuva 16. Neljän kangasmaan kasvupaikan maan A-horisontin näytteistä määritetyt ominaissäteilykeskiarvot. Mittausolosuhteet olivat seuraavat: (a) mittaus keinovalossa, maa kenttäkapasiteetissa, (b) mittaus auringon valossa, maa kenttäkapasiteetista, (c) mittaus keinovalossa, maa kasteltuna ja (d) mittaus keinovalossa, maa kuivattu.*

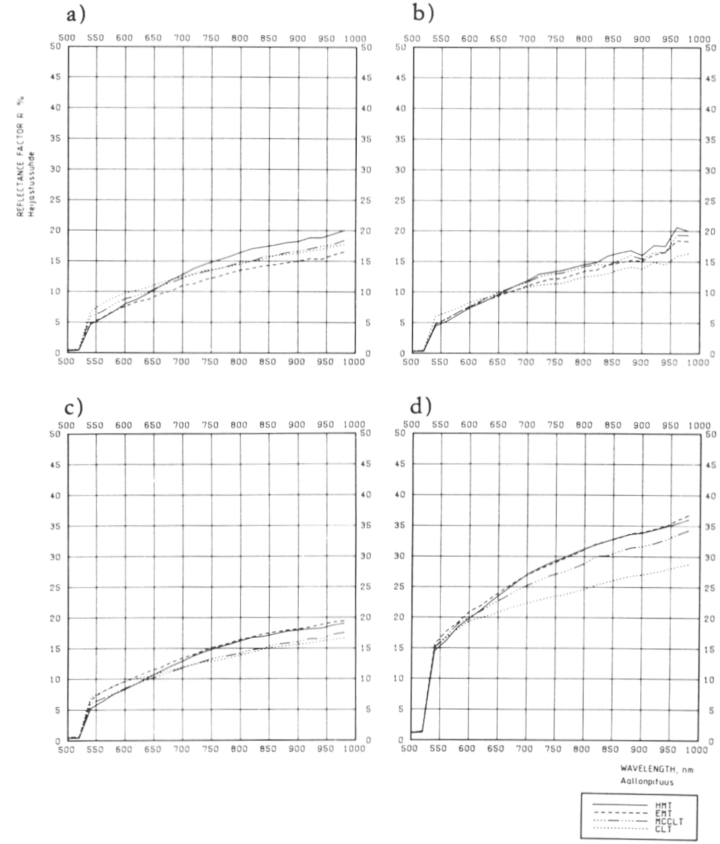



Fig. 17. Averaged spectral signatures as determined from the B horizon of the soil for the four mineral soil sites. Measurement conditions as in Fig. 16.

*Kuva 17. Neljän kangasmaan kasvupaikan B-horisontin näytteistä määritetyt ominaissäteilykeskiarvot. Mittausolosuhteet kuten kuvassa 16.*

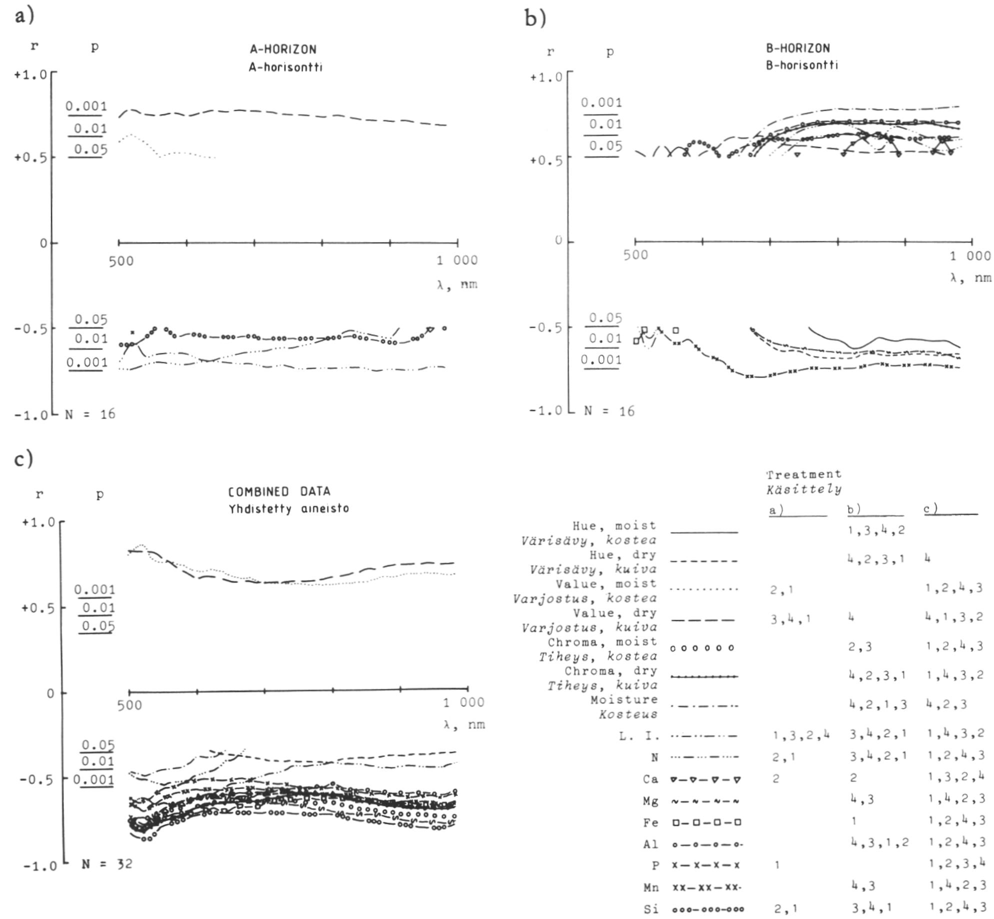



Fig. 18. The linear correlation between the reflectance factors (in 20 nm channels) and certain properties determined from the A and B horizons of the soil according to wavelength. The greatest correlations between the reflectances and the different properties for samples measured in a different conditions have been drawn onto the figure. Order of size for the subfigures is presented with explanation of curves. For treatments, see Fig. 16.

*Kuva 18. Heijastussuhteiden (laskettu 20 nm:n kanavissa) ja eräiden pintamaan A- ja B-horisonteista määritettyjen ominaisuuksien välinen lineaarinen korrelaatio aallonpituuden mukaan järjestettynä. Kuvaan on piirretty suurimmat heijastussuhteiden ja eri ominaisuuksien väliset korrelaatiot eri mittausolosuhteissa (suuruusjärjestys osakuville viivaselityksen yhteydessä, käsittelyt ks. kuva 16).*

## 54. Correlation between reflectance factors and the soil properties

The correlation between reflectance factors and soil properties was studied separately for the samples of the A and B horizons (Fig. 18). The explanation for the figure includes the treatments for which it has been possible to establish statistically significant correlations between reflectance factors and the analyzed physical and chemical properties.

As regards chemical properties for the A horizon samples, statistically significant correlation coefficients ($p \leq 0.05$) were found only between the loss on ignition and N, Si (Ca, P) contents and the reflectance factor. Color value correlated most strongly with the reflectance factor for the color characteristics analyzed. For the other properties analyzed, no significant correlation was found for pH (water and $CaCl_2$ suspensions), electrical conductivity, Mg, Fe, Al and Mn contents nor for the color characteristics hue and chroma. Soil moisture did not correlate significantly either.

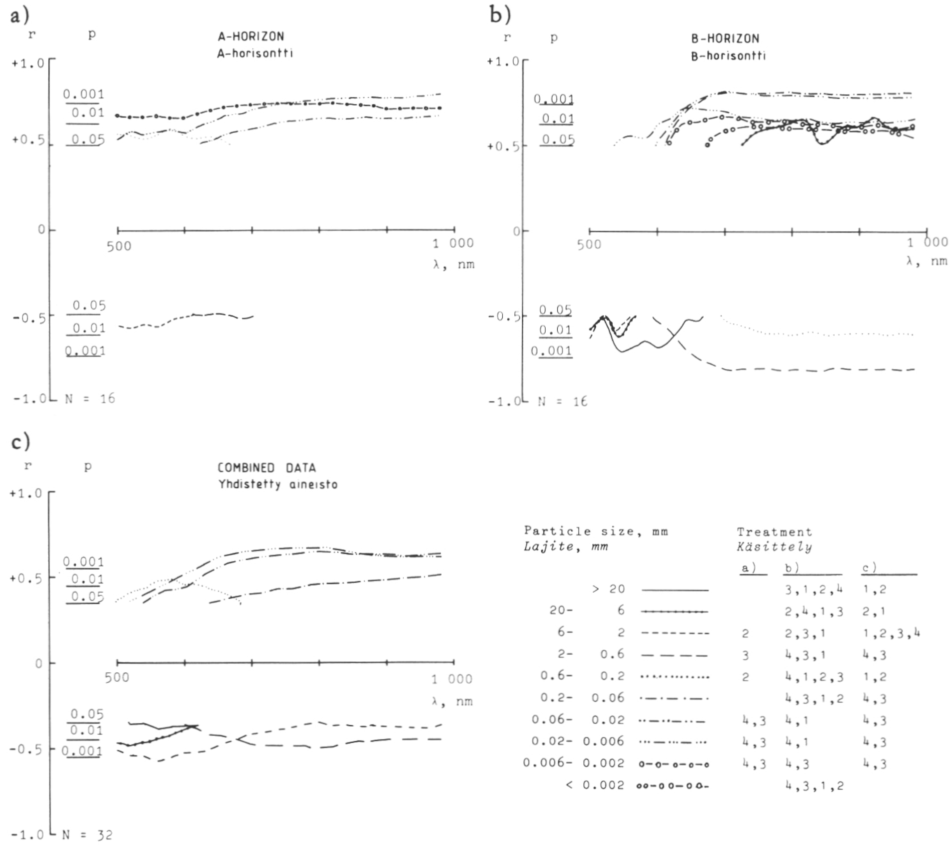



Fig. 19. The linear correlation between the reflectance factors (in 20 nm channels) and the quantity of different particle sizes from the A and B horizons of the soil according to wavelenght. The greatest correlations between the reflectances and the different size classes for samples measured in a different conditions have been drawn onto the figure. Order of size for the subfigures is presented with explanation of curves. For treatments, see Fig. 16.

*Kuva 19. Heijastussuhteiden (laskettu 20 nm:n kanavissa) ja A- ja B-horisonttien eri maalajitteiden määrän välinen lineaarinen korrelaatio aallonpituuden mukaan järjestettynä. Kuvaan on piirretty suurimmat heijastussuhteiden ja eri ominaisuuksien väliset korrelaatiot eri mittausolosuhteissa (suuruusjärjestys osakuville viivaselityksen yhteydessä, käsittelyt ks. kuva 16).*

For the B horizon samples, on the other hand, it was possible to ascertain statistically significant correlation coefficients between reflectance factors and most of the properties measured. Worthy of note is the fact that the greatest dependencies appeared frequently only in the red and infrared ranges ($\lambda > 600$ nm). No significant correlation could be established for the following: cH (water and $CaCl_2$ suspensions), electrical conductivity, P-content and color chroma (dry). In the combined data (Fig. 18c) the greatest values for the correlation coefficient were located in the green and infrared regions of the spectrum. The coefficients were negative with the exception of the hue values.

The soil moisture and the measurement conditions affected in different ways the dependencies between many of the properties and the reflectance. For example, the correlation between the loss on ignition and N content of the B-horizon soil and the spectral reflectance factor is greatest in moistened soil (artificial light); following that are dried soil (artificial light), soil at field capacity (sunlight) and soil moisture at field capacity (artificial light).

Fig. 19 shows in corresponding fashion the correlations as a function of wavelength between the relative quantity of different particle sizes determined separately for the A and B horizons and the reflectance factors. In both horizons, the soil type is fine sand till. The soil in the A horizon was somewhat coarser than that in the B horizon (see Fig. 6). The greatest correlation coefficient values appeared only in the red and infrared ranges of the spectrum. However, for most particle sizes the values for the statistically significant correlation coefficients between the quantity of the particle and the reflectance factor could be already ascertained in the range of visible light. The dependency of different particle sizes on the reflectance factors was most prominent when the radiometric measurements were taken from dried samples under artificial light. In both horizons, particle sizes finer than fine sand (< 0.2 mm) correlated positively with the reflectance factors (with the exception of gravel size 20—6 mm in the green and fine sand (0.6—0.2 mm) in the infrared range of the spectrum in B horizon soil). Negative correlation coefficients between coarse soil particles and the reflectance factors were most probably caused by the effect of the large grains on the color and texture of the surface (shadows). This could also be seen in the combined data (Fig. 19c).

# 6. DISCUSSION

## 61. Methods and results

Reflected radiation contains a great deal of information on the properties of the reflecting object (Gates 1970, Stepanov 1974). This characteristic of radiation is being used at present in different remote sensing applications. Forest site types (forest ecosystems) contain a number of site factors which determine the growth and development of the forests. The same silvicultural measures can be employed on similar sites. Indeed, these considerations have prompted this study, i.e., an investigation of whether or not sites classified on the basis of ground vegetation can be distinguished on the basis of the radiation reflected by the vegetation and the soil surface (cf. Cajander 1949, Lehto 1978) and an examination of the physical and chemical properties of the vegetation and soil which affect the reflection of radiation. The study set out to examine primarily the effects of properties which are known to be pertinent in describing a site and which would presumably affect the reflective properties of the surface. The experimental procedures used made it possible both to study the distinguishability of sites and to analyze properties of the objects in relation to radiation reflection from their surface.

The results indicate that the sites studied could be distinguished on the basis of the radiation reflected by the ground vegetation and the soil surface. HMT was best distinguishable from EMT in the region of infrared light and MCClT from ClT in the region of green and red. Damp and subdry upland sites were distinguishable from dry and barren sites in the region of both red and infrared light.

A characteristic spectral signature curve for the objects (vegetation and soil surface and the soil of the A and B horizons) recurred in all measurements and made it possible to distinguish the samples under both natural and artificial light. Atmospheric absorption in the infrared region did not affect the distinguishability of the sites (cf. Gates 1981). The ratio channels which describe the form of the spectral signature curve provided the most effective means of distinguishing the sites. The use of these ratio channels has applications in the numerical interpretation of scanner data (Kilpelä et al. 1978, Häme & Saukkola 1982).

In general moistening resulted in a systematic decrease in reflectance values due to the absorption by the water film on the sample surface (Idso et al. 1975, Peterson et al. 1979). This phenomenon may impair the distinguishability of HMT and EMT from drier types. Moistening lowered reflectance in the A horizon of the podsolic soil as well; moistening of the B horizon soil did not, however, have any appreciable effect, partly because B horizon soil already had a greater initial moisture content. Drying the samples brought about a distinct and reasonably systematic rise in the reflectance factors of both A and B horizon soils.

An examination of the intercorrelations between reflectance factors (in 20 nm channels) and the properties of the vegetation and the humus-layer yielded new knowledge. Of particular interest is the circumstance that the factors increasing or decreasing the reflection of radiation in the region of the visible light frequently operate in reverse fashion in the infrared region. The correlation between the coverage of different plant species or other substances on the ground and reflectance factor was normally smallest near the wavelengths 540 nm and 700 nm. At these wavelengths also a strong increase in reflectance factor can be observed; this phenomenon is referred to as the "reflectance edge" (Gates 1981). Worth noticing is, however, that the sign of the correlation coefficient only changed near the latter wavelength. This was also true for the variables describing the properties of the forest floor when the same reflectance data was used.

The results indicate that it is possible to distinguish many properties of the ground cover and soil from the background, properties which appear in the reflectance factor in a certain wavelength range. In addition, one can establish an order of significance among the reflectors (properties) or, indirectly, among the factors which correlate with them. Inasmuch as the classificatory criteria for the sites in this study are based on established characteristics of the vegetation cover and soil, if sites correspond as to their characteristics to the ones in this study, it will be possible to choose the appropriate wavelength and remote sensing method on the basis of the results presented here. On the other hand, the classification can be based on "unknown" background variables, whereby it would depend entirely on the spectral signature. This would make a spectral classification of sites possible.

The coverage of some plant species in the ground vegetation correlated strongly with the reflectance factor. It is possible that species are involved whose reflective properties affect reflectance more strongly than do other background reflectors for the wavelength being examined. An example of these species is *Vaccinium myrtillus* on HMT. High correlations were also observed between the coverage of the nonliving material on the soil surface and the reflectance factor.

The reflective properties of forest floor involved, e.g. K and P concentrations in their own specific wavelength ranges. Different sites showed a great deal of variation, as was to be expected from the different plant species and humus types on them. This study did not investigate the common effect of exchangeable cations on reflectance factors as an attempt was made to determine nutrient reserves through a stronger extraction; this effort was thought as pointing up better the effects of different elements on the reflectivity (cf. Montgomery & Baumgardner 1974, Stoner et al. 1980). It is realized, however, that different extraction methods may end up with different correlations.

In examining the interdependence between the properties of mineral soils of the A and B horizons and the reflectance factors, one can find that the conditions under which the measurements were recorded affect the results. For this reason, one must be familiar with these conditions when interpreting study results on the basis of the reflected radiation.

In samples of the B horizon, most elements were found in higher concentrations than for those from the eluviated A horizon. Often the correlation between reflectance factor and chemical property was also higher for B horizon soil. The highest correlations in B horizon soil generally appeared in the red and infrared regions of the spectrum. Some statistically significant correlations existed between reflectance factor and color characteristics as determined visually using the Munsell scale: in A horizon soil for value only, in B horizon soil for hue, chroma and value. The Munsell scale, however, places limitations on the interpretation of the results particularly as far as hue is concerned. Through radiometric measurement it is possible to obtain more definite values for the color characteristics used in classifying soils than by using the Munsell color: the region beyond the range of visible light can be studied as well.

The correlation analysis revealed the possibility of analyzing reflected light to determine the particle size distribution and texture of mineral soil using remote sensing techniques (cf. Montgomery & Baumgardner 1974, Weissmiller & Kaminsky 1978, Gerberman & Neher 1979). As noticed earlier identifying different size fractions and assessing their reflective properties requires that measurement conditions be taken into account. The highest correlations between channel-spesific reflectances and most particle sizes occurred in soil which had been dried or whose moisture content corresponded to field capacity (cf. Stoner et al. 1980). As far as soil is concerned, it is necessary to point out that reflected radiation contains information on the surface soil only; thus the method used is only applicable when studying surface phenomena of the soil or phenomena correlating with these.

## 62. Potential applications

It is sensible to carry out spectroradiometric measurements of the surfaces as a preliminary study prior to taking aerial photographs if the interpretation process is planned to be spectrally dominated. In this way it is possible to save a great deal on the costs of photography and interpretation, particularly in cases where ground interpretation of the aerial photographs does not even prove successful. Measurement of the spectral signature thus clarifies the following:

— the identifiability of the surfaces in general
— the best wavelengths for interpretation, i.e. the optimal film-filter combination
— the lightness of the surfaces to be interpreted relative to the surfaces being used for comparison (anticipation of tones)
— the significance of the conditions under which the imaging takes place from the point of view of the results.

The differences in the ground vegetation of the four site types in spectral signature as determined from the samples collected yield a basis for the interpretation of a site from an aerial or satellite image. The background visible between treetops has its own tones which are specific to the site, a significant finding for Lapland especially, where the crown closure of the trees is frequently only around 30 %. The effect of the ground vegetation is enhanced by the fact that its reflectance is most often higher than that of the treetops, which, being darker, blend into the background due to scattering.

The most promising applications in practice are probably those involving the interpretation of aerial photographs of sites; in these, it is possible to

— choose the appropriate film-filter combination and use a filter when copying the pictures, which screens out unsuitable wavelengths
— anticipate the relative tones of each site on the picture.

In interpreting satellite pictures or other multispectral scanner images it is possible to search for differences in sites using the wavelength channel combinations which the study has established as being the best. Correspondingly, in producing color composites as a combination of several wavelength channels for purposes of visual interpretation, it is possible to choose a channel combination which maximizes the color tone differences of the sites. Since the correlation between reflectance factors measured on different wavelengths and the properties of the site can be calculated — if the effect of the matrix is not disturbing and there exists data for comparison — possibilities exist for identifying the site and determining some of its properties quantitatively using the information in reflected radiation (Colwell 1969, Jaakkola & Saukkola 1980, Saukkola & Jaakkola 1983). The use of the spectral signature as an indicator of the site properties and a criterion variable in site and soil classification is, according to the results obtained here, possible even in the conditions prevailing in the mature stands of northern Finland.

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# SELOSTE

## Spektrinen heijastussäteily pintakasvillisuuden ja maan ominaisuuksien kuvaajana Pohjois-Suomessa

Kohteesta heijastunut säteily sisältää runsaasti informaatiota kohteen ominaisuuksista. Tätä säteilyn ominaisuutta käytetään hyväksi monilukuisissa kaukokartoitustekniikan sovellutuksissa. Menetelmien kehittyessä on tullut mahdolliseksi ulottaa säteilyspektrin alue myös näkyvän valon ulkopuolelle.

Metsätaloudessa käytetään nykyisin tavallisten mustavalko- ja värikuvien ohella infrapunakuvia, joiden herkkyysalue sijoittuu osaksi lähi-infrapunasäteilyn alueelle. Myös monikanavaisten keilainten käyttöä on Suomessa kokeiltu, ja amerikkalaisen luonnonvarasatelliitin (Landsat) aineistoa on ollut saatavilla vuodesta 1972 lähtien. Maastoelementin koon pieneneminen satelliittikeilainaineistossa avaa uusia, mm. elementin sijaintitarkkuuden ja pinta-alaarvioiden paranemisesta seuraavia näköaloja metsätaloudellisissa sovellutuksissa. Niistä tähän mennessä on kokeiltu lähinnä hakkuiden ja maankäyttömuotojen seurantaa sekä eräiden puustotunnusten arviointia.

Käsillä olevan työn tarkoituksena oli selvittää mahdollisuuksia erottaa toisistaan keskikesän olosuhteissa eräitä Pohjois-Suomessa yleisesti esiintyviä kasvupaikkatyyppejä (tuore kangas, kuivahko kangas, kuiva kangas, karukkokangas) pintakasvillisuuden ja maanpinnan heijastusominaisuuksien perusteella. Lisäksi haluttiin tutkia lähemmin tekijöitä, jotka kullakin tarkasteltavalla säteilyspektrin alueella vaikuttavat heijastussuhteisiin ja ominaissäteilykäyrän muotoon[1]).

Maaperän osalta tarkasteltiin erikseen podsolimaannosten A- ja B-horisonttien heijastusominaisuuksia. Työssä esitetään myös teoreettiset perusteet ominaissäteilymittaukselle ja mittauskohteiden heijastusominaisuuksille.

Tutkimuksen aineisto kerättiin neljältä koealueelta, jotka sijaitsivat 50 km säteellä Rovaniemen kaupungista (taulukko 2). Kasvipeite- ja humusnäytteet irroitettiin 25 × 40 cm:n laikkuina, kivennäismaanäytteet erikseen horisonteittain. Havaintotoistojen määrä koealuetta kohden oli radiometrimittauksissa pintakasvillisuus- ja humusnäytteiden osalta 40 kpl ja kivennäismaanäytteiden osalta 8 kpl. Mittaukset suoritettiin pääosin Rovaniemellä kohta näytteiden keruun jälkeen. Käytetty aallonpituusalue oli 0.5—1.0 μm. Kohteen heijastaman säteilyn spektrinen jakauma mitattiin erilaisissa olosuhteissa: 1) näytteet normaalikosteudessa, keinovalo, 2) näytteet kasteltuina, keinovalo ja 3) näytteet normaalikosteudessa, auringonvalo. Maanäytteet mitattiin myös kuivattuina. Sekä kasvipeite- että maanäytteistä määritettiin tämän jälkeen joukko fysikaalisia ja kemiallisia ominaisuuksia, joiden oletettiin vaikuttavan kohteesta heijastuvaan säteilyyn tai, joita käytetään kasvupaikkojen ominaisuuksia luonnehdittaessa. Niitä olivat eri kasvilajien ja maanpinnalla olevien ainesten peittävyysarvot, kasvillisuuden korkeus, humuskerroksen paksuus, maanäytteiden väri arvioituna silmävaraisesti Munsell-asteikkoa käyttäen, humuksen ja kivennäismaan happamuus, johtokyky sekä hehkutuskevennys, typpi-, kalium-, kalsium-, magnesium-, rauta- ja alumiinipitoisuudet. Kivennäismaasta määritettiin edellisten lisäksi mangaani- ja piipitoisuudet sekä lajitekoostumus. Mittaustulosten tilastollisessa analyysissä käytettiin Mann-Whitneyn U-testiä sekä korrelaatio- ja regressioanalyysiä.

Tulosten mukaan tuore kangas (metsätyyppi HMT), erottui kuivahkosta kankaasta (EMT) parhaiten infrapuna-alueella, kuiva kangas (MCCLT) sen sijaan erottui karukkokankaasta (CLT) parhaiten vihreän ja punaisen valon alueella. Sekä tuore että kuivahko kangas erottuivat kuivasta ja karukkokankaasta punaisen ja infrapunan alueella (kuvat 11 ja 12). Ominaissäteilykäyrän muotoa kuvaavat suhdekanavat, esim. vihreän suhde punaiseen tai infrapunan suhde punaiseen, erottivat tarkasteltavat kasvupaikkatyypit kaikkein parhaiten toisistaan (taulukko 6). Näytteiden kastelu aiheutti heijastussuhteiden tason alenemisen, mutta ei yleensä vaikuttanut kohteiden erottuvuuteen tarkastellulla säteilyspektrin alueella. Tulokset mittauksista keinovalossa ja auringonvalossa osoittautuivat hyvin samankaltaisiksi. Ilmakehän absorptiosta johtuen auringonvalossa tehtyjen mittausten tuloksissa esiintyy infrapuna-alueella kuitenkin jonkin verran systemaattista epästabiilisuutta.

Heijastussuhteiden sekä kasvillisuuden ja humuksen ominaisuuksien välistä riippuvuutta tarkasteltiin korrelaatio- ja regressioanalyysin avulla (kuvat 13, 14 ja 15 sekä yhtälöt 3—8). Tuloksista nähdään mm., että HMT:llä esiintyy yhteensä neljä, EMT:llä kuusi, MCClT:llä kaksi ja ClT:llä kaksi kasvilajia tai lajiryhmää, joilla peittävyyden ja heijastussuhteen välinen korrelaatiokertoimen arvo oli tilastollisesti merkitsevä 5 %:n riskitasolla. Suurimmat kertoimet esiintyivät ko. lajeille ja kasvupaikoille ominaisilla säteilyspektrin alueilla. Karuimmilla kasvupaikoilla karikkeet muodostivat maanpinnan peittävyysarvoista huomattavan osan (ClT:llä neulaskarikkeiden peittävyys oli 30,1 % ja oksien, kuorien ja käpyjen peittävyys 23,6 %), mikä voitiin todeta myös heijastussuhteiden ja peittävyysarvojen riippuvuuksien voimakkuutena. Merkillepantavaa oli, että ominaisuudet, jotka näkyvät valon alueella lisäsivät tai vähensivät säteilyn heijastumista (tarkemmin sanottuna korreloivat positiivisesti tai nega-

[1]) *Spektrisellä heijastussuhteella* tarkoitetaan tässä kohteen tietyllä aallonpituusalueella ja tiettyyn suuntaan heijastaman säteilyn osuutta siitä säteilystä, jonka sataprosenttisesti heijastava kohde samoissa olosuhteissa heijastaisi sille tulleesta säteilystä. *Ominaissäteily (tai ominaisspektri)* on kohteelle tyypillinen ominaisuus heijastaa tai emittoida sille tullutta säteilyä. Heijastuvan säteilyn alueella ominaissäteilyn yksikkönä käytetään mm. heijastussuhdetta.

tiivisesti), vaikuttivat infrapunaisella alueella usein päinvastaisesti. Ilmiö näkyy selvästi kuvien 13, 14 ja 15 yhdistetyissä aineistoissa. Kuvista näkyy myös se, että korrelaatiokertoimet olivat pienimmillään lähellä aallonpituuksia 540 ja 700 nm. Riippuvuuden suunta muuttui kuitenkin ainoastaan jälkimmäisen aallonpituuden lähellä.

Kasvillisuuden ja humuksen kemiallisten ominaisuuksien ja heijastussuhteiden välisiä korrelaatiokertoimia tarkasteltaessa todettiin kertoimien merkitsevyyksien ja vastaavien aallonpituusalueiden vaihtelevan kasvupaikoittain. Erilaisuudet kertoimissa, kysymyksen ollessa samoista muuttujista eri kasvupaikoilla, johtuvat osaksi erilaisen taustan vaikutuksesta, jolloin riippuvuudet eivät ole aina suoraviivaisia. Tuloksissa voidaan todeta esim. kalium- ja fosforipitoisuuksien tilastollisesti merkitsevä korrelaatio heijastussuhteisiin HMT:llä ja EMT:llä (kuvat 14 ja 15). Sen sijaan MCClT:llä ja ClT:llä ei vastaavaa korrelaatiota tavattu.

Podsolimaannosten A- ja B-horisonttien ominaissäteilykäyrät poikkesivat muodoltaan kasvipeitteen ja maanpinnan vastaavista käyristä (kuvat 16 ja 17, vrt. kuva 11). Noin 540 nm:stä lähtien heijastussuhteiden arvot kasvoivat A-horisontin näytteissä lineaarisesti aallonpituuden funktiona aina 1000 nm:iin saakka. Tummemman B-horisontin näytteistä määritetyt heijastussuhteet sen sijaan olivat tasoltaan selvästi matalampia, ja niiden kasvu hidastui 700 nm:n jälkeen. Auringonvalossa saadut mittaustulokset vastasivat pääosiltaan keinovalossa saatuja tuloksia. Kastelun vaikutuksesta A-horisontin näytteiden ominaissäteilykeskiarvot laskivat 2—3 % ($\lambda > 500$ nm). B-horisontin näytteiden osalta ei vastaavaa siirtymää todettu. Näytteiden kuivaus aiheutti selvän 10—15 %:n kasvun sekä A- että B-horisontin maan ominaissäteilykeskiarvoissa.

Vastaavaan tapaan kuin kasvillisuus- ja humusnäytteistä tarkasteltiin työssä A- ja B-horisonttien maanäytteiden eräiden kemiallisten ja fysikaalisten ominaisuuksien sekä heijastussuhteiden välisiä riippuvuuksia aallonpituuden funktiona (kuvat 18 ja 19). Korrelaatiokertoimet olivat tilastollisesti merkitseviä B-horisontin maassa useimpien määritettyjen kemiallisten ominaisuuksien osalta, A-horisontin maassa lähinnä vain hehkutuskevennyksen sekä kokonaistyppi- ja piipitoisuuksien osalta. Suurimmat riippuvuudet tulivat usein esiin vasta spektrin punaisella ja infrapunaisella alueella. Maalajitteen määrän ja heijastussuhteiden väliset tilastollisesti merkitsevät korrelaatiokertoimet voitiin useimpien lajitteiden osalta todeta kuitenkin jo näkyvän valon alueella. Hienoa hiekkaa (< 0.2 mm) hienompien lajitteiden määrän kasvu lisäsi yleensä heijastussuhdetta. Mittausolosuhteet (valaistus, näytteen kosteus) vaikuttivat sekä kemiallisten että fysikaalisten ominaisuuksien ja heijastussuhteiden välisiin korrelaatiokertoimiin.

Tulosten merkitystä arvioitaessa voidaan todeta, että heijastuneen säteilyn sisältämän informaation avulla on mahdollista erottaa toisistaan tarkastelluissa olosuhteissa erilaisia kasvupaikkoja sekä arvioida eräiden yksittäisten kasvupaikkojen laatua kuvaavien muuttujien mahdollista esiintulemista heijastussuhteissa. Maannosten luokittelussa käytetyille väritunnuksille saadaan spektroradiometrimittauksella yksiselitteisempiä arvoja silmävaraiseen Munsell-luokitukseen verrattuna sekä kyetään ulottamaan tarkastelualue myös näkyvän valon ulkopuolelle. Tärkeimmät spektroradiometrimittaustulosten käytännön sovellutusmahdollisuudet liittyvät ilmakuvien ja satelliittikuvien käyttöön. Kun puiden latvusten peittävyys on Lapin olosuhteissa usein alle 30 % ja luontaisesti tai hakkuiden johdosta puuttomia alueita on runsaasti, latvusten välisen taustan heijastusominaisuudet korostuvat kuvatulkinnassa. Ilmakuvauksiin tutkimustuloksia voidaan soveltaa valitsemalla kuvauksiin sopiva filmi-suodatinyhdistelmä tai käyttämällä kuvakopioiden teon yhteydessä huonot aallonpituudet suodattavaa suodinta.

Satelliittikuvien tulkinnassa voidaan kasvupaikkaeroja etsiä tutkimuksessa parhaiksi havaittujen aallonpituuskanavayhdistelmien avulla. Vastaavasti tuotettaessa useiden aallonpituuskanavien yhdistelmänä värikompositioita visuaalista tulkintaa varten kyetään valitsemaan kasvupaikkojen värisävyerot maksimoiva kanavayhdistelmä.

Spektrisen heijastussäteilyn ja maastomuuttujien välisten yhteyksien selvittäminen on tällä hetkellä lähinnä kaukokartoituksen ja sitä hyväksi käyttävien tieteenhaarojen yhteistä perustutkimusta. Spektroradiometrimittauksia kannattaa kuitenkin harkita ilma- ja satelliittikuvilta tehtävien käytännön kasvillisuus- ja maaperäkartoitusprojektien esivaiheena. Tällöin ominaisspektritiedoista olisi hyötyä varsinkin tapauksissa, jolloin on epävarmuutta kohteiden erottuvuudesta ja tulkinta aiotaan perustaa sävyeroihin.

Ritari, A. & Saukkola, P. 1985. Spectral reflectance as an indicator of ground vegetation and soil properties in northern Finland. Seloste: Spektrinen heijastussäteily pintakasvillisuuden ja maan ominaisuuksien kuvaajana Pohjois-Suomessa. Commun. Inst. For. Fenn. 132: 1—37.

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The goal of the present study was to clarify through spectroradiometric measurement the degree to which four forest site types common in northern Finland can be distinguished on the basis of the spectral reflectance of ground vegetation and surface soil (wavelength range 0.5—1.0 μm). In addition, the optimal wavelenghts for discrimination of the sites, the effects of the measurement conditions and the correlation of certain physical and chemical properties of the ground vegetation and soil with the reflectance factors on different wavelenght channels were studied. The statistical methods used were Mann-Whitney's U-test, correlation and regression analysis.

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Huomautuksia
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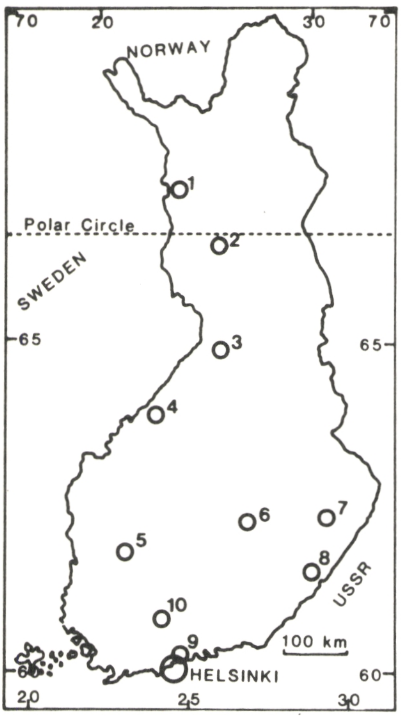


## THE FINNISH FOREST RESEARCH INSTITUTE

DEPARTMENTS (Helsinki)

Administration Office
Information Office
Experimental Forest Office
Dept. of Soil Science
Dept. of Peatland Forestry
Dept. of Silviculture
Dept. of Forest Genetics
Dept. of Forest Protection
Dept. of Forest Technology
Dept. of Forest Inventory and Yield
Dept. of Forest Economics
Dept. of Mathematics

RESEARCH STATIONS

1 Kolari
2 Rovaniemi
3 Muhos
4 Kannus
5 Parkano
6 Suonenjoki
7 Joensuu
8 Punkaharju
9 Ruotsinkylä
10 Ojajoki

## FACTS ABOUT FINLAND

*Total land area:* 304 642 km$^2$ of which 60—70 per cent is forest land.

| *Mean temperature, °C:* | Helsinki | Joensuu | Rovaniemi |
|---|---|---|---|
| January | -6,8 | -10,2 | -11,0 |
| July | 17,1 | 17,1 | 15,3 |
| annual | 4,4 | 2,9 | 0,8 |
| *Thermal winter (mean temp.* $<$ 0°C): | 20.11.—4.4. | 5.11.—10.4. | 18.10.—21.4. |

*Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens*

THE FINNISH FOREST RESEARCH INSTITUTE ● METSÄNTUTKIMUSLAITOS

## Communicationes Instituti Forestalis Fenniae

129 Sepponen, P. The ecological classification of sorted forest soils of varying genesis in northern Finland. Seloste: Syntytavaltaan erilaisten lajittuneiden kangasmetsämaiden ekologinen luokittelu Pohjois-Suomessa.

130 Uusvaara, O. The quality and value of sawn goods from plantation-grown Scots pine. Seloste: Viljelymänniköistä saadun sahatavaran laatu ja arvo.

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132 Ritari, A. & Saukkola, P. Spectral reflectance as an indicator of ground vegetation and soil properties in northern Finland. Seloste: Spektrinen heijastussäteily pintakasvillisuuden ja maan ominaisuuksien kuvaajana Pohjois-Suomessa.

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