TREE - COVER CROP INTERACTIONS: BIRCH GROWTH, COMPETITION AND SOIL PROPERTIES

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Abstract

The main objective of this thesis was to investigate tree - cover crop interactions and soil response in an intercropping system, in which leguminous and grass cover crops were used with birch (red-leaved Downy birch *Betula pubescens* L.). The investigation was conducted in two field experiments in a nursery and in a greenhouse experiment. In the latter the effect of the water supply in interspesific competition was also investigated. The cover crops in the field experiments were perennial clovers *Trifolium pratense* L., *T. repens* L. and *T. hybridum* L. and annual clovers *T. incarnatum* L., *T. resupinatum* L. and *T. subterraneum* L. and perennial *Festuca rubra* L. The height, stem diameter, leaf area and nutrient status of the birch were determined, as well as soil nutrient status and microbial characteristics. The cover crops in the greenhouse experiment were *T. repens*, *T. subterraeum* and *F. rubra*. The biomass, height, leaf area, leaf area index, specific leaf area and N concentration of the birch, the biomass and N concentration of the cover crops were measured, and soil N and microbial characteristics, as well. Bare ground was the control in all the experiments.

The perennial clovers and *Festuca* strongly decreased the birch growth and nutrient status, but the annual clovers sown in midsummer in the field experiments provided about as good growth as bare ground. In the greenhouse experiment all cover crops were effective competitors with the birch. The soil NO_3-N was, in general, the highest on bare ground and second highest in the annual clover plots. Though there were, in general, only minor differences in the soil nutrient concentrations between the treatments, there were significant differences in the tree growth and nutrient concentrations. The interspecific competition in this kind of intercropping system is mainly belowground. The growth reduction in the birch was mainly due to competition for nitrogen but water seems to play an important role in regulating the competitive interaction between the birch and cover crops. The competition for these resources seems to be most crucial at the beginning of the growing season. The microbial biomasses and soil respiration were greatest in the *Festuca* and perennial clover treatments, which may indicate that microorganisms together with these cover crops may seriously compete with birch for nutrients.

Intercropping system is complex and comprises both negative and positive influences. In order to minimize negative competition effects, the cover crop should be non-competitive or the ground should be kept free of vegetation at the beginning of the growing season. By improving soil microbial characteristics, the vegetative ground covers make this cropping system one possiblity towards sustainability in the long-term.

Keywords: Betula pubescens, *Festuca*, nutrient status, *Trifolium*, water supply

To my parents

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Oulu, May, 2002 Kaarina Hänninen

Abbreviations

C_{mic}	microbial biomass-C
dw	dry weight
LAI	leaf area index (leaf area/ground area)
OM	organic matter
qCO_2	microbial metabolic quotient (basal respiration/C_{mic})
RC_R	relative change in belowground biomass
RC_T	relative change in total biomass
RC_S	relative change in aboveground biomass
SIR	substrate induced respiration
SLA	specific leaf area (leaf area/leaf mass)

List of original articles

This thesis is based on the following articles, which are referred to in the text by their Roman numerals.

I Hänninen KS (1998) Effects of clovers as vegetative ground cover on the growth of red birch in nursery field production. J Hort Sci Biotechnol 73: 393–398.

II Hänninen K, Ohtonen R and Huttunen S (1999) Effects of leguminous ground cover competition on red birch and soil nutrient status in the nursery. Plant Soil 216: 129–138.

III Hänninen K, Strömmer R, Ojala R and Hyvärinen M (2002) Competition between birch and ground cover vegetation at different levels of water supply. Manuscript (submitted).

IV Hänninen K, Strömmer R, Ojala R & Hyvärinen M (2002) Effect of clover and fescue ground covers on microbial biomass and activity in an intercropping system with birch. Manuscript (submitted).

Contents

1 Introduction

1.1 Towards more sustainable production systems

Increasing concern over the environment is forcing horticulture, agriculture and forestry to search for alternative, sustainable production systems. The concept of sustainability is multi-dimensional and is defined according to Kennedy and Smith (1995) as "the adoption of practices that allow for the long-term maintenance of the productive capacity, the viability and quality of life, and conservation of the environment and resource base". Questions have been raised concerning the long-term impacts of repeated tillage, the application of pesticides and synthetic fertilizers on the soil quality (e.g. Ghadiri & Payne 1986, Glenn & Welker 1989, Meagher & Meyer 1990, Hipps & Samuelson 1991, Lipecki & Berbec 1997, Goh *et al*. 2001). The use of vegetative ground covers has been studied as one possibility towards sustainability (e.g. Bugg *et al*. 1991, Calkins 1991, Merwin *et al.* 1994, Walsh *et al*. 1996a, Neilsen & Hogue 2000). In this practice, the soil under the main crop is covered with another plant species. This, however, creates interspecific competition and one species may suffer because of resource competition or interference from another species (Begon *et al*. 1996). Interference is mainly understood as allelopathy (Tilman 1990, Begon *et al*. 1996) and resource competition as a mutually negative interaction between species when they consume the same, limited resources (Grover 1997).

In agroecology, interspecific competition has been studied mainly to increase our comprehension about crop – weed competition, optimizing efficiency in intercropping systems and solving spatial problems i.e. to optimize plant density in order to maximize yields in relation to the seed input (Radosevich & Roush 1990, Kropff & Goudriaan 1994). Intensive studies of the interactions between trees and herbaceous plants have been carried out in agroforestry (Ong *et al*. 1991, Ziehm *et al*. 1992, Anderson & Sinclair 1993, Alley *et al*. 1999, Dupraz *et al*. 1999), in the savannah ecosystem (Scholes & Archer 1997) and in temperate and boreal forest plantations (Haines *et al*. 1978, Davey & Wollum 1984, Cogliastro *et al*. 1990). With the increasing interest in alternative production systems in orchards, the impact of herbaceous ground cover on fruit trees has been investigated (Meyer *et al*. 1992, Parker *et al*. 1993, Merwin & Stiles 1994, Hornig &

Bünemann 1995, Creamer *et al*. 1996, Neilsen & Hogue 2000) and some work has also been done with woody plants under landscape conditions (Kristensen 1991). Very little research has been done in the nursery field production of woody plants (Calkins 1991), in which high growth capacity is needed, and good, even exponential nutrient loading for the seedlings is used to garantee a good start after planting (Timmer 1997). The repeated cultivations and synthetic inputs (pesticides and fertilizers), which belong to common production practices in nurseries, have increased concerns about the environment and financial benefits, too. These are forcing the industry to look at alternative production systems, of which the use of cover crops is of great interest (Calkins & Swanson 1996).

1.2 Cover crop and competition

In tree – cover crop systems, where relatively wide spacing is used, the competition for resources is mainly belowground. The aboveground abiotic factors, e.g. light, temperature and humidity are usually of minor importance (Ong *et al*. 1991, Casper & Jackson 1997, Köchy & Wilson 2000). In belowground competition, plants reduce the available soil resources, mainly water and mineral nutrients and decrease the growth and success of their neighbours (Casper & Jackson 1997). The competition for water is believed to have an important role in competition between woody seedlings and herbaceous vegetation (Bohne & Rauch 1996, Davis *et al*. 1999), even though contradictory results exist (Bohne & Rauch 1996, Picon-Cochard *et al*. 2001). In general, it has been suggested that root competition is more important than shoot competition and has a greater impact on plant performance (Wilson 1988, Gerry & Wilson 1995, Weiner *et al*. 1997). However, often the manner in which plants compete is not properly known (Caldwell *et al*. 1985, Kropff & Goudriaan 1994, Schwinning & Weiner 1998, Cahill & Casper 2000).

The suppression of tree growth has been a major problem when cover crops are used (Foshee *et al*. 1995, Calkins & Swanson 1996, Walsh *et al*. 1996a, Alley *et al*. 1999). To have successful tree – cover crop combinations, it is important to find non- or weak-competitive cover crop species (Calkins & Swanson 1995, Parker & Meyer 1996). Furthermore, it is not only important, that the cover crop does not compete for water and nutrients with the tree, but it should not be allelopatic either (Weller *et al*. 1985, Putnam 1986, Skroch & Shribbs 1986); it should have a good weed suppression ability (Echtenkamp & Moomaw 1989, Creamer *et al*. 1996) and it should positively affect the soil quality (Meagher & Meyer 1990, Merwin *et al*. 1994, Walsh *et al*. 1996a). Also, the cover crop should not attract pests but rather sustain beneficial insects (Haley & Hogue 1990, Alston 1994, Bugg & Waddington 1994, Smallwood 1996, Stanyard *et al*. 1997).

Because nitrogen has been considered to limit plant growth most frequently after water stress (Kozlowski *et al*. 1991), legumes have been regularly studied as vegetative ground cover in order to improve the nitrogen economy of the plants and the overall soil quality, (e.g. Haines *et al*. 1978, Hoyt & Hargrove 1986, Bugg *et al*. 1991, Ziehm *et al*. 1992, Gillespie *et al*. 1995, Wagger *et al*. 1998, Alley *et al*. 1999, Dupraz *et al*. 1999, Neilsen & Hogue 2000). Legumes have often proved to be too competitive with a tree (Shribbs & Skroch 1986a, Meyer *et al*. 1992, Calkins & Swanson 1995, Alley *et al*. 1999) but also positive interactions have been shown, e.g. *Platanus* with *Trifolium subterraneum* and

Trifolium incarnatum (Haines *et al.* 1978), *Acer* with *Trifolium repens* (Bohne & Rauch 1996), and *Vitis* with *Trifolium subterraneum* (Klik *et al*. 1998). Though grasses have proved to be strong competitors (Bohne & Rauch 1996, Calkins & Swanson 1996, Parker & Meyer 1996, Walsh *et al*. 1996a, Alley *et al*. 1999, Neilsen & Hogue 2000), they also have many good cover crop characteristics, e.g. improving the soil quality.

1.3 Soil responses to cover crops

Soil quality has been the object of growing interest during the last years and several authors have confirmed intergrated or organic management systems to be associated with better soil quality (e.g. Hoyt & Hargrove 1986, Karlen *et al*. 1999, Liebig & Doran 1999, Glover *et al*. 2000, Islam & Weil 2000, Goh *et al*. 2001). Though the overall soil quality is difficult to define, many authors have made propositions (Doran & Parkin 1994, Stenberg 1999). Karlen *et al*. (1997) defined soil quality as "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enchance water and air quality, and support human health and habitation". This concept gives the idea about soil being a key natural resource and its fundamental importance in sustainable production systems.

A lot of work has been done regarding the studies of the physical and chemical characteristics of soil in intercropping systems, e.g. the structure (Hoyt & Hargrove 1986, Calkins 1991, Walsh *et al*. 1996a, Karlen *et al*. 1999, Glover *et al*. 2000), moisture (Calkins 1991, Merwin *et al*. 1994, Hornig & Bünemann 1996b, Walsh *et al*. 1996a), nutrient status and pH (Haynes & Goh 1980, Hoyt & Hargrove 1986, Calkins 1991, Hipps & Samuelson 1991, Hornig & Bünemann 1996b). The results especially show that the physical indices of soil have been improved by cover crops and less tillage. An increase in the soil organic C by vegetative ground covers has also been reported (Hoyt & Hargrove 1986, Hogue & Neilsen 1987, Hipps & Samuelson 1991).

Grasses and N_2-fixing plants like legumes have often been reported to enchance the soil quality. Grasses, in general, have an extensive root system and their positive influence on the physical (Oades 1984, Drury *et al*. 1991, Haynes & Francis 1993, Carter *et al*. 1994, Walsh *et al*. 1996a, Chantigny *et al*. 1997, Haynes & Beare 1997) and biological properties of soil (Drury *et al*. 1991, Haynes & Francis 1993, Haynes & Beare 1997) is well known. Grasses can also prevent the leaching of agrochemicals (Glenn & Welker 1989, Merwin *et al*. 1996, Wiedenfeld *et al*. 1999). The most important property of legumes as a cover crop may be their positive influence on nitrogen cycling (Hoyt & Hargrove 1986, Breland 1994, Harris *et al*. 1994, Wagger *et al*. 1998). Besides grasses, legumes have also been reported to positively affect the physical (Hoyt & Hargrove 1986, Haynes & Beare 1997, Mullen *et al*. 1998, Wagger *et al*. 1998), and biological (Doran *et al*. 1987, Drury *et al*. 1991, Kirchner *et al*. 1993, Harris *et al*. 1994, Haynes & Beare 1997, Mullen *et al*. 1998) characteristics of soil.

According to Kennedy and Smith (1995) the maintenance of viable and diverse microbial communities in soil is essential to sustainable agriculture. Microorganisms decompose organic matter, release nutrients into plant-available forms and affect the soil aggregation, having thus an essential role in the nutrient cycling and formation of the soil structure (Sparling 1997, Stenberg 1999). Though it has not been possible to have any critical values for the microbial characteristics in good soil, many authors consider microbial fraction to be, due to the fast rate of turnover, a sensitive indicator and an early predictor in changes in the soil processes and soil quality (Campbell *et al*. 1992, Sparling 1997, Torstensson *et al*. 1998, Kandeler *et al*. 1999, Karlen *et al*. 1999, Stenberg 1999, Bending *et al*. 2000, Goh *et al*. 2000, Islam & Weil 2000).

The interactions between plants and soil microbes comprise of a complex network of both positive and negative influences. Fine-root production has a substantial influence on the building up of soil carbon storage. Cover crops have long been recognised in agriculture in this respect (Hoyt & Hargrove 1986, Wagger *et al*. 1998). There are plant-induced quantitative and qualitative variations in the fine root production and carbon flow to the soil, however, and different plant species maintain a different microbial biomass and activity (Drury *et al*. 1991, Haynes & Francis 1993, Groffman *et al*. 1996, Chantigny *et al*. 1997, Angers & Caron 1998, Mullen *et al*. 1998). Soil micro-organisms make nutrients available for plants via mineralization processes, but they also use belowground resources for their own growth and thus can be real competitors with plants (Kaye & Hart 1997, Korsaeth *et al*. 2001). The competition for nitrogen between micro-organisms and plants has been found even in relative fertile sites (Kaye & Hart 1997, Stark & Hart 1997). The complexity of these interactions may also have important consequences for tree – cover crop systems.

To sum up, tree – cover crop system concerns many factors above- and belowground (Fig. 1). These can have significant effects on major processes in agricultural ecosystems and positively influence the soil and environmental quality in a long-term (Reicosky & Forcella 1998, Wardle *et al*. 2001). The interspecific competition, which is obvious in an intercropping system, is still inadequately known. The selection of species to be used as cover crops plays a key role because of the species specific effects on both the main crop and the soil.

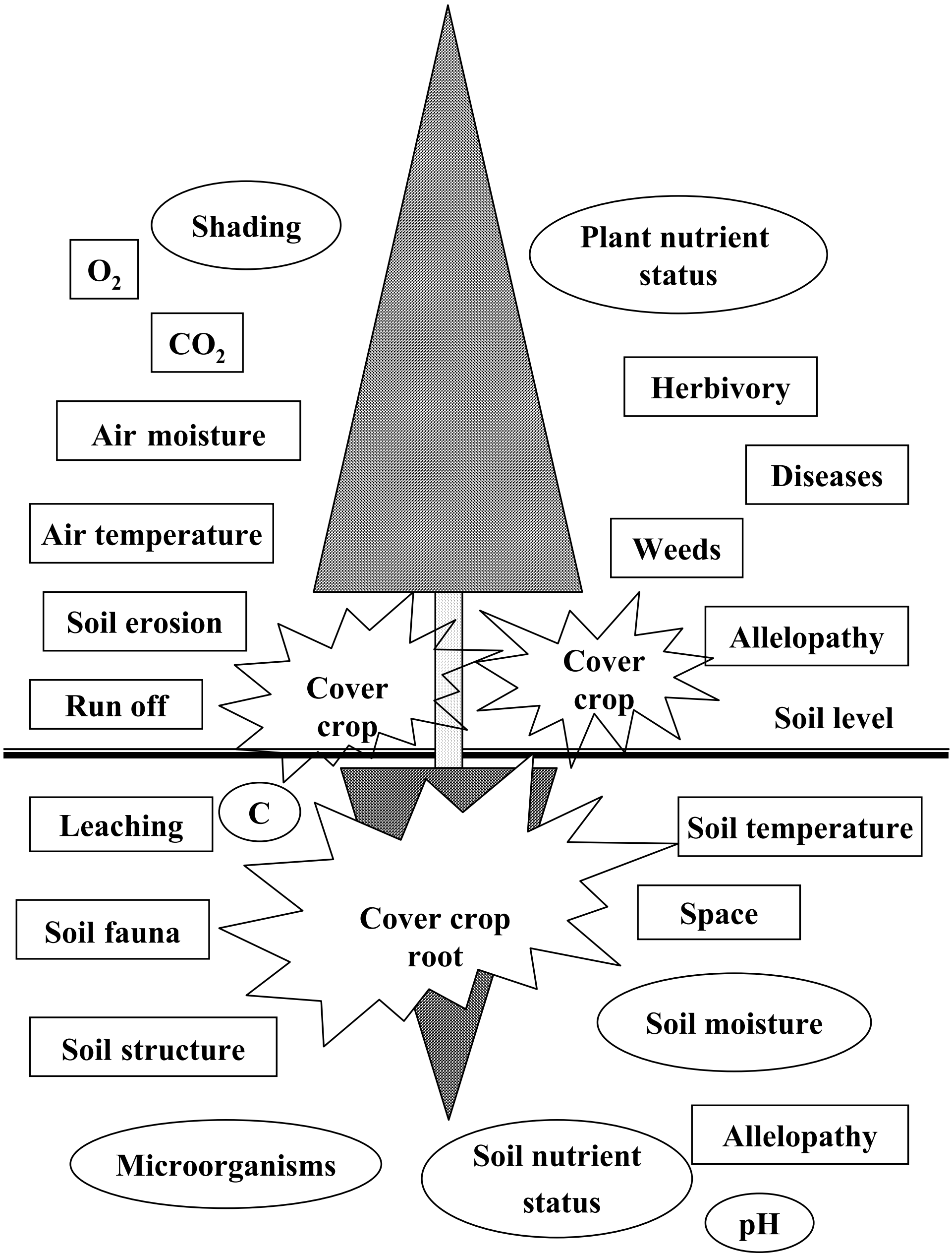

Fig. 1. Schematic representation of the factors concerning in tree – cover crop system above- and belowground. The factors presented in the ellipses are discussed in the present study.

2 Aims of the research

The main objective of this thesis was to investigate tree – cover crop interactions in an intercropping system. This was carried out, first, by studying the effects of leguminous and grass ground covers on birch in an intercropping system in a nursery field (I, II). Second, in a greenhouse experiment the effects of different levels of water supply on the competition between birch and cover crops was studied (III). In both experiments the soil chemical and microbiological properties were also studied (II, IV). 'Red birch' (red-leaved Downy birch *Betula pubescens* Ehrh. *f. rubra* Ulvinen) was chosen for this study, firstly, because it is a new and interesting tree for landscaping and, secondly, because the micropropagated, genetically uniform plant material was available. Clovers (*Trifolium* spp.) were chosen as cover crops mainly from a soil biological point of view. Many clovers also grow well in northern environments. Because of the relatively low growing habit they can be optimal as cover crops. The grass cover crop (*Festuca rubra* L.) was chosen because grasses tend to have many good properties as ground cover; though they may also have negative effects on the main crop. Bare ground was the control, being a widely used approach in nurseries.

The main objective of this thesis can be divided into the following themes:

1. to analyse the response of growth and nutrient uptake of birch to competition with leguminous and grass cover crops (I–III),
2. to determine the importance of water as a limiting resource for birch in competition with leguminous and grass cover crops (III),
3. to examine the soil nutrient status as affected by leguminous and grass cover crops (II), and
4. to evaluate the effects of leguminous and grass cover crops on microbial biomass and activities in soil (IV).

3 Materials and methods

3.1 Experimental designs

3.1.1 Field experiments

Two field experiments, each of two years' duration were conducted between 1992–1995 in a nursery at Kempele Institute of Horticulture (65°00´N, 25°30´E). The experiments were established on a former *Ribes rubrum* L. field, which had been uncultivated for three years prior to the experiments and were rototilled to remove weeds. Seven clover plots and one *Festuca rubra* L. 'Ensylva' plot were established in a randomized blocks design with four replications. There were four perennial clovers, *Trifolium pratense* L. 'Bjursele', *T. repens* L. 'Jogeva' *T. repens* L. 'Sonja' and *T. hybridum* L. 'Frida', and three annual clovers, *T. incarnatum* L. 'Opolska', *T. resupinatum* L. and *T. subterraneum* L. The control, coverless ground, was kept weed free by hand hoeing. The information referring to the sowing which took place in 1992 is presented in paper I. In the following years the annual clovers were resown yearly at the end of June and the perennial clovers were resown accordingly to winter survival at about the same time. The halm of the clover from the previous year was mixed into the soil of the respective plot just before sowing. (I–II, IV)

For the first experiment, two birches were planted from four months old micropropagated plants 75 cm apart on each plot. They were planted on 18 June, 1993 and harvested destructively on 3 September, 1994. The second experiment was carried out from 21 June, 1994 to 29 August, 1995. Fertilizers were not used in order to better determine the relative impacts of the ground cover treatments on the nutrient status in the soil. (I–II, IV)

3.1.2 Greenhouse experiment

The experiment was carried out in a greenhouse situated in the Botanical Gardens at the University of Oulu from 14 Dec 1998 to 9 March 1999 (III, IV). A total of 48 seven months old dormant micropropagated birch plants were planted in 25 cm diameter pots with 7.5 kg mull-sand mixture (3:1 vv). A split-plot experimental design was applied. The main plots received three watering levels of 1, 1.5 or 2 l of water per pot per week. The sub-plots consisted of one of each of the cover crop treatments: bare ground as the control and three cover crops, perennial *Trifolium repens* L. ′Sonja′, annual *Trifolium subterraneum* L. 'Nuba' and perennial *Festuca rubra* L. ′Ensylva′. The cover crops were seeded after planting the trees, and the control pots were left intact.

At the beginning of the experiment all the pots were watered in the same way. The watering treatments began after the leaf burst of the birch, two weeks from planting. The plants were kept in 20/18ºC day/night temperatures and the greenhouse was illuminated by Phillips SON-T 400 bulbs 150 W/m^2 following 18/6 h diurnal rhythm during the experiment. No fertilizers were used.

3.2 Plant analyses

To determine the ground cover effect on the tree growth, the height of the plants (I, III) and the stem diameter 20 cm above ground level were measured (I). The leaves were counted at harvesting (I), and the leaf area was determined with the help of a digital image analyser (Microscale TM/TC, Digithurst Ltd) using a video camera (Hitachi CCD KP-C571) (I, II), and the LAI (leaf area index: leaf area/ground area) and the SLA (specific leaf area: leaf area/leaf mass) were calculated (III).

For the nutrient analysis (II, III) and for the dry mass determination (III) the birches and the cover crops (III) were harvested destructively at the end of the experiments. The leaves, stems, branches and roots were separated, and the roots were washed. All parts of the plant were kept frozen (II) and before the analyses dried at a temperature of 60ºC. The samples were ground into a fine powder (through <1 mm mesh) and then compressed into a flat disc in a hydraulic press. The discs were stored in a desiccator until used for the elemental analyses. Concentrations of P, K, Ca, Mg, Fe, S, Mn, Zn, Ni, Cu, Al and Si were determined using X-ray fluorescence spectrometer (Siemens SRS 303 AS) with an AG Rh 66 anode and Lif 100, PET (pentaerythritol) and OVO 55 crystals. Standard Reference Material 1575 (SRM 1575) (National Institute of Standards and Technology, NIST) was used as the standard. The concentrations of Cu in the roots, stems and branches and Ni in all parts of the plant were below the detection limit of about 5 ppm. In order to determine the total N (II), the oven-dried samples were digested using the Kjeldahl method (Bremner & Mulvaney 1982). In the greenhouse experiment (III) nitrogen concentrations of the dried plant parts (60ºC) were analyzed using a CHNS analyser EA1110, (CE Instruments).

In the greenhouse experiment (III), the relative change in the biomass of the birch grown with different cover crops and watered using 1, 1.5 and 2 l/week, compared to the biomass of the birch grown without competition on an unlimited water supply, was calculated as follows:

Relative change in total biomass $RC_T = (TB_{NGC2} – TBcomp)/ TB_{NGC2}$
Relative change in belowground biomass $RC_R= (RB_{NGC2} – RBcomp)/ RB_{NGC2}$
Relative change in aboveground biomass $RC_S= (SB_{NGC2} – SBcomp)/ SB_{NGC2}$

where TB_{NGC2} is the total biomass of the birch growing without competition and watered using 2 l/week and TBcomp is the biomass of the birch from each cover crop and watering treatments. RB_{NGC2}, SB_{NGC2}, RBcomp and SBcomp are respective root and shoot biomasses. These were used as indices of the competition intensity between the birch and cover crops. Values ranging from 0 to 1 indicate a negative effect of ground cover vegetation on the birch growth and the larger the value the higher the intensity of competition is (Belcher *et al*. 1995).

3.3 Soil nutrient analyses

For the soil analyses (II), samples were collected at depths of 0–20 cm and 20–50 cm at the end of May and at the turn of August/September between 1993–1995. The samples were stored frozen (–18ºC). Soil pH was determined potentiometrically from distilled water extracts using glass electrodes. The total N was determined using the Kjeldahl method (Bremner & Mulvaney 1982). NO_3–N was extracted with water and determined colorimetrically (Koroleff 1973). Ammonium acetate (1 M, pH 4.65) was used to extract exchangeable cations. P was determined colorimetrically, using ammoniummolybdate and ascorbic acid as reagents (John 1970). K, Ca, Mg, Fe, Mn, Zn and Cu were determined by Atomic absorption spectrophotometer. The soil Cu was below the detection limit in most cases.

3.4 Soil moisture and microbial characteristics

The soil samples collected for the nutrient analyses in August/September were used also for microbial analyses in the field experiment (IV). The samples were stored frozen (–8ºC). In the greenhouse experiment (IV), the soil samples were collected at the end of the experiment and also stored frozen (–18ºC). The soil moisture (105ºC over night) was determined gravimetrically.

From the soil samples duplicate or triplicate analyses were made for microbial biomass and basal respiration by using a respirometer (Nordgren 1988, Nordgren *et al*. 1988). The sample weight was calculated to correspond to one gram of OM in a sample. The basal respiration rate was first analysed for a 40-hour-stable respiration-period, after which substrate induced respiration (SIR) was analysed for a five-hour-period after an addition of 200 mg glucose, 22 mg of N as $(NH_4)_2SO_4$ and 2.4 mg of P as KH_2PO_4 per sample by vigorous shaking. The microbial biomass-C (C_{mic}) was calculated from SIR by using an equation modified from Anderson & Domsch (1978). The relative measurement of specific activity, i.e. microbial metabolic quotient (qCO_2) was calculated as a ratio of basal respiration to C_{mic} (Anderson & Domsch 1990) and is used here as a measure of microbial inefficiency (Wardle & Ghani 1995).

3.5 Data analyses

In the field experiments (I–II) a two-way analysis of variance (ANOVA) was used to test the effects of the ground cover management system on the growth of the birch and the nutrient concentrations of the birch and soil. The means were separated by an LSD-test for $\alpha < 0.05$. Pearson's correlation coefficient were calculated in order to detect the relationships between the tree growth and nutrient status. MSTAT statistical software was used. To analyze the effects of the ground cover management system on microbial charasteristics of soil in the field experiment (IV) a two-way analysis of variance was used for evaluating the effects of treatment and year and their interaction on the measured variables. ANOVA was followed by Tukey's HSD test for pairwise comparison of the treatments. These statistical tests were made by using a statistical package SAS (SAS Institute Inc. 1989). In the greenhouse experiment (III, IV), the data was analysed as split-plot ANOVA using R statistical software (Ihaka & Gentleman 1996) watering level and cover crop being main factors. When analysing the effect of watering treatment, the block*watering was used as an error term, and when analysing the effect of cover crop and cover crop*watering interaction, block*cover crop*watering was used as an error term.

3.6 Meteorological data

There were considerable differences in the weather between the years the field experiments took place. The first summer 1992 was unusually wet and the summers 1993 and 1994 were dry. The rainfall from May to September between the years 1992–1995 was 370, 177, 173 and 228 mm (cf. the average rainfall of 243 mm for 1961–1990). May 1993 (7 mm) and 1994 (14 mm) as well as July 1994 (17 mm) were exceptionally dry periods during the field experiments. June 1993 (36 mm) was also rather dry (Finnish Meteorological Institute 1992–1995).

4 Results

4.1 Plant growth

All the measured growth parameters of the birch were strongly affected by cover crop competition and the greatest effect was found in the leaf area (I, III). In the second field experiment the birches grown with the perennial clovers had 55 % and those growing with *Festuca* 90 % less leaf area than those growing on bare ground. In contrast, the annual clovers as cover crops increased their leaf area by 17 % (I). In the greenhouse experiment all cover crops decreased the birch leaf area as well as leaf biomass by about 30 %. Also the leaf area index (LAI) of the birch was clearly lower in the cover crop treatments than on bare ground (III).

In the field experiments (I) the birch height and stem diameter increments were about the same in the plants grown on bare ground as with the annual clovers. In competition with the perennial clovers the birch height increment was lowered by 44 % and the stem diameter by 57 % compared to the situation on bare ground. *Festuca* as a cover crop decreased stem growth even more, the stem height increment being 71 % and the stem diameter increment being 80 % smaller compared to the control (I). In the greenhouse experiment (III), *T. repens* reduced the birch height growth by 11 % and *T. subterraneum* and *Festuca* by more than 20 %. The total biomass of the birch was 23–27 % lower in competition with the cover crops compared to a non-competitive situation.

In the greenhouse experiment (III) the biomass of the birch was 20 % lower at the lowest compared to the two higher watering levels, though the watering level did not significantly affect the biomass or other growth parameters of the birch. It should be mentioned, however, that at the lowest watering level, the specific leaf area (SLA) of the birch was higher in all cover crop treatments compared to the birch growing on bare ground. Though neither competition nor water supply affected the biomass allocation of the birch, there was a trend that in non-competitive conditions the biomass allocation to the roots increased with increasing water supply but in competition the trend was opposite.

In the greenhouse experiment (III), the total biomass of the cover crops per pot was generally larger than the biomass of the birch in the same pot. The largest biomass among the cover crops was gained by *T. subterraneum*, followed by *F. rubra* and *T. repens*. The root biomass of *Festuca* was four and 2.5 times larger than that of *T. repens* and *T. subterraneum*, respectively. The watering level significantly affected the shoot biomass of the cover crops, the biomasses being lowest at the highest watering level. The biomass allocation to the roots by *Festuca* was highest at the highest watering level, but the clovers did not show any clear trend in this respect.

4.2 Plant nutrient status

In the field experiment (II) the impact of the ground cover on tree nutrition was most pronounced in the birch leaves, in which the treatments differed significantly in all elements, except in Ca in the second experiment (Fig. 2). In most cases, there were also significant differences between the treatments in the concentrations of the elements in the stems, branches and roots. The concentrations of N, K, Fe, S, Al and Si in various parts of the birch were generally the highest on bare ground, second highest in the annual clover plots and the lowest in the *Festuca* plots. The order was opposite in P, Mg, Mn and Zn concentrations, the values being highest in the *Festuca* plots, second highest in the perennial clover plots and lowest on bare ground. The nutrient concentrations of the birch in the annual and perennial clover plots usually differed distinctly, but Fe, Al and Si concentrations were at about the same level in both clover groups. There were significant positive correlations between the birch growth and the leaf N, K, S, Fe, Al and Si concentrations as well as the root N and Fe concentrations (data not shown). On the contrary, the birch growth correlated negatively with the leaf P, Mg and Mn concentrations and with Mg and Mn concentrations in the stems and branches and in the roots.

In the greenhouse experiment (III) the highest N concentrations in the birch were recorded on bare ground and the lowest in competition with *Festuca*. The N concentration, in general, increased by decreasing the water supply, the difference being significant in all parts of the birch except the coarse roots.

The ground cover had a great impact on the relative amounts of nutrients in the birch leaves in the field experiment (II). Leaf N/P, N/Mg and K/P were distinctly higher on bare ground and in the annual clover plots than in the perennial clover and the *Festuca* plots. N/K was about the same in all treatments. In the stems and branches and in the roots the nutrient ratios were more uniform than those in the leaves. The greatest differences were found in N/Mg in the stems and branches, in which the ratio was highest on bare ground and in the annual clover plots, somewhat lower in the perennial clover plots and much lower in the *Festuca* plot. The same pattern was observed in N/P, N/K and N/Mg in the roots.

In the greenhouse experiment (III) the N concentrations of the clovers were distinctly higher than those of *Festuca*. The N concentrations of the clovers were slightly higher in the roots than in the shoots. The situation was opposite in *Festuca*. The watering level did not affect the cover crop N concentrations.

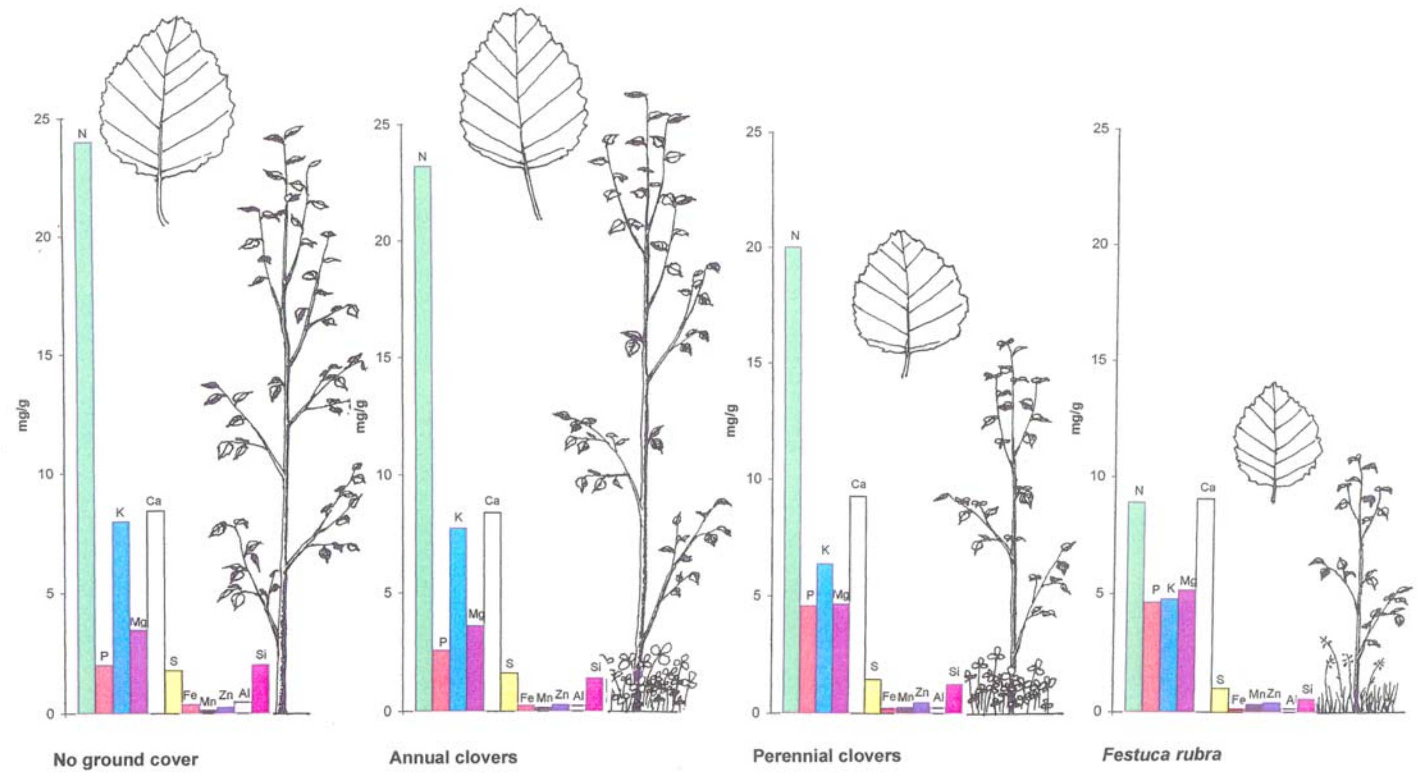

Fig. 2. Leaf nutrient concentrations (mg/g dw) and relative tree and leaf sizes of the birches grown with the annual clovers, perennial clovers and *Festuca rubra* as compared to the birch grown on bare ground in the field experiment in 1995 (I, II). (Hänninen K. & Härmä E.)

4.3 Nutrient status in soil

Towards the end of the experiments in the field, soil pH and the nutrient concentrations increased in most cases, but there were generally no significant treatment effects (II). The soil acidity was greater in the upper than in the deeper soil layer and on bare ground it was significantly higher than in the cover crop treatments. There were no treatment effects on the total N in the surface soil layer, but in the deeper layer the total N was generally the highest on bare ground treatment (II). NO_3–N concentrations were generally the highest on bare ground, second highest in the annual clover plots and the lowest in the *Festuca* plots. K showed the same trend, the values being generally the highest on bare ground in the surface soil layer. In the deeper soil layer soil K was generally the highest on bare ground and in the *Festuca* plots. There were no significant differences in P concentrations between the treatments in either of the soil layers, though P varied more in the deeper layer. The P concentration in the surface soil layer remained on a constant level during the first two years, but increased considerably in the last year. There were no significant differences in the other nutrients in soil.

4.4 Soil microbial characteristics

The basal respiration in the surface soil layer in the field experiment (IV) was on average 1.30 ± 0.04 and in the deeper soil layer 0.31 ± 0.01 µg CO_2–C g^{-1} dw h^{-1}. The basal respiration was significantly higher in the *Festuca* plots than under the annual clovers or on bare ground. The basal respiration in the surface soil layer was generally highest in 1993 and lowest in 1994, and the deeper soil layer showed an increasing trend from 1993 to 1995 irrespective of the cover crop treatment. However, no such trend was noticed in the surface soil layer. The microbial biomass (C_{mic}) in the surface soil layer was on average 0.31 ± 0.01 and in the deeper soil layer 0.07 ± 0.004 mg C g^{-1} dw. C_{mic} was larger in the *Festuca* plots than in any of the other treatments. The lowest C_{mic} value was found on bare ground, which was significantly lower than in all the perennial clover plots. C_{mic} in the deeper soil layer showed an increasing trend from 1993 to 1995 irrespective of the cover crop treatment, but no such trend was noticed in the surface soil layer. C_{mic} in the surface soil layer was generally higher in 1993 than in 1994 or 1995. Specific activity measure, microbial metabolic quotient, showed some variation between the years but was not affected by any of the treatments, as the soil moisture and organic matter content, too. The soil moisture and organic matter content did not show any treatment effects, except only in the deeper soil layer, where the soil was moister and its OM content was larger on bare ground than in most of the other treatments. There was some yearly variation in moisture but not in OM.

The basal respiration in the greenhouse experiment (IV) was on average 0.61 ± 0.04 µg CO_2–C g^{-1} dw h^{-1}. The basal respiration tended to decrease with increasing watering level. There was no difference between the cover crop treatments. C_{mic} was on average 0.10 ± 0.005 mg C g^{-1} dw. It did not show any difference between the watering treatments but tended to be lower on bare ground than in the other treatments.

5 Discussion

5.1 Tree growth and competition

Competition affected strongly birch growth. This was especially seen in the greatly reduced leaf size (I), leaf area (I, III) and LAI (III) of the birch when growing with clovers or *Festuca*. Also Shribbs & Skroch (1986a) reported a decreased leaf size in apple trees because of competition with grasses and Kolb and Steiner (1990) a decreased leaf area in oak and yellow-poplar in competition with *Poa pratensis*. Weller *et al*. (1985) measured a decreased leaf area index in newly planted peach with increased grass density. Water deficit and other environmental stresses are known to inhibit leaf expansion (Chapin 1991, Kozlowski *et al*. 1991, Larcher 1995, Van Volkenburgh 1999, Lambers *et al*. 2000). The present results may thus indicate that cover crops are better competitiors for water than the main crop. Good nutrient, especially the nitrogen status, is also important for leaf growth (II, Kozlowski *et al*. 1991) and high N has been found to result in almost twice the total leaf area as low N (Wendler & Millard 1996). The birch competing with cover crops and simultaneously suffering from the low water supply decreased its biomass allocation to the leaves and had a higher SLA compared to the birch which grew without competition in a good water supply (III). According to Aerts *et al*. (1991) plants can compensate a low biomass allocation to the leaves by high SLA, thus maximizing light capture and growth with minimal cost for leaf structures. The leaves were thin and tended to fall off early in the cover crop treatments (I, III). Premature leaf abscission of birch in drought stress is also reported by Wendler & Millard (1996).

The stem diameter of trees is sensitive to competition with grasses (I, Welker & Glenn 1989, Meyer *et al*. 1992, Calkins & Swanson 1995, Parker & Meyer 1996) and most legumes (I, Merwin & Stiles 1994, Calkins & Swanson 1995, Foshee *et al*. 1995), though annual clovers (I) and a grass *Muhlenbergia schreberii* (Shribbs and Skroch 1986a, Meyer *et al*. 1992, Parker & Meyer 1996) have given almost as good growth as bare ground. The effect of cover crops on the stem diameter was already found after the first growing season in birch (I) and also in a young pecan (Welker & Glenn 1988, Meyer *et al*. 1992, Foshee *et al*. 1995), but not until after the second growing season or later in apple (Merwin & Stiles 1994). Calkins (1991) also reported early effects in the growth of caliper in a nursery production of various deciduous and evergreen trees, and found stressed caliper to be a more consistent indicator of plant growth than plant height or plant form characteristics under different soil management systems. Kozlowski *et al.* (1991) pointed out that water stress usually reduces cambial growth before height growth. This seems to be supported by the results of the present study (I), though height growth was also severely decreased by the perennial clovers and *Festuca* (I, III). Ferm *et al.* (1994) also reported a significant decrease in the height increment of birch seedlings (*Betula pendula*) when grown with *Trifolium repens* compared to the well-controlled plots, where weeds had been treated with herbicides.

Much of tree growth takes place in early summer. Root growth begins usually shortly after the soil becomes free of frost (Kozlowski *et al.* 1991). Birch leaves on short-shoots and the early leaves on long-shoots expand during the spring and early summer, while the late leaves on long-shoots expand during the elongation of the long-shoots (Macdonald & Mothersill 1983, Macdonald *et al.* 1984, Atkinson 1992). The height increment of birch takes place in the early season and growth usually continues into August (Kauppi *et al.* 1988). Birches are known to be rather intolerant of drought (Ranney *et al.* 1991, Atkinson 1992) and their roots are mainly superficial (Laitakari 1935). Competition for nutrients and water, potentially suppressing growth, thus plays an important role mainly from spring to July. Besides, dry conditions affect the tree diameter growth by depressing especially early wood growth (Kozlowski *et al.* 1991). I thus supposed after the field experiments that a reduced water supply together with cover crop competition may have decreased the leaf growth in the first part of the summer (I). During the experiments in 1993 and 1994 precipitation in May was very low and in June 1993 also below the normal range. The perennial clovers and *Festuca* started to grow in early spring, before the birch leaf burst. Furthermore, herbaceous plants generally compete well with woody seedlings in dry conditions (Davis *et al.* 1998) and *Festuca rubra* is known to be drought tolerant (Aronson *et al.* 1987), which explain the benefit of these cover crops and the suffering of birch. The birch responded to competition by increasing the biomass allocation to the roots (III). This kind of adaptive adjustment is also reported by Kolb and Steiner (1990) in the seedlings of oak and yellow-poplar in competition with *Poa pratensis*. Besides, Khalil and Grace (1992) found drought to stimulate reallocation of assimilates to the roots. The perennial clovers did not restrict the birch growth as much as *Festuca* did (I). In the annual clover plots, the soil was bare until the beginning of July and there was no competing vegetation for the birch. Neilsen & Hogue (1985) also stressed the importance of the absence of ground cover competition early in the season. Finally, in the greenhouse experiment it became obvious that the growth of birch was more affected by competition with cover crops than by the water supply (III), though these cannot be totally separated from each other (Collet *et al.* 1996).

In a tree – cover crop combination, competition is mainly belowground (III, Casper & Jackson 1997). This is the situation especially during the first years, when trees are small and their roots are still shallow, and the roots of both crops use resourses from the same soil layers. Later on, at least some trees are boring their roots deeper into the soil and are able to explore resources in different soil layers than herbaceous plants, though some herbaceous plants are also deep-rooted and restrict tree root growth both vertically and horizontally (Parker *et al.* 1993, Parker & Meyer 1996). The root system of many legumes is less competitive than that of grasses (Thomas 1984, Alley *et al*. 1999), but I especially found perennial legumes to be almost as competitive as *Festuca* (I, III, Van Sambeek *et al*. 1986, Alley *et al*. 1999, Dupraz *et al*. 1999). Cahill & Casper (2000) reported that even small amounts of neighbour root biomass can cause very strong belowground competition. They suggested that this kind of belowground competition could result in asymmetric competition and could arise from interference rather than resourse exploitation.

Aboveground competition, which may be fairly asymmetric (Schwinning & Weiner 1998), affects, more strongly seedlings than bigger trees. High growing cover crops may partly shade seedlings and also affect the light quality, air composition, temperature and moisture in the vegetation. Later on when trees grow or on the other hand, when young densely planted, trees may suppress ground vegetation by shading. *T. subterraneum* is reported to have a high shade tolerance (Ziehm *et al*. 1992) in contrast to *T. repens*, which has shown a low tolerance for shade (Heraut-Bron *et al*. 1999, Marcuvitz & Turkington 2000). I suppose that in the greenhouse experiment (III) by the highest water supply, when birch had highest LAI, growth of *T. repens* was slightly suppressed by shade of the birch foliage. Kropff and Goudriaan (1994) stated that even small differences in leaf area or plant height development may cause dramatic changes in competitive relations, although total biomass production may be more or less the same.

5.2 Tree nutrition and soil fertility

Several authors have reported decreased leaf nitrogen concentration in trees as a result of cover crop competition. Especially grasses have proved to be serious competitors for N (II, III, Shribbs & Skroch 1986b, Bohne & Rauch 1996, Calkins & Swanson 1996, Neilsen & Hogue 2000). Because of symbiosis with N_2-fixing bacteria, *Rhizobium*, leguminous cover crops have been studied to maintain nitrogen in plants at a satisfactory level (e.g. Cogliastro *et al*. 1990, Merwin & Stiles 1994, Bohne & Rauch 1996, Calkins & Swanson 1996). The results have been contradictory, however, and mostly N status of the tree has remained below the level, which has been received without competition (I, III, Ferm *et al*. 1994, Merwin & Stiles 1994, Calkins & Swanson 1996, Hornig & Bünemann 1996a, Neilsen & Hogue 2000). In my studies the birch on bare ground and growing with the annual clovers had about the same N concentration, which was higher than in the birch growing with the perennial clovers (II). This may be due to the lack of competing vegetation at the beginning of the growing season on bare ground and in the annual clover plots. Similar results have also reported by Neilsen and Hogue (1985). In the greenhouse experiment (III), perennial *T. repens* and annual *T. subterraneum* both grew simultaneously and did not cause differences in birch N status. In my studies (II, III) only the birch in the *Festuca* plots in the field experiments (II) had a leaf N concentration close to the deficient level (cf. Marschner 1995). At the lowest watering level the birch had a higher N concentration than at the two higher watering levels. This may have been due to the slower growing plants maintaining higher tissue nutrient concentrations than the rapidly growing plants (Chapin 1991).

It is worth noticing that though there are only minor differences in the soil nutrient concentrations between the treatments, there may be significant differences in tree growth and nutrient concentrations (II, Merwin & Stiles 1994, Hornig & Bünemann 1996b) as well as in the nutrient ratios in the tree (II). The reason for this may be the competitive exploitation as a mechanism of interspecific competition as suggested by Caldwell et al. (1985). They found that different species can influence the target plant nutrient level in different ways. In their field study the sagebrush *Artemisia tridentiata* obtained much less P from soil shared with *Agropyron desertorum* than from soil shared with *Agropyron spicatum* (see also Caldwell 1994). The tree nutrient status as well as the nutrient ratios were approaching close to each other on bare ground and in the annual clover plots (II). In the perennial clover plots the nutrient concentrations and the ratios resembled more the ones found in the *Festuca* plots than those found in the annual clover plots (II). Consequently, competition distinctly affects the nutrient uptake of plants, not only in nitrogen, but also their uptake of some other nutrients.

Tree nutrition has usually been discussed as leaf nutrient status, and indeed, there are correlations between the growth and leaf nutrient concentrations (Shribbs & Skroch 1986b, Calkins & Swanson 1996). In the present study the nutrient concentrations in the stems, branches and roots of the young trees also reflect the influence of competition in the tree nutrition (II, III). There are, however, contradictory results concerning the relationship between the tree growth and concentrations of single nutrients in the tree. For instance, Shribbs & Skroch (1986b) discovered a negative correlation between apple leaf K and tree growth, and a positive correlation between twig Mg and tree growth.

The soil nutrient status in the field experiment (II) was generally at a satisfactory level (Anon. 1996) and mostly provided good nutrition for birch as compared to three years old birches analysed in August by Ferm & Markkola (1985). The effects of ground covers on soil nutrient status were minor, only in NO_3–N concentration as an exception (II, IV). The soil NO_3–N concentration was generally the highest on bare ground (see also Haynes & Goh 1980, Merwin & Stiles 1994, Walsh *et al*. 1996b). Legumes do not necessarily increase soil NO_3–N concentration (II, Calkins & Swanson 1996). In the present study the annual and perennial clover plots differed distinctly from each other, the NO_3–N concentration being, in general, higher in the annual clover plots than in the perennial clover plots. The conditions for nitrifying micro-ogranisms seem to have been more favourable on bare ground (Ohtonen *et al*. 1992, Norton & Firestone 1996) and in the annual clover plots than in the perennial clover and *Festuca* plots. Thus, nitrification has been intensive (II, IV). The reason may be higher soil temperature, which has been measured on bare ground compared to plant covered soil (Meagher & Meyer 1990, Ohtonen *et al*. 1992, Walsh *et al*. 1996a). Calkins and Swanson (1997) measured higher temperature on bare ground even in a 50 cm depth of soil.

A viable and diverse microbial community has been considered as essential in sustainable agriculture (Kennedy & Smith 1995), and in this respect an intercropping system has been appreciated. However, from the plant point of view, the microbial community has at least two roles, which affect two opposite directions. A vigorous microbial community is important in nutrient cycling and in building up soil structure through e.g. soil aggregation. The microbial biomass was the largest and the activity the highest in *Festuca* and the perennial clover treatments (IV). Though the physical parameters of the soil were not measured in the present study, the soil in these treatments will obviously turn towards better physical condition, according to vast litterature about this topic (e.g. Haynes 1981, Hoyt & Hargrove 1986, Calkins 1991, Walsh *et al*. 1996a). Oliveira and Merwin (2001), however, reported better soil physical condition in herbicide and mulch plots than under mowed sod (*Festuca rubra*) in apple orchard. The reason, according to the authors, might be the cumulative effects of tractor traffic during mowing the sod plots. The other point is that the birch growth with *Festuca* and the perennial clovers was poor (I). Sparling (1997) has also reported that a higher microbial biomass and greater soil respiration are not necessarily related to greater productivity. The question remains, if the microbial community is an effective competitor for nitrogen and suppresses plant growth for this reason. Soil microbes have been found to compete with plants for nitrogen (Kaye & Hart 1997, Stark & Hart 1997) and may have affected the N uptake of plant. The great microbial biomass in connection with the perennial clovers and *Festuca* seems to have created a competitive combination against the nitrogen exploitation of birch (IV).

It has been reported that the microbial biomass declines in agricultural disturbance and that the microbial biomass can act as an early indicator of changes in soil processes (Granatstein *et al*. 1987, Campbell *et al*. 1992, Sparling 1997, Torstensson *et al*. 1998, Kandeler *et al*. 1999, Karlen *et al*. 1999, Stenberg 1999, Bending *et al*. 2000, Goh *et al*. 2000, Islam & Weil 2000). The results of this study concerning the microbial biomass (IV) are consistent with those reports as showing a quick increase in the microbial biomass in the perennial clover and *Festuca* treatments. The same trend was seen also in the three-months greenhouse experiment. The basal respiration also showed increase in *Festuca* and the perennial clover treatments in the field, but not in the greenhouse experiment. Microbial metabolic quotient did not have any indicative value as describing changes in the soil in the different treatments. Accumulation of organic matter in soil is also an indicator of good soil value, but in my quite short term experiments there was no increase detectable, except a trend in the deeper soil layer in the field. Four years is a rather short period to study the soil effects after changing the production practices (Wardle *et al*. 1999). However, ideally, as Karlen *et al*. (1999) suggest, the indicators should detect differences in 1 to 5 years after changing practices. On the whole, biological indicators seem to be sensitive and detectable rather early in assessing the soil quality in comparable to the soil chemical and physical indicators (Karlen *et al.* 1999).

5.3 Tree – cover crop interactions: facilitation vs. competition

An intercropping system is complex and comprises of many influences on all partners, both positive and negative. These phenomena are met for instance in pest dynamics. A good cover crop does not attract pests, on the contrary, it should affect and maintain natural enemies of pests (Haley & Hogue 1990, Meyer *et al*. 1992, Alston 1994, Bugg & Waddington 1994, Smallwood 1996, Stanyard *et al*. 1997). In my field experiments, clovers attracted hares (I). Ferm *et al*. (1994) found white clover to increase damages made by voles and susceptibility of birch seedlings to bark necrosis. Calkins and Swanson (1997) reported that field management treatments, which promoted vigorous growth, increased tree susceptibility to stem cancers on a deciduous tree *Gleditsia* sp.

Thus, the competition is not the only question to be solved and more reseach is needed to determine the ability of a cover crop system to maintain pest management resistance of the main crop. Because soil nutrient levels can influence plant chemical resistance against herbivores and pathogens (e.g. Bryant *et al*. 1983, Gershenzon 1984), the effects of cover crop on the soil quality can be important in this respect, too.

A good weed suppression ability is also an important cover crop characteristic. Cover crops should be able to create good coverage throughout the whole season without becoming too high, in relation to the main crop (Echtenkamp & Moomaw 1989, Meyer *et al*. 1992, Calkins & Swanson 1995, Creamer *et al*. 1996). There is also evidence that some cover crops could interfere weeds through allelopatic properties, either during their growth or through residues (Creamer *et al*. 1996, Weston 1996). The use of herbicides can in these cases be minimized or even avoided.

An important facilitative characteristic of cover crops is that they maintain a resource quality by improving the physical, chemical and biological properties of soil. Cover crops, used either in an intercropping system or during the off-season of the economic crops, play an important role in carbon, water and nitrogen cycles. Their importance for water quality through controlling runoff and erosion is obvious as well as their influence in the reduction of the leaching of contaminants. The air quality may also be improved by cover crops through carbon dioxide fixing and oxygen releasing in the photosynthetic processes (Reicosky & Forcella 1998). Soil temperature and temperature range (maximum - minimum) on bare ground have generally been higher than under vegetative ground cover. The effect of the cover crop on the soil temperature has been species dependent (Calkins & Swanson 1997, Walsh *et al*. 1996a). Soil temperature may influence the winter hardiness of trees, but also overwintering of cover crops. Before a larger use of cover crops these factors in our climate should be investigated. In addition, the soil temperature affects the relation of the soil water. Calkins and Swanson (1996) and Hornig and Bünemann (1996b) measured higher soil moisture under cover crops than on bare ground, and explained this partly through higher soil temperature on bare ground. On the contrary, Walsh *et al*. (1996a) measured significantly lower soil moisture under grass and mixed flora cover crop than on bare ground. Because of competition for water, supplementary irrigation has been suggested, when cover crops are used (Hipps & Samuelson 1991, Walsh *et al*. 1996a). Plants can at least to some extent, adapt to dry conditions and competition by increasing their biomass allocation in competitive conditions to the roots in order to increase belowground resource exploitation (III, Kolb & Steiner 1990, Khalil & Grace 1992). However, this reallocation was not enough for maintaining good birch growth in the present study (III). Thus, irrigation seems to be necessary during dry periods. However, high moisture cannot always quarantee good growth of crop trees, if interference from cover crops suppresses their growth (Fales & Wakefield 1981, Cahill & Casper 2000). It should be noted that according to the most extreme claims concerning sustainable production and the ecosystem's long-term productivity, no supplementary irrigation should be allowed (Calkins & Swanson 1996). In such a case cover crop species will be set even higher demands for low competitiveness.

As has been seen above, sustainable production systems using an intercropping system have usually proved to restrict crop growth and nutrition at least to some extent. A lot of research is needed to solve many practical problems, of which, the finding of suitable main crop – cover crop combinations is of fundamental importance. The cover crop should not be too competitive, it should not be allelopatic to the main crop (Fales & Wakefield 1981, Weller *et al*. 1985, Putnam 1986, Skroch & Shribbs 1986), and it should tolerate shade (Meyer *et al*. 1992). There is also a need to find such cover crop densities, which create a good soil covering, without being competitive. Furthermore, there are technical problems to be solved when cover crops are used especially in nurseries. There should not be any cover crop roots with the tree roots when the trees are harvested to markets. This problem is actual, especially if perennial cover species are used and there is living ground cover vegetation at the time of harvest. For nursery enterprisers an important issue is the effect of vegetative ground covers on the economy of the nursery. According to Calkins (1991) cover crops and rye cover crop/mulch systems were less expensive to maintain than cultivation or herbicide management. There is a need for a detailed cost analysis.

According to current knowledge about facilitation and competition in a tree – cover crop system, I would suggest that the alleys are seeded with *T. repens* or with a mixture of *T. repens* and a grass, which has a low growing habit. *T. subterraneum* is seeded under the tree rows yearly before midsummer. This will ensure that the alleys are fit for traffic throughout the growing season and the most important ground area for the tree roots is coverless during the early summer. The rest of the annual *T. subterraneum* covers the soil after the winter with a paper-like surface and prevents or retards weed emergence before midsummer and resowing. This combination may not be too competitive to the main crop and would maintain long-term soil productivity.

6 Conclusions

Birches both in the field and in the greenhouse experiment grew best on bare ground. Annual clovers as a cover crop provided an almost as good growth and nutrient status for the birch as did bare soil. On the other hand, perennial cover crops, as well as *Festuca*, were strong competitors reducing the tree growth and they also failed to improve the tree nutrition. The growth suppression of birch was mostly due to competition for belowground resources, mainly for nitrogen and partly for water, too. Though competition with cover crops is obvious, competition with soil microbes can not be ruled out. Competition for the resources seemed to be most crucial early in the growing season, as annual cover crops seeded at the end of June did not affect birch growth during this most intensive growth period. Competition most strongly affected the birch leaf growth, but was clearly also seen in the decreasing LAI, stem diameter, tree height and biomass. An increased biomass allocation to the roots, high SLA, thin leaves and early abscission were typical of the birches growing in competition with the cover crops.

Though there were great differences in the birch nutrition and growth in various treatments, there were only minor differences in the soil nutrient concentration, NO_3–N as an exception. The NO_3–N concentration was the highest in the plots without any cover crops most of the time in the upper soil layers and all the time in the deeper layers. The NO_3–N of soil was, in general, higher in the annual than in the perennial clover plots and the lowest values were measured in the *Festuca* plots. The microbial biomass of soil and soil respiration were greatest in *Festuca* and in the perennial clover treatments, and were not related to good growth, which may indicate competition for nutrients between plants and microorganisms. The lowest microbial biomass was measured on bare ground, where the best birch growth was achieved, but where the danger of nitrogen leaching was obvious, too. Thus, bare ground may not be sustainable in the long-term.

There are many problems concerning the use of vegetative ground covers, of which good crop combinations is one of the most important factors. The role of a soil microbial community in belowground resource competition, and especially in nitrogen cycling is of great interest, but not well known. Long-term soil productivity, however, should be kept in mind as the most important aspect.

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