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Simulations on the effects of timber harvesting and forest management on the nutrient cycle and productivity of Scots pine stands

Seppo Kellomäki and Matti Seppälä

TIIVISTELMÄ: EKOSYSTEEMIMALLIIN PERUSTUVIA LASKELMIA PUUN KORJUUN JA METSÄNKÄSITTELYN VAIKUTUKSESTA MÄNNIKÖN RAVINNEKIERTOON JA TUOTTAVUUTEEN

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Effects of varying rotation, thinning, fertilization and harvest intensity on the productivity and nitrogen cycle of a Scots pine (*Pinus sylvestris* L.) stand were studied on the basis of computer simulation. The increasing intensity of management increased the loss of nitrogen in the cycle. Short rotation, associated with early thinning by means of the whole tree harvest, proved to be especially detrimental regarding the productivity of the forest ecosystem. Fertilisation associated with thinnings is of great importance in maintaining the productivity of a forest ecosystem during an intensive timber harvest.

Tutkimuksessa on simulointimallin avulla selvitetty kiertoajan pituuden, harvennushakkuiden, typpilannoituksen ja puunkorjuutavan vaikutusta männiköiden (*Pinus sylvestris* L.) typenkiertoon ja tuottavuuteen. Metsänkäsittelyn voimistuminen kasvatti metsikön ulkopuolelle joutuvan typen määrää. Lyhyt kiertoaika yhdistyneenä varhaiseen harvennukseen ja kokopuukorjuuseen lisäsi erityisen paljon typen menetystä. Kiertoajan pidentäminen ja tavaralajimenetelmän käyttö puunkorjuussa säästivät metsän typpivaroja. Lannoitus osoittautui erityisen tärkeäksi silloin, kun puustoa harvennettiin kokopuumenetelmällä jo ensiharvennuksesta lähtien.

Keywords: Simulation, nitrogen, harvest, management, Scots pine, nitrogen cycle, Forcyte-10
ODC 181.65+181.321.35+63

Correspondence: Seppo Kellomäki, University of Joensuu, Faculty of Forestry, P.O. Box 111, SF-80101 Joensuu, Finland.

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1. Introduction

In Finnish forestry the concept of the sustained yield has been applied since the early 1900s emphasizing the role of regrowth in balancing growth and removal. This concept has proved to be successful, as indicated by the increasing volume of standing crop since the 1920s (Metsätilastollinen . . . 1986). Forestry has, however, greatly intensified since the early 1900s. This is well demonstrated by the fact that the turn-over of the standing crop of forest resources is shorter than in any other region in the boreal forest zone, only about 25 years.

The utilisation and management of forest resources are expected to be intensified further in the future (The forest . . . 1986). Consequently, an increasing amount of tree biomass is expected to be harvested through intensive and systematic silvicultural management of forests. These tendencies may be associated with the following risks to sustained yield:

(i) the effects of logging practices on the long term nutrient balance is poorly understood and not predictable with sufficient certainty, and

(ii) the effects of silvicultural management on the structure and functioning of the forest ecosystem, especially on soil process and nutrient balance, are poorly understood.

The nutrient balance of the forest ecosystem is changed even though only stems and their bark are logged (conventional harvest) (Mälkönen 1976). The nutrient losses are, however, enhanced substantially, if branches, stumps and leaves are logged (whole tree harvest) (Mälkönen 1978). Particularly on nutrient-poor sites do these logging practices seem to have detrimental, long-term effects on the productivity of the forest ecosystem. It is possible that the humus resources in forest soil decrease, giving rise to a deterioration of the retention capacity of water and nutrients (Juutinen et al. 1979).

The effects of intensified silviculture comprise the enhanched mobilisation of nutrients from litter and humus. If this equals the demand of trees and other vegetation, no excess loss outside the site occurs. In the opposite case, nutrient losses to surface and ground waters are expected, as are future losses in the productivity of the forest ecosystem (Rosen 1982, Björkroth 1984). Apparently, nutrient losses and supply interact so that the timing and intensity of the management practices affect the nutrient resources of the forest ecosystem. Therefore there is a need to investigate the effects of harvesting and silvicultural management as interacting processes with long-term effects on the productivity of the forest ecosystem. This implies that the concept of the sustained yield of the forest ecosystem would be determined as balance of nutrient input and output during a selected rotation.

The outlined hazards associated with the silvicultural management of the forest ecosystem are not easily evaluated by experimental studies. In particular, the long rotation of timber production makes it difficult to evaluate the future development of the forest ecosystem when subjected to a particular treatment. These difficulties could be overcome with the help of simulation where the silvicultural and harvesting practices are incorporated into the dynamics of the forest ecosystem as control factors of the processes of the forest succession (Kimmins & Scoullar 1983, Kimmins 1986). This approach will be applied in the following in order

(i) to study the effect of timber harvesting and silvicultural measures as single factors on the productivity of the forest ecosystem;

(ii) to study the interaction between timber harvesting, silvicultural measures and the length of rotation which affect the productivity of the forest ecosystem; and

(iii) to study the proper patterns of silvicultural management when the site fertility, timber harvesting regime and length of the rotation varies.

The effects of timber harvesting and silvicultural practices are evaluated on the basis of the nutrient balance and productivity of

the forest ecosystem so that a high timber yield and balanced nutrient cycle are the aims of management. These criteria are used in selecting the appropriate combination for timber harvesting, rotation and silvicultural management.

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2. Methods

2.1. Model for simulation of management scenarios

The study is based on simulation techniques, where a model ecosystem of a Scots pine (*Pinus sylvestris* L.) stand is manipulated through a set of harvesting and silvicultural regimes in order to select and appropriate management regime for timber production. The simulations are representative of the boreal vegetation zone (60°–62° latitudes, 20–100 m above sea level), covering most of the sites of importance in management of Scots pine in Finland.

The simulations were based on the Forcyte-10 model developed by Kimmins and Scoullar (1983) for comparing different harvesting and management regimes, regarding their ecological effects and effectiveness. The model is based on the nitrogen cycle, which selects the basic trends of forest succession, given in growth and yield tables, to match the actual availability of nutrients (Fig. 1). This makes it possible to treat harvesting, regeneration, thinning and fertilisation as control factors which disturb the dynamics of ecosystem processes. The details of the model and its management implication are given by Kimmins and Scoullar (1983, 1984) and Kimmins (1986) so that only the outlines of the model are described below.

The Forcyte-10 model comprises of three main compartments, i.e. biomass of trees and ground vegetation (total vegetation) including their nitrogen content; litter and humus layer in forest soil including their nitrogen content and nitrogen (ammonium and nitrate) in forest soil available for plants (Fig. 1). Thus, the nitrogen cycle is divided into three phases, i.e. the uptake, release and storing of nitrogen by trees and ground vegetation (grasses, herbs and dwarf shrubs). Consequently, the processes affecting the nitrogen cycle can be divided into those increasing and decreasing the amount of nitrogen in a particular component of the forest ecosystem (Table 1). The same process can be either increasing or decreasing, depending on the component for which the calculations are made.

The properties of the nutrient cycle determines the dynamic of the Forcyte-10 model. In particular, the availability of nitrogen in forest soil controls the successional process. Availability of nitrogen depends on the decomposition and amount of litter and humus, biological nitrogen fixation, wet and dry deposion and leaching and uptake of vegetation (Fig. 1). The decomposition rate of litter and humus is specific for each component of litter and humus as a function of the site fertility. The amount of the nitrogen released annually is directly related to the amount of litter and humus. Similarly, nitrogen leaching is directly proportional to the amount of available nitrogen (ammonium and nitrate combined). The uptake of nitrogen is directly related to the amount of the available nitrogen, amount of roots and growth of trees and ground vegetation, respectivevly. Nitrogen sypply (biological fixation and dry and wet deposition combined) was 3.1 kg/ha/a on each site (Mälkönen 1974).

The above processes modify the growth and yield tables which are representative of the region under study. Thus, the growth and yield tables scale the results of the simulations to represent the range of variability occuring in the region. In our case the growth and yield tables for natural Scots pine stands representing *Myrtillus*, *Vaccinium* and *Calluna* site types (Koivisto 1959) were utilised. The

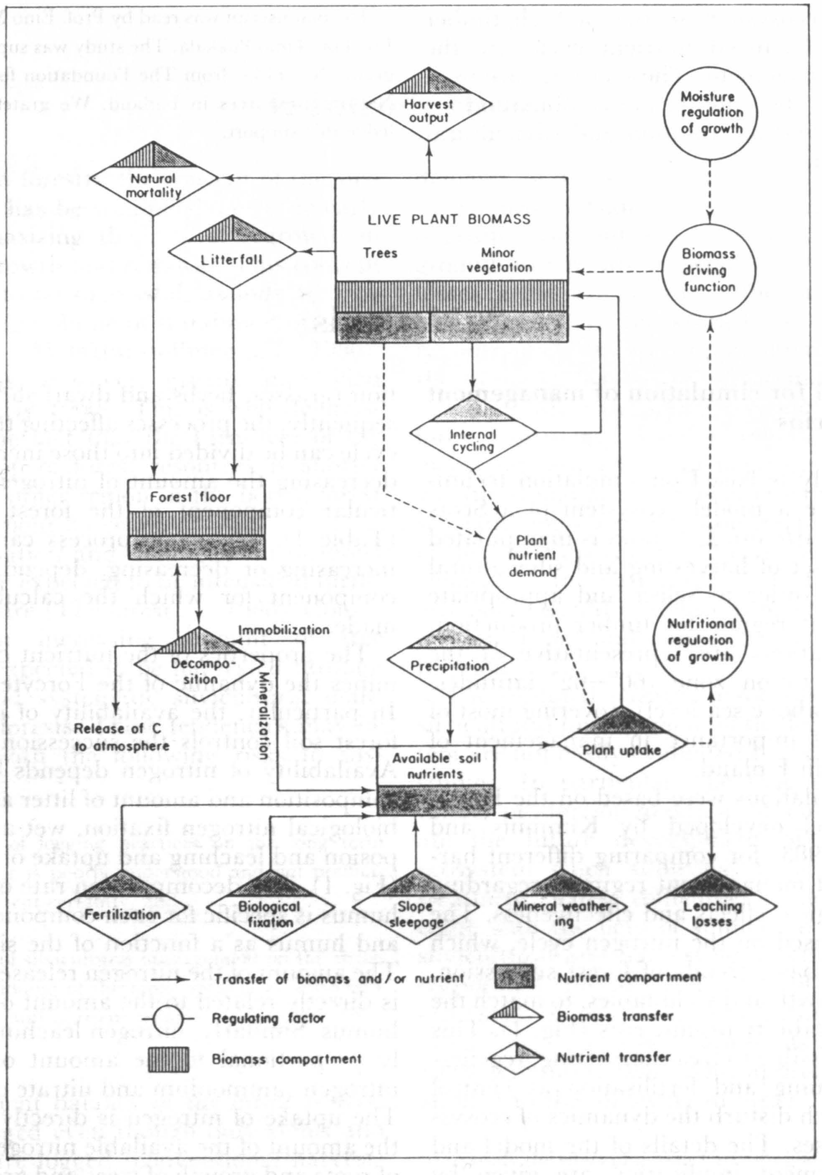

Figure 1. General description of Forcyte-10 model. Redrawn from Kimmins and Scoullar (1983).

parameters of the modifying processes of nitrogen cycle represent the same site types. They are mainly based on empirical material given by Mälkönen (1974) for Scots pine stands.

The model input includes site type, harvesting method and rotation and a set of silvicultural measures, which can be varied in timing and intensity. The model will give as output a prediction of how the tree stand will develop under the given management regime. Several variables representing the properties of the standing crop, yield and nitrogen cycle can be obtained as an output. The model is, thus, most suitable for the studies concerning the consequences of a given management re-

Table 1. Components used for describing the structure of the model for the forest ecosystem.

Component	Explanation
Vegetation including the combined nitrogen	Tree and other vascular plants as divided into different parts and nitrogen combined in them
Litter and humus in soil	Litter and humus divided into cohorts and nitrogen combined in them
Soil nitrogen available for growth	Nitrogen capable for leaching in different layers of soil

gime (scenario techniques) (Kimmins & Scoullar 1983).

The Forcyte-10 model is a complex hybrid of processes modifying the predictions given by yield tables. The validity of the model is still under study, but promising results are obtained in several studies regarding the dynamics of biomass during the succession (Kellomäki 1985, Sachs & Solling 1986, Yarie 1986). This is expectable since the yield tables do not allow predictions to fall outside the range of productivity representing by yield tables. Also the response of model ecosystem to silvicultural measures, for example to thinning, has proved to be in accordance with the yield tables (Kellomäki 1985). Because the modifying process are still under study, one must be careful and apply the model mainly for the studying the mutual relations of different management regimes as recommended also by Kimmins and Scoullar (1983).

2.2. Management scenarios

The simulations will describe the growth and development of Scots pine on different sites under a set of management regimes. The regimes represent a wider selection of management options than traditionally accepted. For example, in some cases the rotation is shorter and nitrogen application greater than applied in the present-day management. It is, however, probable that only an approach based on wide variability in management regimes will effeciently outline the sustained-yield management of the forest ecosystem.

The modules of the different management scenarios are presented in Table 2 and an example of the resulting management scenarios in Table 3. First, on each site the scenarios represent the management regimes where the rotation varies with a terminal cut based on conventional or whole tree harvest at the end of the rotation, excluding thinning and fertilisation during the management. Second, on each site there are also scenarios which include thinning and fertilisation during the rotation. The timber harvesting in these cases also represents conventional or whole tree harvests, which are applied both at thinning and terminal cutting.

The initial density of the seedling stand was 2000 ha^{-1} in each scenario, regardless of the site quality. Ten years later the model stand was thinned to a density of 1800 ha^{-1}. Thereafter, the model stand was managed following the selected scenarios. On sites of

Table 2. Management scenarios applied in the study.

1. Site type: MT (H_{100}=27), VT (H_{100}=24), CT (H_{100}=18)
2. Rotation: 60, 80, 120 a
3. Thinnings:
   - No thinning
   - Removal 30 % of volume of stem wood
4. Harvesting intensity:
   - Conventional : 88 % of stem wood and bark excluding branches, needles and roots
   - Whole 1 : 93 % of stem wood and bark excluding branches, needles and roots
   - Whole 2 : 95 % of stem wood and bark
     : 50 % of branches and needles
     : 19 % of roots (valid only in terminal cuttings)
5. Nitrogen fertilisation
   - No treatment
   - Application: 150 kg N/ha
   - Application: 250 kg N/ha

MT = *Myrtillus* type, VT = *Vaccinium* type, CT = *Calluna* type, H_{100} = dominant height at the age of 100 years.

Table 3. Example of the layout of the treatment of the model ecosystem: mangement scenarios for the *Myrtillus* site (MT (H_{100}=27).

No	Rotation	Harvesting	Thinning time	Thinning % of volume	Fertilisation time	Fertilisation kg/ha
	No thinning, no fertilisation					
1	60	Conv				
2	60	Whole1				
3	60	Whole2				
4	80	Conv.				
5	80	Whole1				
6	80	Whole2				
7	120	Conv.				
8	120	Whole1				
9	120	Whole2				
	Thinning, no fertilisation					
10	60	Conv	30–40–50	30		
11	60	Whole1	30–40–50	30		
12	60	Whole2	30–40–50	30		
13	80	Conv.	35–50–65	30		
14	80	Whole1	35–50–65	30		
15	80	Whole2	35–50–65	30		
16	120	Conv.	40–60–80	30		
17	120	Whole1	40–60–80	30		
18	120	Whole2	40–60–80	30		
	Thinning, fertilisation 150 kg/ha four times					
19	60	Conv	30–40–50	30	41–46–51–56	150
20	60	Whole1	30–40–50	30	41–46–51–56	150
21	60	Whole2	30–40–50	30	41–46–51–56	150
22	80	Conv.	35–50–65	30	51–56–66–71	150
23	80	Whole1	35–50–65	30	51–56–66–71	150
24	80	Whole2	35–50–65	30	51–56–66–71	150
25	120	Conv.	40–60–80	30	61–66–81–86	150
26	120	Whole1	40–60–80	30	61–66–81–86	150
27	120	Whole2	40–60–80	30	61–66–81–86	150
	Thinning, fertilisation 250 kg/ha four times					
28	60	Conv	30–40–50	30	41–46–51–56	250
29	60	Whole1	30–40–50	30	41–46–51–56	250
30	60	Whole2	30–40–50	30	41–46–51–56	250
31	80	Conv.	35–50–65	30	51–56–66–71	250
32	80	Whole1	35–50–65	30	51–56–66–71	250
33	80	Whole2	35–50–65	30	51–56–66–71	250
34	120	Conv.	40–60–80	30	61–66–81–86	250
35	120	Whole1	40–60–80	30	61–66–81–86	250
36	120	Whole2	40–60–80	30	61–66–81–86	250

Explanations: Conv. = conventional harvest, whole1 = the first alternative of the whole tree harvest, whole2 = second alternative of the whole tree harvest.

good quality the seedling stand established was close to that desired in practical forestry. On poor sites the stand density was to some extent too high but still acceptable.

The parameters of the model ecosystem varied according to the site fertility so that their variability covered *Calluna, Vaccinium* and *Myrtillus* site types (Table 2). The rotation was 60, 80 and 120 a. Thinning intensity in each treatment was 30 % of the volume of stem wood, based on studies by Vuokila (1971, 1972, 1976, 1983), Parviainen (1978) and Vuokila (1971, 1972, 1976, 1983), Parviainen (1978) and Vuokila and Väliaho (1980). Thinning was repeated three times during the rotation. The timing of the treatment varied according to site fertility as follows:

Rotation, a	Timing of thinnings, a		
Myrtillus type			
60	30	40	50
80	35	50	65
120	40	60	80
Vaccinium type			
60	30	40	50
80	40	50	65
120	40	60	80
Calluna type			
80	40	50	65
120	45	65	90

The harvesting intensity in the conventional harvest (Conv.) was 88 % of stem wood and bark (total stem wood and bark (100 %) minus harvesting residue (6 % of total) minus above-soil part of stump (6 % of total) based on studies by Hakkila (1972, 1974, 1978), Hakkila et al. (1977) and Mikkola (1972). In the first alternative method of whole tree harvest (Whole 1) the stem was totally harvested along with the above-soil part fo stump, with an ensuring loss of 1 % or harvesting residue (stem and bark). Thus, the harvesting intensity was 93 % (88 % + 5 %) of above-soil biomass of stem excluding branches and needles. In the second alternative method of whole tree harvest (Whole 2) the harvested biomass also included the above-soil part of stump when 95 % of stem wood was harvested. Harvesting intensity for root was 19 % of total root wood and for branches and needles 50 % of total amount of branches and needles (Hakkila 1978). Root wood was harvested only in terminal cuttings.

The first alternative in fertilisation was 150 kg N/ha, which is widely used in forest management. The second alternative was 250 kg N/ha which is close to the saturation of the growth response of Scots pine to nitrogen (Brantseg 1970, Erken 1969, Möller 1971, Friberg 1971, 1973, Gustavsen & Lipas 1975, Kukkola & Saramäki 1983). The first application occurred at the culmination of the growth rate (at the age of 40–60 a) a year after the second thinning. Fertilisation was repeated three times durig the rotation after the first fertilisation, each time a year after the thinning except the first thinning when no fertilisation was done as follows

Rotation, a	Timing of fertilisation, a			
Myrtillus type				
60	41	46	51	56
80	51	56	66	71
120	61	66	81	86
Vaccinium type				
60	41	46	51	56
80	51	56	66	71
120	61	66	81	86
Calluna type				
80	51	56	66	71
120	66	71	91	96

2.3. Selection of management regime for timber production

The selection of an appropriate management regime among those possible for timber production aims at recognising the regimes which maximise the harvested biomass on the sustained-yield basis. The selection is based on the recognition how the timber production Y as described by the fucntion $Y = f(X_1, X_2, \ldots X_n)$ change in response to changing values of the independent variables $X_1, X_2, \ldots X_n$ representing varying combinations of the management practices. A proper regime is characterised by high timber yield and balanced nutrient cycle compared with the results of other regimes (Watt 1968, p. 403–435).

The selection process proceeded in three phases. First, the management scenarios for each site were ranked on the basis of criteria given below. Second, the total rank score for the scenarios was computed with the help of the values of the rank scores given on the basis of different criteria. Third, the scenarios were ordered according to the total rank score, and the different management regimes were evaluated according to how well they satisfy the aim of maximising the harvested biomass on the sustained-yield basis.

The following criteria were applied in ranking the management regimes:

(i) The effectiveness of ecological resources, indicated in terms of the harvested biomass (Y, kg) per nitrogen unit (N, kg). An appropriate management regime maximises (Y/N, kg/kg).

(ii) The intensity of utilisation of ecological resources, indicated in terms of the loss of nitrogen (N_o, kg) per unit of harvested biomass (Y, kg). An appropriate management regime minimises (N_o/Y, kg/kg).

(iii) The intensity of harvest, indicated in terms of the amount of harvested biomass (Y, kg) from that produced (Y_{tot}, kg). An appropriate management regime maximises (Y/Y_{tot}, kg/kg).

(iv) The maximisation of total harvested biomass (Y, kg), indicated in terms of the amount of harvested biomass per unit land area during the whole rotation (amount of harvested biomass at thinnings and terminal cutting combined). An appropriate management regime maximises (Y, kg/ha).

The values of each criteria for each management regime were computed, and the management regimes were ordered separately according to each of them in descending order. Thereafter, the figures indicating the order were added so that the value of the sum gave the final order of the management regimes. The most appropriate management regime got the highest scores and the least appropriate the lowest scores on the basis of productivity and balance of nutrient cycle.

2.4. Variables computed for the scenarios

The Forcyte-10 model produces a wide set of variables which indicate the structure and functioning of the forest ecosystem as influenced by different management regimes (Kimmins & Scoullar 1983). In this study the following variables were used in evaluating the effects of timber harvesting and management on the dynamics of the forest ecosystem.

(i) The total biomass yield of trees (needles, branches, stems and roots) in kg/ha for the selected rotation and respective value of the mean annual yield in kg/ha/a.

(ii) The total litter production (needles, branches, stems and roots) in kg/ha/a for the selected rotation and respective value of the mean annual production in kg/ha/a.

(iii) The amount of harvested biomass in kg/ha for the selected rotation and the respective value of the mean annual harvest in kg/ha/a.

(iv) The share of the total litter production from the total biomass yield in percents.

(v) The total uptake of nitrogen in kg/ha for the selected rotation and the respective mean annual uptake in kg/ha/a.

(vi) The total return of nitrogen in litter in kg/ha for the selected rotation and the respective mean annual recycling in kg/ha/a.

(vii) The total internal cycle of nitrogen in trees in kg/ha for the selected rotation and the respective mean annual cycling in kg/ha/a.

(viii) The ratio between the total biomass yield and the amount of nitrogen used in production in kg dry weight/kg nitrogen.

(ix) The total accumulation of nitrogen in trees in kg/ha and the respective mean annual accumulation in kg/ha/a.

(x) The total leaching of nitrogen (ammonium and nitrate) in kg/ha for the selected rotation and the respective mean annual leaching in kg/ha/a.

(xi) The total loss of nitrogen bound in harvested biomass in kg/ha and the respective mean annual loss in kg/ha/a.

(xii) The nitrogen gain/loss in kg/ha (difference between nitrogen input and output in and out of the forest ecosystem) for the selectred rotation and the respective mean annual balance in kg/ha/a.

The above variables were also utilised in computing the values of the scenarios for the ranking of the management regimes. The results of the computations are presented in figures and tables in appendices which give the reader an opportunity to compare the effects of different management regimes, regarding their effects on the amount of harvested biomass and stability of nitrogen dynamics in the forest ecosystem.

3. Results

3.1 Total growth, litter crop and harvested biomass

The total production of dry matter (needles, branches, stems and roots) on *Myrtillus* type sites varies between 500–1700 Mg/ha depending on management regime. The same values on the *Vaccinium* type site were 400–1200 Mg/ha and on the *Calluna* type site 400–900 Mg/ha and on the *Calluna* type site 400–900 Mg/ha. These values imply that the mean annual values of the total production of dry matter vary within a range of 9–14 Mg/ha/a on sites of the *Myrtillus* type, 6–10 Mg/ha/a on sites of *Vaccinium* type and 6–10 Mg/ga/a on sites of *Vaccinium* type and 5–7 Mg/ha/a on sites of *Calluna* type.

On all sites, productivity increases with increasing number of scenario, especially when the management regime is compiled by whole tree harvesting with regular thinning and fertilisation (scenarios 34, 35 and 36 for the *Myrtillus* type, scenarios 34, 35 and 36 for the *Vaccinium* site, scenarios 22, 23 and 24 for the *Calluna* site) (Fig. 2). The opposite takes place when the logging is based on whole tree harvesting without thinning. In particular, a shorter rotation combined with whole tree harvesting and no fertilisation gives a considerably lower mean annual production of dry

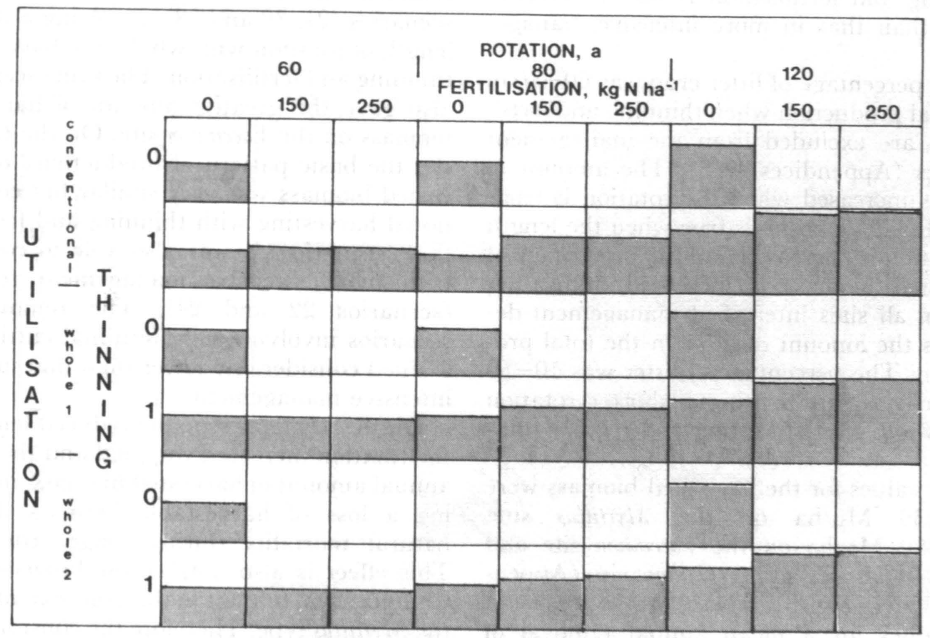

Figure 2. Total production at different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %.

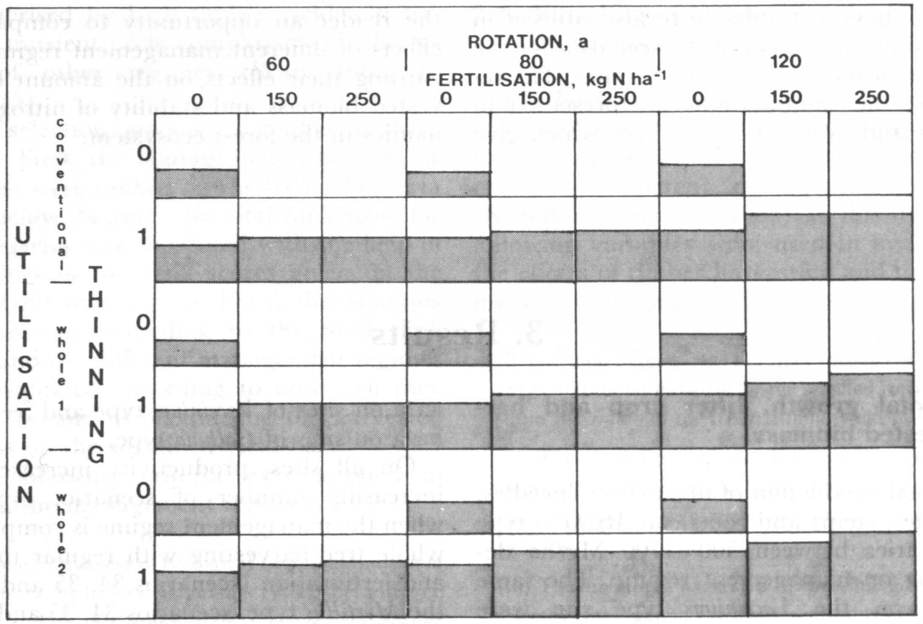

Figure 3. Total cutting removal at different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %.

matter than other scenarios. Productivity in scenarios involving varying rotation without thinning and fertilisation is on the average lower than that in more intensive management.

The percentage of litter crop was 60–70 of the total production when thinning and fertilisation are excluded from the management regimes (Appendices 1–3). The amount of litter is increased when the rotation is lengthened. The opposite is true when the length of rotation is decreased and the percentage of harvested biomass is increased, indicating that on all sites intensified management decreases the amount of litter in the total production. The percentage of litter was 40–50 in scenarios representing a shorter rotation with whole tree harvesting and regular thinning.

The values for the harvested biomass were 150–530 Mg/ha on the *Myrtillus* site, 120–380 Mg/ha on the *Vaccinium* site and 110–340 Mg/ha on the *Calluna* site (Appendices 1–3) (Fig. 3). These figures represent the values for a mean annual removal of 1.6–8 Mg/ha/a for the *Myrtillus* type, 1.6–4.8 Mg/ha/a for the *Vaccinium* type and 1.1–3.1 Mg/ha/a for the *Calluna* type.

The greatest values for the mean annual removal on the *Myrtillus* site are given in scenarios (21, 30 and 33), involving a shorter length of rotation with whole tree harvesting, thinning and fertilisation. The same scenarios also gave the greatest amount of harvested biomass on the *Vaccinium* site. On the *Calluna* site the basic pattern of productivity of harvested biomass was very similar but conventional harvesting with thinning and fertilisation (scenario 13) was also able to compete with more intensive management regimes (scenarios 22 and 24). The removal in scenarios involving only terminal cutting remained considerably lower than that in more intensive management.

On the *Myrtillus* type the reduced length of the rotation increased the total and the mean annual amount of harvested biomass, indicating a loss of harvestable biomass due to natural mortality during longer rotations. This effect is also notable on *Vaccinium* and Calluna sites, but not to the same extent as on the *Myrtillus* type. Therefore the constant harvest ratio (percentage of harvested biomass from the total biomass) gives the cutting removal directly related to the total production, if the effects of natural mortality on the standing crop are eliminated.

3.2 Nitrogen cycle

The total uptake of nitrogen is directly proportional to production of dry matter (Appendices 4–6) (Fig. 4). The mean annual uptake of nitrogen varied within the range of 26–35 kg/ha/a on the *Myrtillus* site, 19–26 kg/ha/a on the *Vaccinium* site and 17–21 kg/ha/a on the *Calluna* site. On all sites the nitrogen uptake was enhanched by intensive management regimes indicating the effect of the productivity of dry matter on the rate of nitrogen uptake. On the other hand, a delayed thinning reduced the mean annual uptake due to decreased growth of trees. This was especially true on *Myrtillus* and *Vaccinium* sites (scenarios 15–18).

The total amount of nitrogen returned to the soil through litter crop was related to the total production of dry matter (Appendices 4–6) (Fig. 5). The mean annual return of nitrogen from trees to soil was 16–26 kg/ha/a on the *Myrtillus* site, 11–18 kg/ha/a on the *Vaccinium* site and 11–16 kg/ha/a on the *Calluna* site. Early thinning combined with whole tree harvesting reduces the mean annual return of nitrogen. This is especially clear on the *Myrtillus* site, but also recognisable on *Vaccinium* and *Calluna* sites. Fertilisation, however, partly compensates for this reduction but the effect of early thinning is still recognisable.

The internal cycle of nitrogen supplies was nearly the same size as that of uptake in terms of the total internal cycle and mean annual cycle (Appendices 4–6). The internal cycle was positively related to the rate of production of dry matter, being 25–37 kg/ha/a on the *Myrtillus* site, 19–25 kg/ha/a on the *Vaccinium* site and 16–21 kg/ha/a on the *Calluna* site. Early thinning combined with whole tree harvesting reduced the importance of the internal cycle in the total nitrogen supply for growth. This reduction can be compensated for with fertilisation.

The total dry matter production (kg) per nitrogen unit (kg) was 360–400 on the *Myrtillus* site, 340–390 on the *Vaccinium* site and

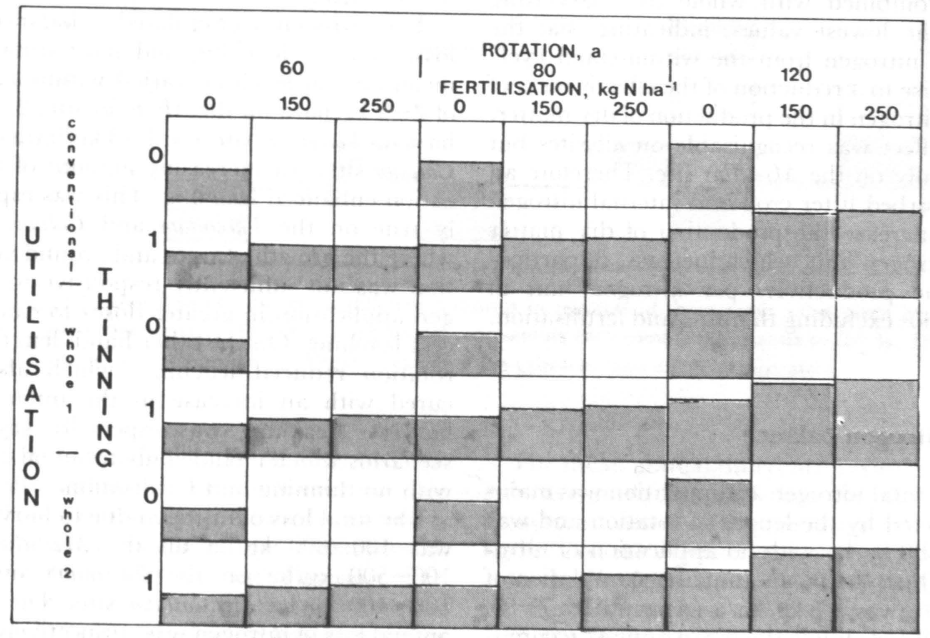

Figure 4. Total uptake of nitrogen at different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %.

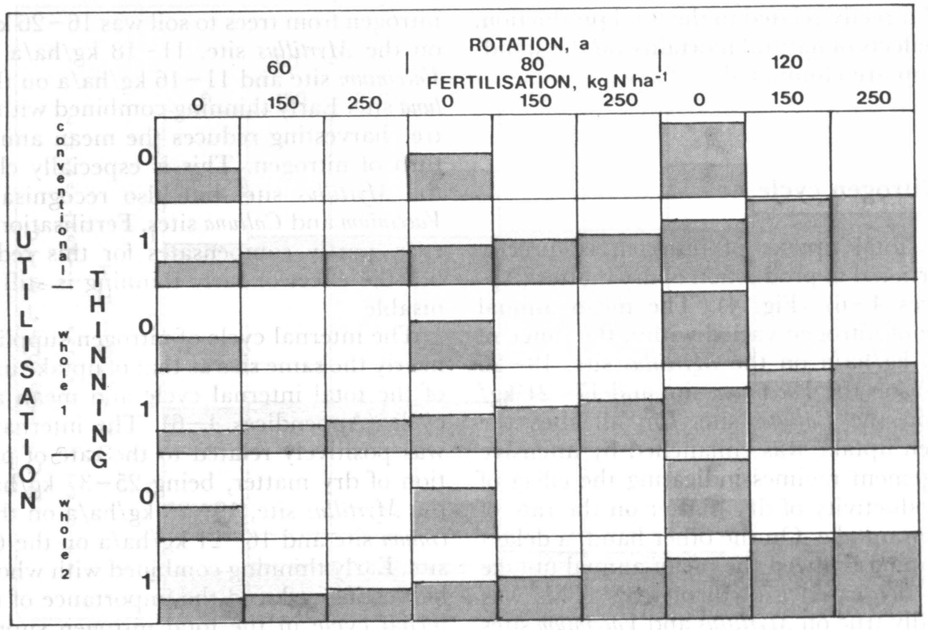

Figure 5. Total litter crop at different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %.

310–330 kg dry matter/kg nitrogen on the *Calluna* site (Appendices 4–6). Early thinning combined with whole tree harvesting gave the lowest values, indicating that the loss of nitrogen from the within-stand cycle gives rise to a reduction of the effectiveness of total nitrogen in the production of dry matter. This effect was recognisable on all sites but especially on the *Myrtillus* site. Therefore an undisturbed litter crop and internal nitrogen cycle increase the production of dry matter per nitrogen unit, which increase, in particular, the productivity per nitrogen unit in scenarios excluding thinning and fertilisation.

3.3 Nitrogen balance

The total nitrogen accumulation was mainly affected by the length of rotation and was 180–380 kg/ha with no application of nitrogen. Thus, the mean annual accumulation of nitrogen was 3.1 kg/ha/a (Appendices 7–9). In fertilised stands the mean annual accumulation of nitrogen increased up to 18 kg/ha/a, depending of the amount of fertilization. Consequently, the total nitrogen accumulation can be as great as 1270 kg/ha at the maximum during the rotation.

The nitrogen accumulated is balanced by losses due to leaching and harvesting. The mean annual leaching varied within a range of 2–5 kg/ha/a on the *Myrtillus* site, 2–6 kg/ha/a on *Vaccinium* site and 1–3 kg/ha/a on the *Calluna* site. An increasing amount of fertilization enhanced leaching. This was especially true on the *Vaccinium* and *Calluna* sites, where the growth of trees and ground vegetation was not sufficiently responsive to nitrogen application in greater doses to cause excess leaching. On the other hand, lengthened rotation reduced leaching, which also occured with an increase in the intensity of harvest. Leaching was especially small in scenarios which include only terminal cutting with no thinning and fertilisation.

The total loss of nitrogen due to harvesting was 100–600 kg/ha on the *Myrtillus* site, 100–500 kg/ha on the *Vaccinium* site and 100–400 kg/ha on *Calluna* site. The mean annual loss of nitrogen was, respectively, 1–9 kg/ha/a on the *Myrtillus* sites, 1–8 kg/ha/a on the *Vaccinium* site and 1–5 kg/ha/a on the

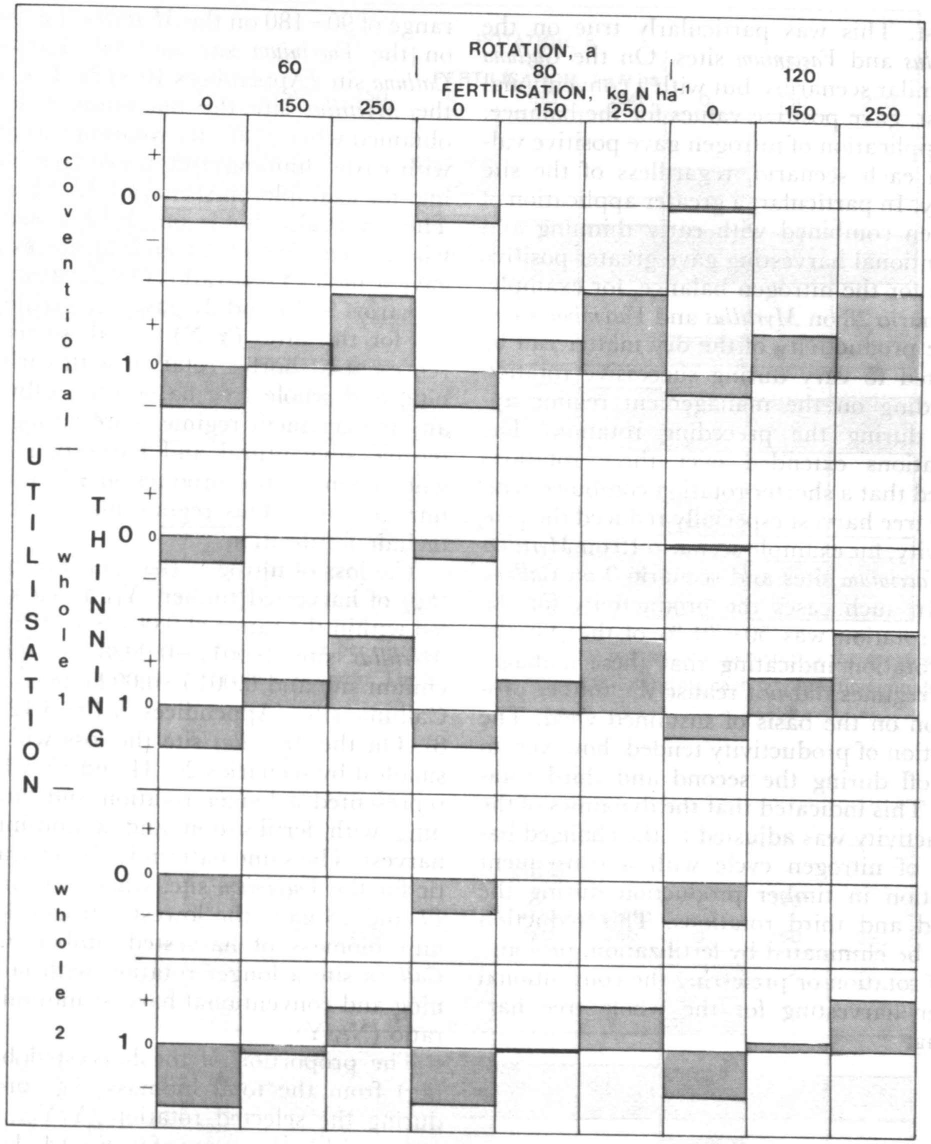

Figure 6. Gain/loss of nitrogen at different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %. The scaling for the positive and negative values of the gain/loss-ratio are done separately.

Calluna site (Appendices 7–9). The loss was especially enhanced by shortened rotation and whole tree harvest combined with excess application of nitrogen, for example, in scenario 30 on *Myrtillus* and *Vaccinium* sites. Longer rotation and conventional harvesting resulted in only a negligible loss of nitrogen compared with intensified regimes of management.

The mean annual difference between nitrogen accumulation and loss in the forest ecosystem varied within the range of −5–+8 kg/ha/a on the *Myrtillus* site, −4–+10 kg/ha/a on the *Vaccinium* site and −1–+10 kg/ha/a on the *Calluna* site (Appendices 3.7–3.9) (Fig. 6). In the each case, management with no fertilisation gave a negative balance, regardless of the rotation and intensity of the harvest. This was particularly true on the *Myrtillus* and *Vaccinium* sites. On the *Calluna* site similar scenarios, but with a conventional harvest, gave positive values for the balance. The application of nitrogen gave positive values in each scenario, regardless of the site quality. In particular, a greater application of nitrogen combined with early thinning and conventional harvesting gave greater positive values for the nitrogen balance, for example, in scenario 28 on *Myrtillus* and *Vaccinium* sites.

The productivity of the dry matter can be expected to vary during successive rotation depending on the management regime applied during the preceding rotation. The simulations extended over three rotations showed that a shorter rotation combined with whole tree harvest especially reduced the productivity, for example scenario 15 on *Myrtillus* and *Vaccinium* sites and scenario 9 on *Calluna* site. In such cases the productivity for the third rotation was 50–70 % of that for the first rotation indicating that these management regimes did not realise the timber production on the basis of sustained yield. The reduction of productivity tended, however, to level off during the second and third rotations. This indicated that the dynamics of the productivity was adjusted to the changed balance of nitrogen cycle with a consequent reduction in timber production during the second and third rotations. This reduction could be eliminated by fertilization, prolonging of rotation or preferring the conventional timber harvesting for the whole tree harvesting.

3.4. Selection of management regime for timber production

3.4.1. Total production, harvested timber and efficiency of nitrogen use

Total production and harvested timber for each scenario have been discussed above. Therefore only the efficiency of nitrogen use and timber production are considered here as selection criteria for a proper management regime for timber production. The production of harvested biomass (kg) per nitrogen unit (kg) (Y/N, kg/kg) varied withing the range of 90–180 on the *Myrtillus* site, 90–190 on the *Vaccinium* site and 60–150 on the *Calluna* site (Appendices 10–12) (Fig. 7). On the *Myrtillus* site the maximum value was obtained when a shorter rotation was applied with early thinning and whole tree harvesting, for example, in scenarios 12, 21 and 30. The same also holds on the *Vaccinium* site, where scenarios 12, 21 and 30, for example, gave a high (Y/N)-ratio. On the *Calluna* site scenarios 9, 15 and 21 gave the greatest values for the ratio (Y/N). All these scenarios represent a shorter rotation with early thinning and whole tree harvesting. Obviously, any management regime representing an intensive silvicultural and harvesting pattern will maximise the production of timber per nitrogen unit. This regime may or may not include fertilisation.

The loss of nitrogen (kg) per unit biomass (kg) of harvested timber (Y_O/Y, kg/kg) varied within the range of 0.0013–0.0026 on the *Myrtillus* site, 0.0017–0.0028 on the Vaccinium site and 0.0015–0.0023 kg/ha on the Calluna site (Appendices 3.10–3.12) (Fig. 8). On the *Myrtillus* site the loss will be the smallest by scenarios 26, 34 and 35, which all represented a longer rotation and late thinning with fertilisation and a non-intensive harvest. The same pattern is also characteristic for the *Vaccinium* site, where scenarios 16, 17 and 23 gave the lowest nitrogen loss per unit biomass of harvested timber. On the *Calluna* site a longer rotation with late thinning and conventional harvest minimises the ratio (N_O/Y).

The proportion of the harvested biomass (kg) from the total biomass (kg) produced during the selected rotation (Y/Y_{tot}, kg/kg) varies within the range of 0.16–0.47 kg/kg on the *Myrtillus* site, 0.19–0.54 kg/kg on the *Vaccinium* site and 0.19–0.48 on the *Calluna* site (Appendices 3.10–3.12) (Fig. 9). On the *Myrtillus* and *Vaccinium* sites the greatest values were obtained in scenarios 12, 21 and 30, which involved short rotation with early thinning and whole tree harvesting. This pattern was also partly valid for the *Calluna* site, where scenarios 15 and 21 gave the highest values for the ratio (Y/Y_{tot}). Scenario 10 is, however, representative of a longer rotation with late thinning and conventional harvest.

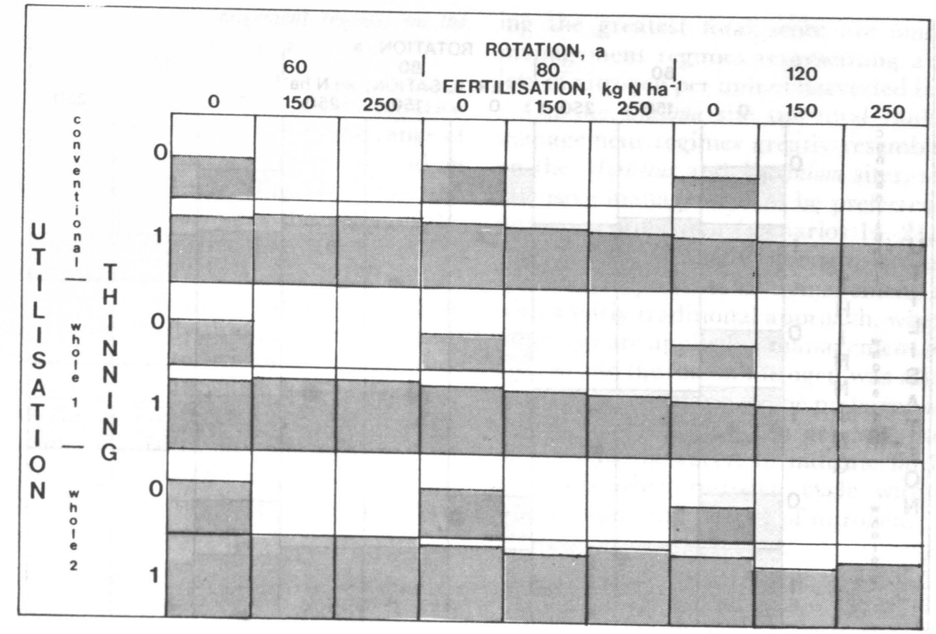

Figure 7. Production of dry matter per nitrogen unit at different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %.

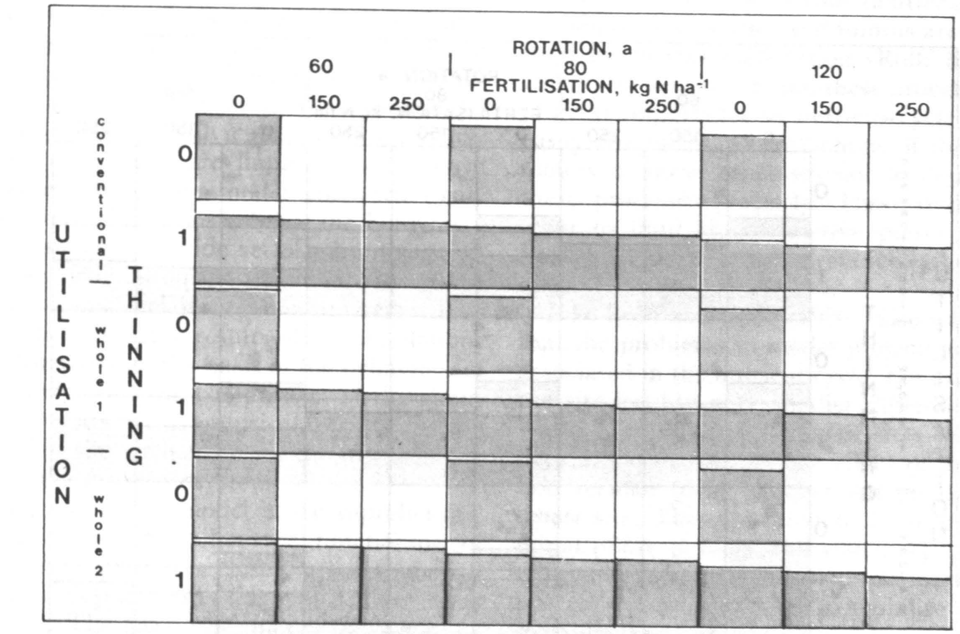

Figure 8. Loss of nitrogen per unit of harvested timber at different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %.

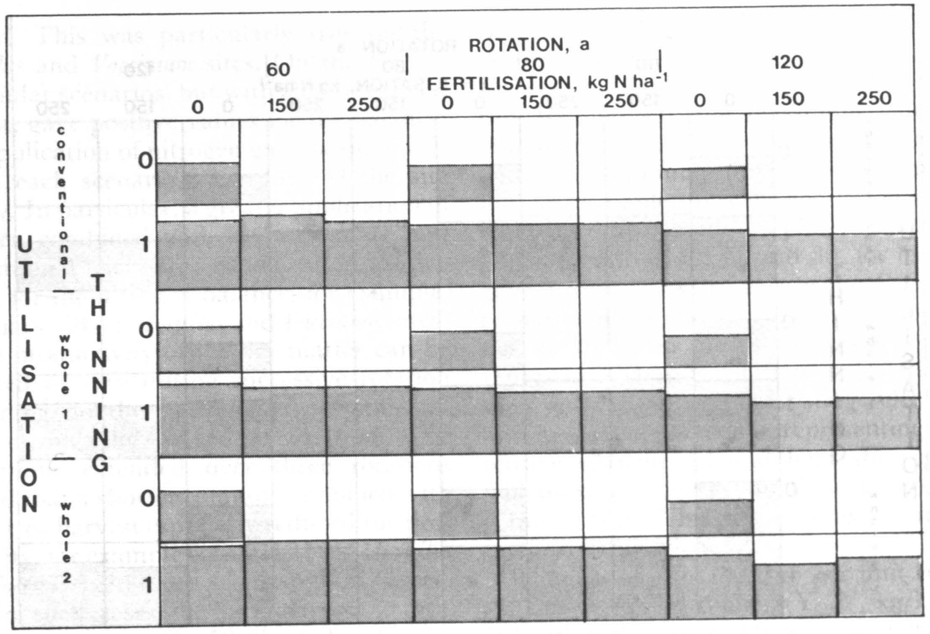

Figure 9. Share of the harvested biomass of the total production at different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %.

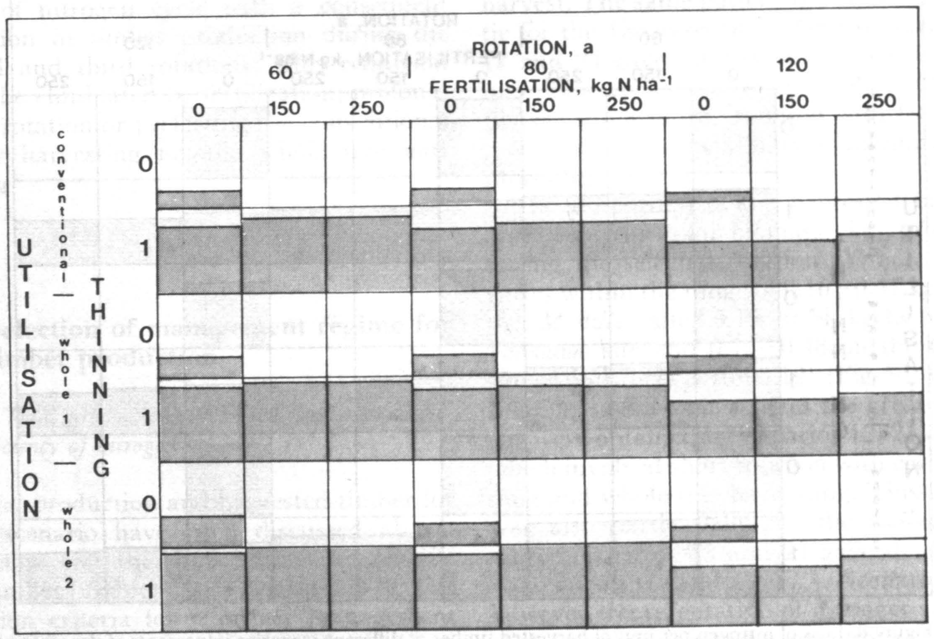

Figure 10. Preference of different scenarios in percents of the greatest value given by a particular scenario. The area of the square representing each combination equals to 100 %.

3.4.2. Ranking of the management regimes on the basis of the selected criteria

The total score of the rank of the scenarios varied on the *Myrtillus* site within the range of 15–113, on the *Vaccinium* site 13–124 and on the *Calluna* site 13–79 (Fig. 10). On the *Myrtillus* and *Vaccinium* sites the value of the score number was greater than 100, for example, for scenarios 24, 33, 30, 21, 20, 29 and 12 which involve a shorter rotation with whole tree harvesting. Early thinnings and fertilisation are also characteristic of these scenarios, except for scenario 12 which had no fertilisation. All the criteria except the loss of nitrogen per unit of harvested biomass gave nearly the same order for the scenarios. On the *Myrtillus* sites in particular the scenarios having the greatest total score are among the management regimes representing a greater loss of nitrogen per unit of harvested biomass.

On the *Calluna* site the total rank of the management regimes greatly resembled that on the *Myrtillus* and *Vaccinium* sites, showing intensive management to be preferred in appropriate utilisation (scenarios 14, 21, 20, 15 and 8). Interestingly enough, scenario 8, however, represents a management regime with a fairly traditional approach, where only thinnings are applied in management. On the *Calluna* site the loss of nitrogen was also magnified by the scenarios to be preferred according to the total score. In general, the total rank seems, however, to indicate fairly well an undisturbed nitrogen cycle with a balanced input and output of nitrogen.

4. Discussion and further elaboration

4.1. Reliability of the results

This study aimed at the recognition of the effects of timber harvesting and silvicultural management on the productivity of a forest ecosystem, based on simulation over one rotation and the changes in successional dynamics due to silvicultural interference. Thus, the results are liable to any bias in parameterisation of a model which will easily give a biased prognosis. Since the Forcyte-10 model includes a wide set of parameters, no detailed evaluation on the reliability of the model at the level of single parameters will be given here, but the results of the simulations are discussed on the basis of the behaviour of the model and the comparison of the simulated results with empirical results on the effects of timber harvest on the nitrogen balance of a forest ecosystem.

The Forcyte-10 model is a comprehensive system which describes the functioning of some basic processes closely associated with nitrogen cycle and the consequent tree growth. Therefore the model incorporates well verified as well as poorly verified assumptions. For example, Rolff and Dyck (1986) critisise the Forcyte-10 model for the too complicate structure which results in uncertainty in the model projections. Especially, the processes of the formation of litter and the decomposition of litter and humus are still in need for further elaboration (Rolff & Dyck 1986). On the other hand, these processes are of great importance in nutrient cycle giving easily rise to biased predictions, if the parameters of these processes fail to determine these processes precisely. These difficulties seem to limit the predictive power of the Forcyte-10 model into the relative rather than absolute terms.

Like Rolff and Dyck (1986), also we found that the problems in model projections were associated in the nutrient cycle. For example, the site fertility gave smaller differences between *Myrtillus* and *Vaccinium* sites than expected. Consequently, the effect of fertilisation seemed to be exaggerated on the *Vaccinium* site. This appeared to be due to the initial phase of forest soil which represented too good site fertility due to ample nitrogen in litter and humus capable to mobilise to ammonium and nitrate. This increased the amount of nitrogen available for trees during the course of succession more than expectable on the basis of the site type. This deficiency can be eliminated with the help of careful consideration of the variables describing the properties of the forest soil.

Our experiences of the Forcyte-10 model are also similar to those by Sachs and Sollings (1986) who found the model being extremely sensitive to the rate of mineralisation of soil organic matter, variation in C:N ratio of soil organic matter, site quality, the soil extractable NO_3^- : NH_4^+ ratio and the decomposition rate and nitrogen mineralisation pattern of large and medium-size roots and woody debris. For example, a high rate of decomposition of soil organic matter resulted in high levels of available nitrogen with consequent rate of tree growth and nitrate leaching which are not found in natural or managed tree stands.

Apparently, the above reasons were affecting that the calculations of the nitrogen balance at the greatest dosage of nitrogen (250 kg/ha) for the longest rotation (120 a) gave the leaching on the *Vaccinium* site values which were unexpectedly great compared with the values on the *Myrtillus* site. This result probably indicates the situation where the potential growth as determined by the growth and yield tables is limiting the actual growth. Consequently, the growth of the tree stand is not able to match the available nitrogen which will not be bound in vegetation but be leached. The great values of the leaching could also be due to the natural sypply of nitrogen which was probably too great on the *Vaccinium* site. This combined with the ample sypply of nitrogen could easily exceed the capacity of tree growth to absorb nitrogen. In the case of ample sypply of nitrogen the supply of other nutrient could limit the growth but the model fails to simulate, since nitrogen is the only nutrient included into the model.

The comparison of the simulated results with the empirical ones can also be done in terms of single processes and the total output of scenarios. For example, the nitrogen removed in litter was 16–26 kg/ha/a on the *Myrtillus* site, 13–18 kg/ha/a on the *Vaccinium* site and 11–16 kg/ha/a on the *Calluna* site depending on the management scenario. Mälkönen (1974) gives the values of 15–34 kg/ha/a for the closed Scots pine stands at the age 28–47 kg/ha/a on the *Vaccinium* and *Myrtillus* sites the biggest value representing the *Myrtillus* site. The results of the simulations are in this sense close with those by Mälkönen (1974).

The total output of the simulations in terms of dry matter was 9000–14000 kg/ha/a on the *Myrtillus* site, 7000–9000 kg/ha/a on the *Vaccinium* site and 6000–7000 kg/ha/a on the *Calluna* site depending on the management scenario. Mälkönen (1974) gives in the above mentioned study the following values of the annual dry matter production: the *Vaccinium* type 3400–5100 kg/ha/a and the *Myrtillus* type 6400 kg/ha/a. The results of the simulations are of the same magnitude but clearly greater than those by Mälkönen (1974). Probably part of this difference is due to the fact that the simulations give a complete account of the dry matter but the empirical studies do not. The same is apparently also true of the total annual litter crop, which is five to ten times greater in this study than the values reported by Mälkönen (1974).

The nitrogen loss in harvesting Scots pine timber in terms of nitrogen (kg) removed per unit of harvested timber (m^3) for thinnings and terminal cuts can be compared with the empirical results given by Mälkönen (1972) and (Kukkola and Mälkönen (1985). The comparisons are made between figures which are representative of the management regimes most closely resembling each other, i.e. the management regimes using only the terminal cut. The value of basic density, 420 kg/m^3, was used when the nitrogen loss in kg/kg was converted into kg/m^3.

Harvest method	Nitrogen loss, kg/m^3 Mälkönen (1972)	Present study
Conv.	0.34	0.30
Whole 1	0.54	0.30
Whole 2	0.74	0.44

The loss of nitrogen in scenarios 7, 8 and 9 representing a rotation of 120 a without thinnings and fertilisation (terminal cutting only), on the *Vaccinium* site was 0.3–0.5 kg/m^3 which is of the same magnitude as that obtained by Mälkönen (1972) for similar conditions. The Forcyte-10 model yielded results which indicate a smaller nitrogen loss for whole tree harvesting than that obtained by Mälkönen (1972). For conventional harvesting the result is almost the same. The nitrogen loss per area unit for scenarios 7, 8 and 9 was 129, 137 and 222 kg/ha. These values are close to estimates derived from of Mälkönen (1972, 1976) and Juutinen et al. (1979).

4.2. Discussion of the results

The results of the simulations represent a wide variation of managements, some of the combinations falling outside the present practise. For example, the rotation of 60 years without thinning, the application of 250 kg/ha nitrogen successively or the delayed terminal cutting after fertilisation (scenarios 34–36 on the *Myrtillus* and *Vaccinium* sites and scenarios 22–24 on the *Calluna* site) are not commonly accepted in forestry due to environmental hazards or poor economic expectations associated with them. The scenarios of this kind are, however, needed to outline the limits of the sustained yield of forest ecosystem and the intensity of silvicultural management which could be allowed in forestry. Similarly, the same method could be applied for determining the optimal silvicultural regime which will give the balance between the timber production and environmental values.

The effects of timber harvesting and silvicultural management on the productivity and nitrogen cycle of a forest ecosystem was closely related to the management regime. As expected, the increasing intensity of management increases the loss of nitrogen in the cycle. On the other hand, it was very obvious that the nitrogen loss could be compensated for through fertilisation. In particular, fertilisation associated with thinnings are of great importance in maintaining the productivity of a forest ecosystem during a intensive timber harvest. In the simulations the timing of fertilation failed, however, in some cases to realise the common practice. Especially at the rotation of 120 a the intervals between the second and third and the last treatment and terminal cutting was too long. Therefore the effectiveness of the fertilisation for compensating the nutrient loss in harvest remained unclear.

The selection of proper management regimes for timber production aimed to the maximum timber at minimum nitrogen loss as measured by sum of several indices. To the authors' knowledge any attempt like this is not documented in the relavant literature. Therefore our approach should be kept as a tentative one in order to try to optimise silvicultural management on the ecological basis. Obviously, this kind of techniques makes, however, distiction between different management regimes for selection of a proper regime. For example, on the *Myrtillus* site the most promising regimes of management were expressed in scenarios 21, 24, 30 and 33 and the most detrimental ones in scenarios 11, 12, 15 and 18 (Figures 11–13) compared with the scenario 7 which represented a rotation of 120 a excluding thinning and fertilisation. The scenario 7 was, thus, assumed to be the closest to the natural succession of the forest ecosystem the output of which was used as a base line in comparing the scenarios with each other.

The comparison of the most promising and the most detrimental scenarios with the scenario 7 showed that in the former case the accumulation of the biomass followed closer than in the latter case the accumulation of biomass in the natural succession. In other words, the growth rate at the promising scenarios was nearly equal to the potential capacity of the site with no excess loss of nitrogen. This took place, for example, after thinning or fertilisation, in scenarios representing detrimental management. Consequently, the standing crop in promising scenarios was even higher than that in the scenario representing natural succession. In the detrimental scenarios the standing crop remained considerably lower than that representing natural succession. On *Vaccinium* and *Calluna* sites the relations between the most promising and the most detrimental regimes of management were very similar to those on the *Myrtillus* site.

The most promising regimes of management (as evaluated on the ecological basis) could be further improved. Obviously, the delaying and reducing of intensity of the first two thinnings could decrease the loss of nitrogen through harvesting, since the share of nitrogen-rich tissues in the biomass of young trees is greater than in older trees. Consequently, all harvesting regimes result in a relatively greater loss of nitrogen at early thinning than at late thinning. Therefore, the standing crop remains smaller after the first thinnings than in natural succession, indicating lower growth than the potential. Later, the thinning of the same ratio much better matches the ecological properties of trees and site, giving an accumulation of biomass which is equal to the capacity of the site.

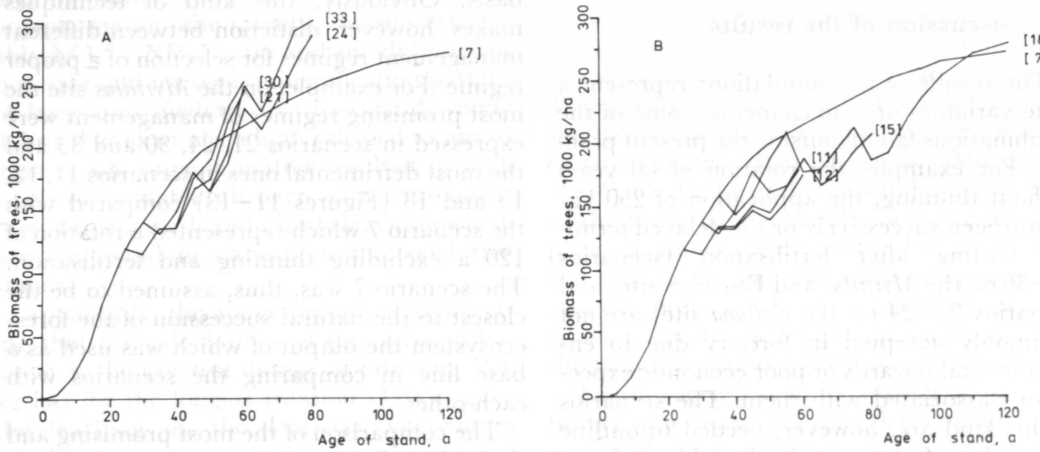

Figure 11. A: The most prefered and B: the most detrimental regimes of management on the *Myrtillus* site. Legend for the scenarios: 7 = Rotation of 120 a without any treatment but terminal cutting with conventional harvest. 11 = Rotation of 60 a with thinning and whole tree harvest of the first alternative. 12 = Rotation of 60 a with thinning and whole tree harvest of the second alternative. 15 = Rotation of 80 a with thinning and whole tree harvest of the second alternative. 18 = Rotation of 120 a with thinning and whole tree harvest of the second alternative. 21 = Rotation of 60 a with thinning and fertilising (150 kg/ha four times) and whole tree harvest of the second alternative. 24 = Rotation of 80 a with thinning and fertilising (150 kg/ha four times) and whole tree harvest of the second alternative. 30 = Rotation of 60 a with thinning and fertilising (250 kg/ha four times) and whole tree harvest of the second alternative. 33 = Rotation of 80 a with thinning and fertilising (250 kg/ha four times) and whole tree harvest of the second alternative.

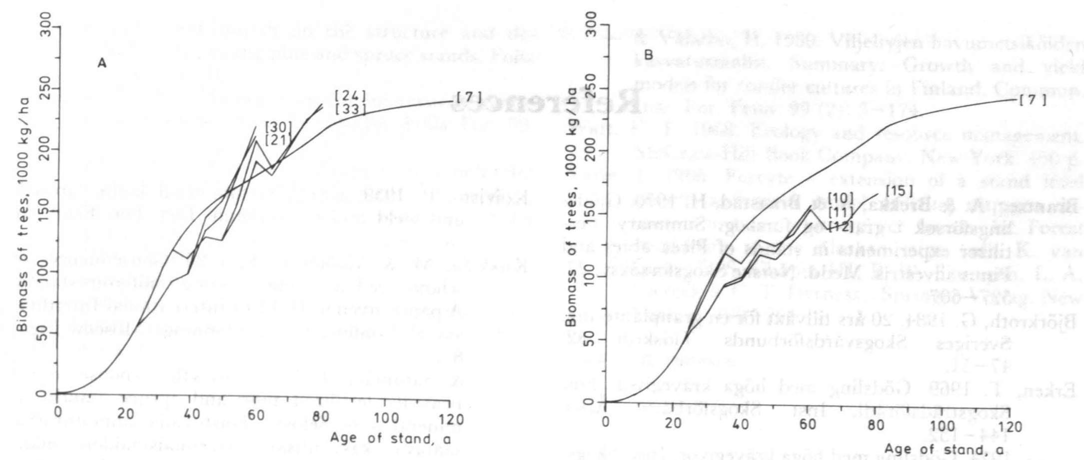

Figure 12. A: The most prefered and B: the most detrimental regimes of management on the *Vaccinium* site. Legend for the scenarios: 7 = Rotation of 120 without any treatment but terminal cutting with conventional harvest. 10 = Rotation of 60 a without any treatment but terminal cutting with conventional harvest. 11 = Rotation of 60 a with thinning and whole tree harvest of the first alternative. 12 = Rotation of 60 a with thinning and whole tree harvest of the second alternative. 15 = Rotation of 80 a with thinning and whole tree harvest of the second alternative. 21 = Rotation of 60 a with thinning and fertilising (150 kg/ha four times) and whole tree harvest of the second alternative. 24 = Rotation of 80 a with thinning and fertilising (150 kg/ha four times) and whole tree harvest of the second alternative. 30 = Rotation of 60 a with thinning and fertilising (250 kg/ha four times) and whole tree harvest of the second alternative. 33 = Rotation of 80 a with thinning and fertilising (250 kg/ha four times) and whole tree harvest of the second alternative.

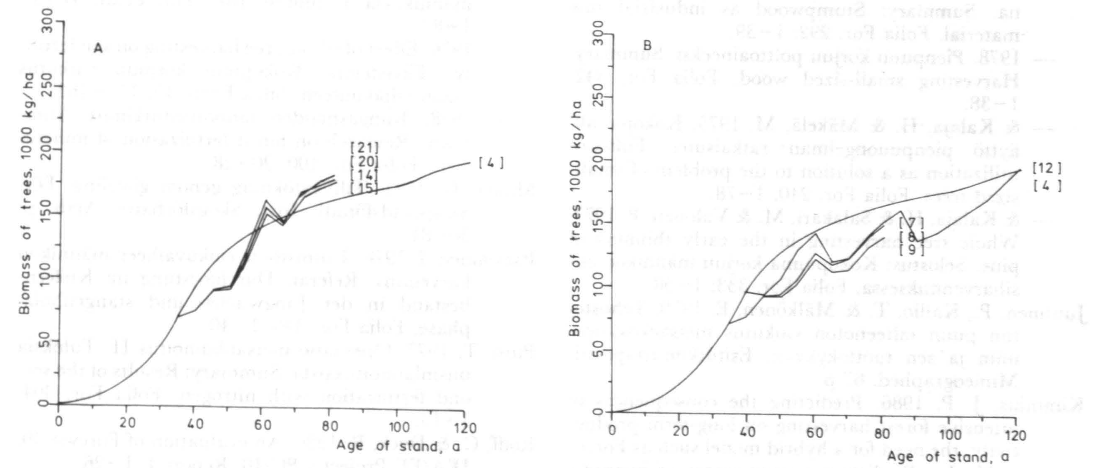

Figure 13. A: The most prefered and B: the most detrimental regimes of management on the *Calluna* site. Legend for the scenarios: 4 = rotation 120 without any treatment but terminal cutting with conventional harvest. 7 = rotation 80 a with thinning and conventional harvest. 8 = rotation 80 a with thinning and whole tree harvest of the first alternative. 9 = rotation 80 a with thinning and whole tree harvest of the second alternative. 12 = rotation 120 a with thinning and whole tree harvest with the second alternative. 14 = rotation 80 a with thinning and fertilisation (150 kg/ha four times) and whole tree harvest of the first alternative. 15 = rotation 80 a with thinning and fertilising (150 kg/ha four times) and whole tree harvest of the second alternative. 20 = rotation 80 a with thinning and fertilising (250 kg/ha four times) and whole tree harvest of the first alternative. 21 = rotation 80 a with thinning and fertilising (250 kg/ha four times) and whole tree harvest of the second alternative.

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Total of 40 references

Appendix 1. Total growth and harvesting yield on the *Myrtillus* site.

Scen-ario No.	Regime Rotat. Harv.[1]	Productivity Total Mg/ha	Productivity Mean Mg/ha/a	Litter crop Total Mg/ha	Litter crop Mean Mg/ha/a	Cutting removal Total Mg/ha	Cutting removal Mean 100 Mg/ha/a	Litter Prod.
	No thinning, no fertilisation							
1	60C	630	10.5	390	6.5	150	2.50	62
2	60W1	630	10.5	390	6.5	159	2.65	62
3	60W2	630	10.5	390	6.5	182	3.04	62
4	80C	828	10.3	549	6.9	172	2.15	66
5	80W1	828	10.3	549	6.9	182	2.27	66
6	80W2	828	10.3	549	6.9	208	2.60	66
7	120C	1192	9.9	866	7.2	193	1.61	73
8	120W1	1192	9.9	866	7.2	204	1.70	73
9	120W2	1192	9.9	866	7.2	233	1.94	73
	Thinning, no fertilisation							
10	60C	608	10.1	241	4.0	232	3.87	40
11	60W1	607	10.1	241	4.0	244	4.07	40
12	60W2	585	9.7	234	3.9	273	4.55	40
13	80C	806	10.1	366	4.6	279	3.49	45
14	80W1	808	10.1	364	4.5	299	3.73	45
15	80W2	768	9.6	351	4.4	322	4.03	46
16	120C	1162	9.7	623	5.2	337	2.81	54
17	120W1	1156	9.6	619	5.2	355	2.96	53
18	120W2	1118	9.3	594	4.9	397	3.31	53
	Thinning, fertilisation 150 kg/ha four times							
19	60C	724	12.1	278	4.6	272	4.54	38
20	60W1	723	12.0	278	4.6	287	4.79	38
21	60W2	714	11.9	274	4.6	338	5.64	38
22	80C	974	12.2	445	5.6	326	4.07	46
23	80W1	979	12.2	446	5.6	347	4.33	46
24	80W2	958	12.0	437	5.5	398	4.97	46
25	120C	1573	13.1	917	7.6	415	3.46	58
26	120W1	1567	13.1	915	7.6	437	3.64	58
27	120W2	1526	12.7	901	7.5	475	3.96	59
	Thinning, fertilisation 250 kg/ha four times							
28	60C	745	12.4	290	4.8	279	4.65	39
29	60W1	749	12.5	290	4.8	296	4.93	39
30	60W2	740	12.3	287	4.8	348	5.81	39
31	80C	1021	12.8	482	6.0	330	4.13	47
32	80W1	1020	12.8	481	6.0	349	4.37	47
33	80W2	1014	12.7	475	5.9	410	5.13	47
34	120C	1634	13.6	943	7.9	440	3.67	58
35	120W1	1649	13.7	953	7.9	473	3.94	58
36	120W2	1634	13.6	945	7.9	531	4.43	58

[1] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest. For further details see Table 2.

Appendix 2. Total growth and harvesting yield on the *Vaccinium* site.

Scen-ario No.	Regime Rotat. Harv.[1]	Productivity Total Mg/ha	Productivity Mean Mg/ha/a	Litter crop Total Mg/ha	Litter crop Mean Mg/ha/a	Cutting removal Total Mg/ha	Cutting removal Mean 100 Mg/ha/a	Litter Prod.
	No thinning, no fertilisation							
1	60C	445	7.4	250	4.2	127	2.12	56
2	60W1	445	7.4	250	4.2	134	2.23	56
3	60W2	445	7.4	250	4.2	153	2.55	56
4	80C	623	7.8	387	4.8	153	1.92	62
5	80W1	623	7.8	387	4.8	162	2.03	62
6	80W2	623	7.8	387	4.8	183	2.29	62
7	120C	922	7.7	645	5.4	176	1.47	70
8	120W1	922	7.7	645	5.4	186	1.55	70
9	120W2	922	7.7	645	5.4	209	1.74	70
	Thinning, no fertilisation							
10	60C	424	7.1	136	2.3	187	3.11	32
11	60W1	423	7.0	136	2.3	197	3.28	32
12	60W2	401	6.7	131	2.2	214	3.56	33
13	80C	584	7.3	230	2.9	231	2.88	39
14	80W1	581	7.3	230	2.9	242	3.03	39
15	80W2	556	6.9	222	2.8	263	3.28	40
16	120C	877	7.3	435	3.6	289	2.41	50
17	120W1	874	7.3	431	3.6	306	2.55	49
18	120W2	824	6.9	395	3.3	335	2.79	48
	Thinning, fertilisation 150 kg/ha four times							
19	60C	530	8.8	165	2.7	233	3.89	31
20	60W1	530	8.8	165	2.7	246	4.11	31
21	60W2	523	8.7	163	2.7	283	4.72	31
22	80C	708	8.8	278	3.5	279	3.49	39
23	80W1	708	8.8	278	3.5	295	3.69	39
24	80W2	697	8.7	273	3.4	334	4.18	39
25	120C	1069	8.9	586	4.9	317	2.64	55
26	120W1	1068	8.9	586	4.9	334	2.78	55
27	120W2	1057	8.8	582	4.8	372	3.10	55
	Thinning, fertilisation 250 kg/ha four times							
28	60C	538	9.0	171	2.9	234	3.90	32
29	60W1	538	9.0	171	2.9	247	4.12	32
30	60W2	535	8.9	170	2.8	287	4.79	32
31	80C	717	9.0	287	3.8	279	3.49	40
32	80W1	717	9.0	287	3.6	295	3.69	40
33	80W2	716	8.9	286	3.6	338	4.23	40
34	120C	1094	9.1	593	4.9	331	2.76	54
35	120W1	1094	9.1	593	4.9	350	2.92	54
36	120W2	1070	8.9	588	4.9	378	3.15	55

[1] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest. For further details see Table 2.

Appendix 3. Total growth and harvesting yield on the *Calluna* site.

Scen-ario No.	Regime Rotat. Harv.[1)]	Productivity Total Mg/ha	Productivity Mean Mg/ha/a	Litter crop Total Mg/ha	Litter crop Mean Mg/ha/a	Cutting removal Total Mg/ha	Cutting removal Mean 100 Mg/ha/a	Litter Prod.
	No thinning, no fertilisation							
1	80C	474	5.9	295	3.7	116	1.45	62
2	80W1	474	5.9	295	3.7	122	1.53	62
3	80W2	474	5.9	295	3.7	139	1.74	62
4	120C	725	5.0	506	4.2	141	1.17	70
5	120W1	725	5.0	506	4.2	149	1.24	70
6	120W2	725	5.0	506	4.2	167	1.39	70
	Thinning, no fertilisation							
7	80C	449	5.6	172	2.1	180	2.25	38
8	80W1	449	5.6	172	2.1	190	2.38	38
9	80W2	428	5.3	165	2.1	208	2.60	38
10	120C	704	5.8	341	2.8	236	1.96	49
11	120W1	698	5.8	339	2.8	249	2.07	48
12	120W2	675	5.6	321	2.7	277	2.30	48
	Thinning, fertilisation 150 kg/ha four times							
13	80C	537	6.7	213	2.7	208	2.60	40
14	80W1	535	6.7	213	2.7	219	2.74	40
15	80W2	527	6.6	210	2.7	249	3.12	40
16	120C	808	6.7	421	3.5	252	2.10	52
17	120W1	835	7.0	416	3.5	294	2.45	50
18	120W2	804	6.7	418	3.5	302	2.51	52
	Thinning, fertilisation 250 kg/ha four times							
19	80C	544	6.8	220	2.7	208	2.60	40
20	80W1	544	6.8	220	2.7	220	2.75	40
21	80W2	544	6.8	219	2.7	255	2.19	40
22	120C	856	7.1	421	3.5	292	2.43	49
23	120W1	856	7.1	420	3.5	308	2.57	49
24	120W2	847	7.1	420	3.5	339	2.83	49

1) Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest. For further details see Table 2.

Appendix 4. Use and cycling of nitrogen on the *Myrtillus* site.

Scen-ario No.	Regime Rotat. Harv.[1)]	Nitrogen uptake Total Mg/ha	Nitrogen uptake Mean Mg/ha/a	Nitrogen in internal cycle Total Mg/ha	Nitrogen in internal cycle Mean Mg/ha/a	Nitrogen in internal cycle Total Mg/ha	Nitrogen in internal cycle Mean Mg/ha/a	Prod. Nitrog. kg/kg
	No thinning, no fertilisation							
1	60C	1637	27.3	1285	21.4	1635	27.2	385
2	60W1	1637	27.3	1285	21.4	1635	27.2	385
3	60W2	1637	27.3	1285	21.4	1635	27.2	385
4	80C	2135	26.7	1765	22.1	2160	27.0	388
5	80W1	2135	26.7	1765	22.1	2160	27.0	388
6	80W2	2135	26.7	1765	22.1	2160	27.0	388
7	120C	3131	26.1	2742	22.8	3275	27.3	381
8	120W1	3131	26.1	2742	22.8	3275	27.3	381
9	120W2	3131	26.1	2742	22.8	3275	27.3	381
	Thinning, no fertilisation							
10	60C	1619	27.0	977	16.3	1564	26.1	376
11	60W1	1615	26.9	976	16.3	1560	26.0	376
12	60W2	1568	26.1	955	15.9	1509	25.1	373
13	80C	2103	26.3	1427	17.8	2120	26.5	383
14	80W1	2099	26.2	1424	17.8	2108	26.3	385
15	80W2	2043	25.4	1392	17.4	2028	25.4	378
16	120C	3039	25.3	2316	19.3	3218	26.8	382
17	120W1	3030	25.2	2307	19.2	3199	26.7	382
18	120W2	2937	24.5	2236	18.6	3054	25.4	381
	Thinning, fertilisation 150 kg/ha four times							
19	60C	1981	33.0	1136	18.9	1867	31.1	365
20	60W1	1977	32.9	1135	18.9	1866	31.1	366
21	60W2	1960	32.7	1118	18.6	1837	30.6	365
22	80C	2595	32.4	1726	21.6	2702	33.8	376
23	80W1	2606	32.6	1731	21.6	2709	33.9	376
24	80W2	2550	31.9	1706	21.3	2667	33.3	376
25	120C	3902	32.5	3021	25.2	4155	34.6	403
26	120W1	3892	32.4	3014	54.1	4146	34.5	403
27	120W2	3819	31.8	2969	24.7	4055	33.8	400
	Thinning, fertilisation 250 kg/ha four times							
28	60C	2033	33.9	1189	19.8	1960	32.7	367
29	60W1	2056	34.3	1187	19.8	1956	32.6	364
30	60W2	2026	33.8	1176	19.6	1939	32.3	365
31	80C	2725	34.1	1839	23.0	2840	35.5	375
32	80W1	2726	34.1	1840	23.0	2839	35.5	374
33	80W2	2728	34.1	1839	23.0	2846	35.6	372
34	120C	4082	34.0	3155	26.3	4374	36.4	400
35	120W1	4082	34.0	3173	26.4	4386	36.6	404
36	120W2	4049	33.8	3148	26.2	4335	36.1	404

1) Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest. For further details see Table 2.

Appendix 5. Use and cycling of nitrogen on the *Vaccinium* site.

Scen-ario No.	Regime Rotat. Harv.[1)]	Nitrogen uptake Total Mg/ha	Nitrogen uptake Mean Mg/ha/a	Nitrogen in internal cycle Total Mg/ha	Nitrogen in internal cycle Mean Mg/ha/a	Nitrogen in internal cycle Total Mg/ha	Nitrogen in internal cycle Mean Mg/ha/a	Prod. Nitrog. kg/kg
	No thinning, no fertilisation							
1	60C	1232	20.5	916	15.3	1161	19.3	361
2	60W1	1232	20.5	916	15.3	1161	19.3	361
3	60W2	1232	20.5	916	15.3	1161	19.3	361
4	80C	1668	20.8	1337	16.7	1607	20.1	374
5	80W1	1668	20.8	1337	16.7	1607	20.1	374
6	80W2	1668	20.8	1337	16.7	1607	20.1	382
7	120C	2412	20.1	2075	17.3	2356	19.6	382
8	120W1	2412	20.1	2075	17.3	2356	19.6	382
9	120W2	2412	20.1	2075	17.3	2356	19.6	382
	Thinning, no fertilisation							
10	60C	1227	20.4	663	11.0	1093	18.2	346
11	60W1	1224	20.4	662	11.0	1091	18.2	345
12	60W2	1175	19.6	643	10.7	1051	17.5	341
13	80C	1645	20.6	1053	13.2	1581	19.8	355
14	80W1	1640	20.5	1051	13.1	1577	19.7	355
15	80W2	1595	19.9	1026	12.8	1520	19.0	348
16	120C	2374	19.8	1761	14.7	2375	19.8	370
17	120W1	2368	19.7	1755	14.6	2371	19.8	369
18	120W2	2335	19.5	1730	14.4	2326	19.4	353
	Thinning, fertilisation 150 kg/ha four times							
19	60C	1544	25.7	808	13.5	1348	22.5	343
20	60W1	1548	25.8	807	13.4	1346	22.4	343
21	60W2	1536	25.6	796	13.3	1327	22.1	341
22	80C	1959	24.5	1257	15.7	1922	24.0	362
23	80W1	1958	24.5	1257	15.7	1921	24.0	362
24	80W2	1914	23.9	1242	15.5	1907	23.8	364
25	120C	2775	23.1	2111	17.6	2771	23.1	385
26	120W1	2774	23.1	2110	17.6	2770	23.1	385
27	120W2	2772	23.1	2101	17.5	2740	22.8	382
	Thinning, fertilisation 250 kg/ha four times							
28	60C	1579	26.3	839	14.0	1399	23.3	341
29	60W1	1579	26.3	839	14.0	1399	23.3	341
30	60W2	1572	26.2	832	13.9	1388	23.1	340
31	80C	1982	24.8	1284	16.0	1951	24.4	362
32	80W1	1982	24.8	1284	16.0	1950	24.4	362
33	80W2	1981	24.8	1285	16.1	1955	24.4	361
34	120C	2837	23.6	2148	17.9	2817	23.5	386
35	120W1	2836	23.6	2147	17.9	2816	23.5	386
36	120W2	2787	23.2	2127	17.7	2792	23.3	384

[1)] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative of the whole tree harvest, W2 = the second alternative for the whole tree harvest.

Appendix 6. Use and cycling of nitrogen on the *Calluna* site.

Scen-ario No.	Regime Rotat. Harv.[1)]	Nitrogen uptake Total Mg/ha	Nitrogen uptake Mean Mg/ha/a	Nitrogen in internal cycle Total Mg/ha	Nitrogen in internal cycle Mean Mg/ha/a	Nitrogen in internal cycle Total Mg/ha	Nitrogen in internal cycle Mean Mg/ha/a	Prod. Nitrog. kg/kg
	No thinning, no fertilisation							
1	80C	1472	18.4	1181	14.8	1405	17.6	322
2	80W1	1472	18.4	1181	14.8	1405	17.6	322
3	80W2	1472	18.4	1181	14.8	1405	17.6	322
4	120C	2214	18.4	1917	16.0	2113	17.6	327
5	120W1	2214	18.4	1917	16.0	2113	17.6	327
6	120W2	2214	18.4	1917	16.0	2113	17.6	327
	Thinning, no fertilisation							
7	80C	1441	18.0	908	11.3	1356	16.9	312
8	80W1	1438	18.0	906	11.3	1353	16.9	312
9	80W2	1379	17.2	873	10.9	1294	16.2	310
10	120C	2182	18.2	1637	13.6	2160	18.0	321
11	120W1	2177	18.1	1632	13.6	2052	17.9	321
12	120W2	2109	17.6	1572	13.1	2070	17.2	320
	Thinning, fertilisation 150 kg/ha four times							
13	80C	1713	21.4	1108	13.8	1663	20.8	313
14	80W1	1702	21.3	1108	13.8	1662	20.8	315
15	80W2	1703	21.3	1095	13.7	1643	20.5	310
16	120C	2510	20.9	1912	15.9	2486	20.7	322
17	120W1	2536	21.1	1887	15.7	2458	20.5	329
18	120W2	2488	20.7	1895	15.8	2463	20.5	323
	Thinning, fertilisation 250 kg/ha four times							
19	80C	1750	21.9	1136	14.2	1698	21.2	311
20	80W1	1749	21.9	1135	14.2	1696	21.2	311
21	80W2	1742	21.8	1135	14.2	1698	21.2	313
22	120C	2587	21.5	1913	15.9	2497	20.8	331
23	120W1	2587	21.5	1912	15.9	2497	20.8	331
24	120W2	2572	21.4	1907	15.9	2486	20.7	329

[1)] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = thesecond alternative for the whole tree harvest.

Appendix 7. Nitrogen balance on the *Myrtillus* site.

Scen-ario No.	Regime Rot Harv.[1]	Accumulation of nitrogen Total kg/ha	Accumulation of nitrogen Mean kg/ha/a	Leaching of nitrogen Total kg/ha	Leaching of nitrogen Mean kg/ha/a	Loss in harvested timber Total kg/ha	Loss in harvested timber Mean kg/ha/a	Nitrogen balance Total kg/ha	Nitrogen balance Mean kg/ha/a
	No thinning, no fertilisation								
1	60C	187	3.1	262	4.4	123	2.0	−198	−3.3
2	60W1	187	3.1	262	4.4	130	2.2	−205	−3.4
3	60W2	187	3.1	262	4.4	227	3.8	−301	−5.0
4	80C	249	3.1	264	3.3	132	1.6	−147	−1.8
5	80W1	249	3.1	264	3.3	139	1.7	−155	−1.8
6	80W2	249	3.1	264	3.3	238	3.0	−253	−3.2
7	120C	371	3.1	269	2.2	137	1.1	− 35	−0.3
8	120W1	371	3.1	269	2.2	145	1.2	− 43	−0.4
9	120W2	371	3.1	269	2.2	250	2.1	−147	−1.2
	No thinning, no fertilisation								
10	60C	187	3.1	274	4.6	212	3.5	−229	−5.0
11	60W1	187	3.1	274	4.6	224	3.7	−310	−5.2
12	60W2	187	3.1	269	4.5	388	6.5	−470	−7.8
13	80C	249	3.1	275	3.4	231	3.0	−257	−3.2
14	80W1	249	3.1	275	3.4	251	3.1	−277	−3.5
15	80W2	249	3.1	271	2.4	408	5.1	−430	−5.4
16	120C	371	3.1	283	2.4	251	2.1	−163	−1.4
17	120W1	371	3.1	282	2.3	264	2.2	−175	−1.5
18	120W2	371	3.1	279	2.3	447	3.7	−355	−3.0
	Thinning, fertilisation 150 kg/ha four times								
19	60C	728	12.1	286	4.8	247	4.1	+195	+3.2
20	60W1	728	12.1	286	4.8	260	4.3	+182	−3.0
21	60W2	728	12.1	286	4.8	516	8.6	− 74	−1.2
22	80C	790	9.9	288	3.6	260	3.2	+243	+3.0
23	80W1	790	9.9	287	3.6	276	3.5	+227	+2.8
24	80W2	790	9.9	285	3.6	521	6.5	− 15	−0.2
25	120C	914	7.6	303	2.5	313	2.6	+298	+2.5
26	120W1	914	7.6	304	2.5	329	2.7	+281	+2.3
27	120W2	914	7.6	306	2.6	545	4.5	+ 63	+0.5
	Thinning, fertilisation 250 kg/ha four times								
28	60C	1089	18.1	283	4.7	251	4.2	+554	+9.2
29	60W1	1089	18.1	283	4.7	266	4.4	+539	+9.0
30	60W2	1089	18.1	282	4.7	522	8.7	+284	+4.7
31	80C	1151	14.4	287	3.6	257	3.2	+607	+7.6
32	80W1	1151	14.4	287	3.6	272	3.4	+558	+7.0
33	80W2	1151	14.4	283	3.5	542	6.8	+326	+4.1
34	120C	1275	10.6	321	2.7	323	2.7	+631	+5.3
35	120W1	1275	10.6	295	2.5	350	2.9	+630	+5.2
36	120W2	1275	10.6	294	2.4	583	4.9	+398	+3.3

[1] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest.

Appendix 8. Nitrogen balance on the *Vaccinium* site.

Scen-ario No.	Regime Rot Harv.[1]	Accumulation of nitrogen Total kg/ha	Accumulation of nitrogen Mean kg/ha/a	Leaching of nitrogen Total kg/ha	Leaching of nitrogen Mean kg/ha/a	Loss in harvested timber Total kg/ha	Loss in harvested timber Mean kg/ha/a	Nitrogen balance Total kg/ha	Nitrogen balance Mean kg/ha/a
	No thinning, no fertilisation								
1	60C	186	3.1	218	3.6	114	1.9	−147	−2.4
2	60W1	186	3.1	218	3.6	121	2.0	−153	−2.5
3	60W2	186	3.1	218	3.6	204	3.4	−237	−3.9
4	80C	247	3.1	224	2.8	130	1.6	−107	−1.3
5	80W1	247	3.1	224	2.8	138	1.7	−114	−1.4
6	80W2	247	3.1	224	2.8	219	2.7	−196	−2.4
7	120C	370	3.1	304	2.5	129	1.1	− 63	−0.5
8	120W1	370	3.1	304	2.5	137	1.1	− 71	−0.6
9	120W2	370	3.1	304	2.5	222	1.8	−156	−1.3
	No thinning, no fertilisation								
10	60C	186	3.1	230	3.8	195	3.2	−240	−4.0
11	60W1	186	3.1	230	3.8	206	3.4	−250	−4.2
12	60W2	186	3.1	226	3.8	341	3.7	−381	−6.3
13	80C	247	3.1	228	2.8	206	2.6	−187	−2.3
14	80W1	247	3.1	228	2.8	217	2.7	−198	−2.5
15	80W2	247	3.1	225	2.8	363	4.5	−340	−4.2
16	120C	370	3.1	272	2.3	233	1.9	−135	−1.1
17	120W1	370	3.1	271	2.3	246	2.0	−147	−1.2
18	120W2	369	3.1	248	2.1	394	3.3	−273	−2.3
	Thinning, fertilisation 150 kg/ha four times								
19	60C	727	12.1	238	4.0	245	4.1	+244	+4.1
20	60W1	727	12.1	238	4.0	259	4.3	+230	+3.8
21	60W2	727	12.1	238	4.0	467	7.8	+ 22	+0.4
22	80C	788	9.8	249	3.1	248	3.1	+291	+3.6
23	80W1	788	9.8	249	3.1	262	3.3	+277	+3.5
24	80W2	788	9.8	247	3.1	434	5.4	+107	+1.3
25	120C	911	7.6	455	3.8	243	2.0	+213	+1.8
26	120W1	911	7.6	452	3.8	256	2.1	+203	+1.7
27	120W2	911	7.6	411	3.4	440	3.7	+ 59	+0.5
	Thinning, fertilisation 250 kg/ha four times								
28	60C	1087	18.1	237	4.0	244	4.1	+605	+10.1
29	60W1	1089	18.1	237	4.0	258	4.3	+591	+ 9.8
30	60W2	1087	18.1	236	3.9	468	7.8	+383	+ 6.4
31	80C	1148	14.3	271	3.4	247	3.1	+630	+ 7.9
32	80W1	1148	14.3	271	3.4	261	3.3	+617	+ 7.7
33	80W2	1148	14.3	260	3.2	447	5.6	+441	+ 5.5
34	120C	1271	10.6	698	5.8	256	2.1	+317	+ 2.6
35	120W1	1271	10.6	695	5.8	270	2.2	+306	+ 2.5
36	120W2	1271	10.6	664	5.5	426	3.5	+180	+ 1.5

[1] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest.

Appendix 9. Nitrogen balance on the *Calluna* site.

Scen-ario No.	Regime Rot Harv.[1)]	Accumulation of nitrogen Total kg/ha	Accumulation of nitrogen Mean kg/ha/a	Leaching of nitrogen Total kg/ha	Leaching of nitrogen Mean kg/ha/a	Loss in harvested timber Total kg/ha	Loss in harvested timber Mean kg/ha/a	Nitrogen balance Total kg/ha	Nitrogen balance Mean kg/ha/a
	No thinning, no fertilisation								
1	80C	247	3.1	122	1.5	104	1.3	+21	+03
2	80W1	247	3.1	122	1.5	110	1.4	+15	+0.2
3	80W2	247	3.1	122	1.5	188	2.3	−63	−0.8
4	120C	369	3.1	160	1.3	122	1.0	+87	+0.7
5	120W1	369	3.1	160	1.3	129	1.1	+80	+0.7
6	120W2	369	3.1	160	1.3	199	1.7	+ 9	+0.1
	No thinning, no fertilisation								
7	80C	247	3.1	132	1.6	180	2.3	− 67	−0.8
8	80W1	247	3.1	131	1.6	190	2.4	− 75	−0.9
9	80W2	247	3.1	128	1.6	322	4.0	−204	−2.5
10	120C	369	3.1	140	1.2	203	1.7	+ 26	+0.2
11	120W1	369	3.1	140	1.2	214	1.8	+ 15	0.1
12	120W2	369	3.1	135	1.1	349	2.9	−116	−1.0
	Thinning, fertilisation 150 kg/ha four times								
13	80C	778	9.8	136	1.7	191	2.4	+460	+5.7
14	80W1	778	9.8	137	1.7	201	2.5	+449	+5.6
15	80W2	778	9.8	135	1.7	377	4.7	+276	+3.4
16	120C	910	7.6	250	2.1	206	1.7	+454	+3.8
17	120W1	910	7.6	265	2.2	258	2.1	+387	+3.2
18	120W2	910	7.6	234	1.9	379	3.2	+298	+2.5
	Thinning, fertilisation 250 kg/ha four times								
19	80C	1148	14.3	138	1.7	191	2.4	+819	+10.2
20	80W1	1148	14.3	138	1.7	202	2.5	+808	+10.1
21	80W2	1148	14.3	139	1.7	378	4.7	+631	+ 7.9
22	120C	1270	10.6	383	3.2	261	2.2	+626	+ 5.2
23	120W1	1270	10.6	382	3.2	275	2.3	+613	+ 5.1
24	120W2	1270	10.6	359	3.0	438	3.6	+473	+ 3.9

[1)] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = thesecond alternative for the whole tree harvest.

Appendix 10. The values of the different ranking criteria of the management regimes for each scenario on the *Myrtillus* site.

Scen-ario No.	Regime Rot. Harv.[1)]	$\frac{Y}{N}$ kg/kg	$\frac{N_O}{Y}$ kg/kg	$\frac{Y}{Y_{tot}}$ kg/kg
	No thinning, no fertilisation			
1	60C	91	.0025	.23
2	60W1	97	.0024	.25
3	60W2	111	.0024	.28
4	80C	80	.0023	.20
5	80W1	85	.0022	.21
6	80W2	97	.0024	.25
7	120C	61	.0021	.16
8	120W1	65	.0020	.17
9	120W2	74	.0022	.19
	Thinning, no fertilisation			
10	60C	143	.0020	.38
11	60W1	151	.0020	.40
12	60W2	174	.0024	.46
13	80C	132	.0018	.34
14	80W1	142	.0017	.36
15	80W2	157	.0021	.41
16	120C	110	.0015	.29
17	120W1	117	.0015	.30
18	120W2	135	.0018	.35
	Thinning, fertilisation 150 kg/ha four times			
19	60C	137	.0019	.37
20	60W1	145	.0019	.39
21	60W2	172	.0023	.47
22	80C	125	.0016	.33
23	80W1	133	.0016	.35
24	80W2	156	.0020	.41
25	120C	106	.0014	.26
26	120W1	112	.0014	.27
27	120W2	124	.0017	.31
	Thinning fertilisation 250 kg/ha four times			
28	60C	137	.0019	.37
29	60W1	143	.0018	.39
30	60W2	171	.0023	.47
31	80C	121	.0016	.32
32	80W1	128	.0015	.34
33	80W2	150	.0020	.40
34	120C	107	.0014	.26
35	120W1	115	.0013	.28
36	120W2	131	.0016	.32

[1)] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest.

Appendix 11. The values of the different ranking criteria of the management regimes for each scenario on the *Vaccinium* site.

Scen-ario No.	Regime Rot. Harv.[1)]	$\frac{Y}{N}$ kg/kg	$\frac{N_O}{Y}$ kg/kg	$\frac{Y}{Y_{tot}}$ kg/kg
	No thinning, no fertilisation			
1	60C	103	.0026	.28
2	60W1	108	.0025	.30
3	60W2	124	.0027	.34
4	80C	91	.0023	.24
5	80W1	97	.0022	.25
6	80W2	109	.0024	.29
7	120C	72	.0024	.19
8	120W1	77	.0023	.20
9	120W2	86	.0025	.22
	Thinning, no fertilisation			
10	60C	152	.0022	.44
11	60W1	160	.0022	.46
12	60W2	182	.0026	.53
13	80C	140	.0018	.39
14	80W1	147	.0018	.41
15	80W2	164	.0022	.47
16	120C	121	.0017	.32
17	120W1	129	.0016	.35
18	120W2	143	.0019	.40
	Thinning, fertilisation 150 kg/ha four times			
19	60C	151	.0020	.43
20	60W1	159	.0020	.46
21	60W2	184	.0024	.54
22	80C	142	.0017	.39
23	80W1	150	.0017	.41
24	80W2	174	.0020	.47
25	120C	114	.0022	.29
26	120W1	120	.0021	.31
27	120W2	134	.0022	.35
	Thinning fertilisation 250 kg/ha four times			
28	60C	148	.0020	.43
29	60W1	156	.0020	.45
30	60W2	182	.0024	.53
31	80C	141	.0018	.38
32	80W1	148	.0018	.41
33	80W2	170	.0020	.47
34	120C	116	.0028	.30
35	120W1	123	.0027	.31
36	120W2	135	.0028	.35

[1)] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest.

Appendix 12. The values of the different ranking criteria of the management regimes for each scenario on the *Calluna* site.

Scenario No.	Regime Rot. Harv.[1)]	$\frac{Y}{N}$ kg/kg	$\frac{N_O}{Y}$ kg/kg	$\frac{Y}{Y_{tot}}$ kg/kg
	No thinning, no fertilisation			
1	80C	78	.0019	.24
2	80W1	83	.0018	.25
3	80W2	94	.0022	.29
4	120C	63	.0020	.19
5	120W1	67	.0019	.20
6	120W2	75	.0021	.23
	Thinning, no fertilisation			
7	80C	125	.0017	.40
8	80W1	132	.0016	.42
9	80W2	150	.0021	.48
10	120C	108	.0014	.33
11	120W1	114	.0014	.35
12	120W2	131	.0017	.40
	Thinning, fertilisation 150 kg/ha four times			
13	80C	121	.0015	.38
14	80W1	128	.0015	.40
15	80W2	146	.0020	.47
16	120C	100	.0018	.31
17	120W1	115	.0017	.35
18	120W2	121	.0020	.37
	Thinning fertilisation 250 kg/ha four times			
19	80C	119	.0015	.38
20	80W1	125	.0015	.40
21	80W2	146	.0020	.46
22	120C	112	.0022	.34
23	120W1	119	.0021	.36
24	120W2	131	.0023	.40

[1)] Regime: the number indicates the length of rotation and C = conventional harvest, W1 = the first alternative for the whole tree harvest, W2 = the second alternative for the whole tree harvest.

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