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Plant Biomass, Primary Production and Mineral Cycling of a Mixed Oak Forest in Linnebjer, Sweden

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Abstract

Plant biomass, primary production and mineral cycling were studied in a mixed deciduous forest (*Quercus robur* L., *Tilia cordata* L. and *Corylus avellana* L.) in southern Sweden. Plant biomass amount above and below ground was 201 and 37 t·ha^{-1}, respectively. Primary production above and below ground was an estimated 13.3 and 2.3 t·ha^{-1}, respectively. Carbon was the dominant element in the forest ecosystem, comprising 133 t·ha^{-1}. Other major elements were: N > Ca > K > Si > Mg > S > Mn > P > Fe and Na (range 1123 to 18 kg·ha^{-1}), followed by some trace elements. Yearly litterfall restored 6.0 t·ha^{-1} organic matter or 2.3 t·ha^{-1} carbon. Approximately 45% decomposed and returned to the soil during the year. Monitoring of other elements revealed that the ecosystem received inputs through dry and wet deposition, in particular 34.4 kg·ha^{-1} S and 9.4 kg·ha^{-1} of N yearly as throughfall. Determination of yearly biomass increase showed that the oak forest ecosystem was still in an aggradation or accumulation phase.

Keywords

Plant Biomass, Primary Production, Litterfall, Deposition, Cycling of C, N, P, K, S

1. Introduction

Over the years, the Linnebjer nature reserve, which lies 7 km NE of the city of Lund in southern Sweden, has been the subject of detailed investigations of its history, vegetation, organic matter, plant biomass, primary production, water profile, soil physics and soil chemistry. The studies on biomass and primary production led to the development of methods which were later used in Sweden and the Nordic countries. The methods used to determine plant biomass and production and the related results are described in Andersson (1970c) and Reichle

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(1981). However, the studies of the mixed deciduous forest in the reserve also included mineral cycling performed in the early 1970s, the results of which were never satisfactorily published. Therefore they are not available in the scientific literature, but are still valid, in demand and are hence presented in this paper.

The results can be applied in monitoring changes in tree biomass and production, as well as cycling of elements over time. It is also important to have information on the distribution of elements in the stand in order to determine temporal changes in air pollution, especially sulfur and nitrogen deposition.

This paper presents the results obtained to date on mineral cycling in the Linnebjer mixed forest. It includes a summary of biomass and primary production by the tree and field layers as essential background and important functional fractions such as litterfall and deposition, as well as data on their contents of elements. The cycling is discussed using a simple model.

2. The Mixed Forest

The dominant vegetation in the Linnebjer nature reserve is mixed deciduous forest. Part of the reserve was used as a special area for detailed investigations (**Figure 1** and **Figure 2**). A full description of the vegetation during the study period is given in Andersson (1970b). In brief, the forest has a number of layers: tree layer > 15 m, upper shrub layer 2 - 15 m, lower shrub layer < 2 m and field and bottom layers. The tree layer is dominated by *Quercus robur* and *Tilia cordata* and the upper shrub layer by *Corylus avellana*. The field layer shows seasonal changes, with *Anemone nemorosa* dominating in spring and *Oxalis acetosella* in summer. The bottom layer is weakly developed.

3. Element Cycling Model

Cycling of elements was assessed using a model developed by Nihlgård (1972) (**Figure 3**). The analysis was limited to the above-ground parts, as root production and the release of nutrients from the root litter and leaching of elements from the soil were not estimated. However, root biomass was measured. In determining the dynamics of organic matter in a forest, the above-ground yearly net primary production (P) the yearly litterfall (L) and the decomposition rate (k) are the most important factors. Understanding element cycling requires information on the amounts of elements in the primary plant production, the biomass increase (ΔB), yearly litterfall (L), surface litter (SL) and the canopy-leached fraction (CL = the difference between total through fall and incoming rainfall).

Figure 1. Photo of the oak forest with *Quercus robur* and *Corylus avellana* also showing litter traps and a rain gauge. —Photo author May 1969.

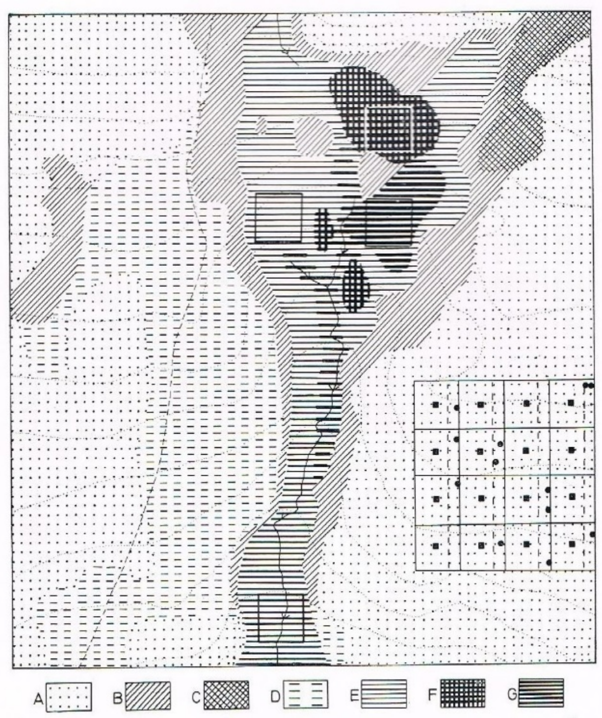

Figure 2. Map of the Special area showing ecosystems and sample areas. Key: A. *Quercus robur-Oxalis acerosella* ecosystem; B. *Quercus robur-Geumrivale* ecosystem; C = *Quercusrobur-Athyriumfilix-femina* ecosystem, D = Clearing phase of ecosystem A and B; E = *Filipendula ulmaria* ecosystem; F = *Carex flacca* ecosystem and G = *Carex caespitose* ecosystem. In the sample area for ecosystem A the situation of 16 litter traps and 12 rain gauges are shown.

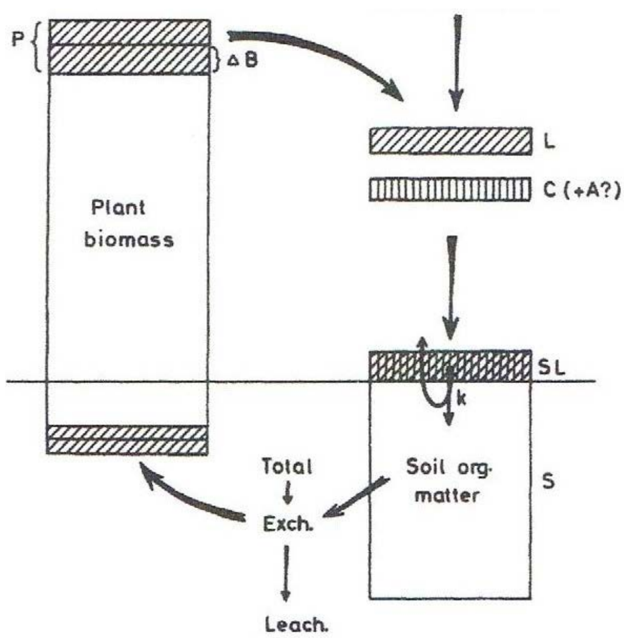

Figure 3. Schematic model of the turnover of organic matter and mineral cycling. For abbreviations see text.

4. Methods

4.1. Tree Biomass and Production

A detailed description of the methods developed and applied to the tree layer and the results obtained are provided in Andersson (1970c) and Nihlgård (1972). Therefore, only a summary is given here. The estimates of tree biomass and production were based on allometric regressions, using the relationship between destructive and non-destructive measurements. The estimation procedure comprised four basic steps:

- Stand analyses of non-destructive measurements—tree height and diameter.
- Destructive measurements of sample trees: stem sections or discs, branches, twigs and roots—diameter, age.
- Application of the stand data to the regressions of the sample trees obtained in (2).
- Additional observations on e.g. litterfall.

The above-ground biomass and production of trees were studied specifically for 11 *Quercus robur*, 6 *Tilia* and *Sorbus* and 18 *Corylus*. Studies of the below-ground parts with roots were limited to three individuals of each tree species. The main root biomass fraction, comprising roots > 0.5 cm in diameter, was collected around the tree. The fine root biomass (<0.5 cm diameter) was collected in 10 pits measuring 50 cm × 50 cm × 60 cm excavated along a transect at regular intervals of 2 m.

4.2. Field Layer

The above-ground biomass of the field layer was sampled on occasions corresponding to the maximum development of the seasonal species. Total primary production was calculated by adding the maximum values obtained for the different species investigated. These were sampled in 16 squares (50 cm × 50 cm) selected at random on each sampling occasion. Below-ground parts were collected within the same squares.

4.3. Litter and Litterfall

Litterfall was collected in 16 litter traps (50 cm × 50 cm × 30 cm) laid out in a systematic way. The trap sides were made of wooden boards and the base of nylon netting and they were placed 20 cm above the ground surface. Coarse litter such as twigs and pieces longer than 0.5 m were collected yearly in a 20 cm × 20 cm square sampling area. Random samples of surface litter were taken twice a year, before and after leaf shedding, in 16 squares measuring 50 cm × 50 cm.

4.4. Deposition

In connection with an investigation of element cycling in the oak forest (Andersson 1970b), rain samples were collected and subjected to chemical analysis in order to determine the deposition of sulfur and nitrogen, as well as other incoming nutrients. These samples were collected as through fall in a special area of the forest (**Figure 1** and **Figure 2**).

4.5. Collectors and Collection

The *incoming rainfall* was measured at a nearby farm 300 m from the *throughfall* sampling area. A rain gauge of type SMHI with a diameter of 16 cm and fitted with a wind shelter was used (SMHI 1958), placed with the opening 1.5 m above ground. A comparison with data obtained with other gauges used in the forest (see below) showed that the results was usually within the reported range of observations (Nihlgård 1970), although occasionally they were 3% lower.

The *throughfall* was collected in 12 gauges randomly spread in a forested area of 1600 m^2. The gauges consisted of 1-L polythene bottles with a plastic funnel with diameter 15 cm fitted in the lid. A filter of inert glass wool was placed in the bottom of the funnel to prevent material entering the bottle. To stabilise the gauges, they were placed on the ground inside metal tubes (diameter 16 cm). The top of the gauges was 30 cm above the ground.

The rain gauges were emptied after each rain event between December 2, 1966 and November 2, 1967. The volume was measured and the pH was determined in order to identify samples with impurities. The bottles were stored cool and then brought to the laboratory on 15 occasions during the measurement period for chemical analyses.

4.6. Chemical Analyses of Water

On arrival at the laboratory, the samples were pooled into four composite samples and kept cool (+4˚C). Analyses were carried out within one month as follows:

pH was determined with a pH-meter, type Beckman N-2 (accuracy ±0.02). In calculating average pH, the pH values were first transformed to concentration of hydrogen ions and the average was converted back to pH (cf. Barrett & Brodin 1955).

Further analyses were performed on filtered water. The *cations* Na, K, Ca, Mg, Fe and Mn were determined on a Perkin-Elmer Atomic Absorption Spectrophotometer, with analytical error normally 1%, estimated from the standard curves.

Chloride concentration was determined with a mercurimetric method using diphenylcarbazon as an indicator (Clarke, 1950). The accuracy was ±5%, calculated as standard deviation of duplicate analyses (Nihlgård, 1970). *Sulphate* concentration was determined with a turbidimetric method using $BaCl_2$ and an acid seed solution (Chesnin Yien, 1950; Rossum & Villarez, 1961). The accuracy ±7%, calculated as for chloride. *Phosphate* concentration was determined with a colorimetric method after reduction with ascorbic acid and addition of K-antimonyltartrate plus ammonium molydate (Murphy & Riley, 1962). The accuracy was ±7%, calculated as above. *Nitrate* concentration was tentatively determined using a colorimetric method (accuracy ±10%, calculated as above), with alpha-naphthylamine and sulphanilic acid after addition of HAc, $BaSO_4$ and $MnSO_4$ (cf Bray, 1945, Method 1, Procedure 1). *Ammonia* concentration was determined tentatively using Nessler's regent after addition of sodium potassium tartrate (accuracy ±7%, calculated as above). Total nitrogen concentration was analysed by a macro-Kjeldahl distillation method (Karlgren, 1962). The accuracy was ±6%, calculated as for chloride.

4.7. Soil Sampling and Chemical Analyses

The soil sampling procedure and the methods applied for determination of exchangeable and total amounts of elements are described in full in Andersson, 1970b (pp. 141-146). Statistical analyses are also described in the same publication.

4.8. Statistics

Results are generally presented as means. Percentage errors are given at 95% confidence limit as percentage of the mean. Andersson (1970b) discuss different statistical aspects of errors in sampling and computations.

5. Results

5.1. Biomass and Production of the Tree, Shrub and Field Layers

Biomass and primary production are essential as carrier substances of the elements treated in this paper, so the results presented by Andersson (1970b) for the Linnebjer nature reserve are summarised here. Tree biomass (B) of the mixed forest was estimated to be 238 $t \cdot ha^{-1}$, with 201 aboveground and 38 $t \cdot ha^{-1}$ belowground (**Table 1**).

Yearly above-ground primary production (PP) was estimated to be 13.3 $t \cdot ha^{-1} \cdot yr^{-1}$. This included plant losses by death and shedding (L), which amounted to 0.7 $t \cdot ha^{-1} \cdot yr^{-1}$, and plant losses by consumers (G), which amounted to 0.4 $t \cdot ha^{-1} \cdot yr^{-1}$. The below-ground production of tree and understory layers was estimated to be roughly 1.8 $t \cdot ha^{-1} \cdot yr^{-1}$ and fine root biomass production 0.5 $t \cdot ha^{-1} \cdot yr^{-1}$ (**Table 1**). The above-ground biomass of the field layer was 0.06 - 0.2 $t \cdot ha^{-1}$ and its below-ground biomass was 2.4 - 2.6 $t \cdot ha^{-1}$ (**Table 1** and **Table 2**).

5.2. Element Amounts and Their Distribution in Biomass and in Production Fractions of the Tree, Shrub and Field Layers

The carbon content in the above-ground fraction of trees and shrubs was 114 $t \cdot ha^{-1}$ and that in the below-ground fraction was 19 $t \cdot ha^{-1}$. A factor of 2 is often accepted for conversion of carbon to biomass. The nitrogen content was 0.81 $t \cdot ha^{-1}$ in above-ground tree and shrub biomass including also the field layer and 0.32 $t \cdot ha^{-1}$ in below-ground biomass. For the finer fractions, a higher relative content was found. The field layer above and below ground contained minor amounts of elements (**Table 2** and **Table 3**).

Table 1. Plant biomass and yearly production (t·ha^{-1} dry weight at 85˚C) of the tree layer in a mixed woodland with *Quercus robur* and *Corylus avellana*. Linnebjer, Sweden.

	Biomass		Production
Shoot			
Overstory trees	155	-	6.3
Quercus robur	-	15.8	-
Understory trees	29		2.1
Tilia cordata	-	25.5	-
Sorbus aucubaria	-	1.6	-
Prunus avium	-	0.6	-
Ulmus glabra	-	0.6	-
Populus tremula		0.2	-
Shrubs	17		3.0
Corylus avellana	-		
Field layer	0.2		0.8
Plant losses by death and shedding (L)	-		0.7
Plant losses by consumers (G)	-		0.4
Total above ground	**201**		**13.3**
Root			
Main root biomass > 0.5 cm Ø			
Quercus robur	27		0.9
Understory trees			
Corylus avellana	7		0.9
Fine root biomass < 0.5 cm Ø-	3		0.5
Trees and shrubs			
Total below-ground	**37**		**2.3**
TOTAL	**238**		**15.6**

Table 2. Plant biomass and yearly production (t·ha^{-1} dry weight at 85˚C) of the tree layer in a mixed woodland with *Quercus robur* and *Corylus avellana*. Linnebjer, Sweden.

	Organicmatter	C	N	C/N	Na	K	Ca	Mg	Mn	Fe	Si	P	S
	kg·ha^{-1}			ratio	g·ha^{-1}								
Above-ground													
Convallaria majalis	10	4.2	0.21	20	0.419	18.8	119	43	12	1.8	0.8	16.2	16
Oxalis acetosella	45	18.7	1.73	14	5.170	126.7	343	148	49	9.4	5.3	96.8	121
Other species	15	7.3	0.53	14	2.760	33.4	102	56	12	4.3	2.1	37.7	29
Total above-ground kg·ha^{-1}	**70**	**30.2**	**2.11**		**0.008**	**0.18**	**0.56**	**0.25**	**0.07**	**0.02**	**0.01**	**0.15**	**0.17**
Below-ground													
Anemone nemorosa	2320	1035	49.0	21	821.4	2812	6790	4400	3820	3320	1550	3366	4990
Other species	290	123	6.5	19	104.0	238	1170	490	43	380	580	284	580
Total below-ground kg·ha^{-1}	**2610**	**1158**	**55.5**		**0.93**	**3.05**	**7.96**	**4.89**	**4.25**	**3.70**	**2.13**	**3.65**	**5.57**
SUM OF ABOVE-AND BELOW-GROUND	**2680**	**1188**	**57.6**		**0.94**	**3.23**	**8.52**	**5.14**	**4.32**	**3.72**	**2.14**	**3.80**	**5.74**

In order to set the concentrations of elements and their distribution in the biomass fractions in the forest into perspective, a comparison was using beech forests along a fertility gradient in the same region (Table 4). The fertility can be described by the degree of base saturation of the soil. The Linnebjer forest had a similar degree (around 20%) as surrounding *Lamium*-type beech forests (Nihlgård & Lindgren 1977). *Mercurialis*-type beech forests have a high soil base saturation and *Deschampsia*-type a low soil base saturation. The *Deschampsia*-type forests also have a lower carbon content than nutrient-richer forests, while K, Ca and Mg are related to availabi-

Table 3. Mineral content (t·ha^{-1} dry weight at 85˚C) of a mixed forest of *Quercus robur* and *Corylus avellana* in Linnebjer, Sweden.

Fraction	C	N	C/N	Na	K	Ca	Mg	Mn	P	S	Fe	Si	Pb	Zn	Cu	Ni
	tha^{-1}		ratio	kg ha^{-1}												
Above-ground																
Tree layer																
Stem wood	75.8	0.219	346	4.8	148	200	25	12	9.5	16.0	5.8	30.8	0.25	0.87	0.32	0.19
Stem bark	8.3	0.104	80	0.8	30	247	12	10	4.2	9.8	2.2	21.7	0.12	0.20	0.09	0.07
Branches	27.1	0.400	68	4.3	60	82	40	29	30.1	21.6	5.6	41.5	0.56	1.37	0.33	0.22
Current twigs	2.8	0.081	35	0.6	30	30	10	9	5.2	5.2	1.5	16.5	0.06	0.26	0.04	0.03
Field layer	0.03	0.002	14	0.01	0.18	0.56	0.25	0.07	0.15	0.17	0.02	-	-	-	-	-
Total above-ground	114.0	0.806	-	10.5	268	559	87	60	49.2	52.8	15.1	110.5	0.99	2.70	0.78	0.51
Below-ground																
Tree layer																
Roots > 0.5 cm	15.8	0.230	69	5.4	8	142	17	6	12.5	20.2	16.3	111	0.09	0.36	0.13	0.11
Roots < 0.5 cm	1.6	0.031	52	1.1	1	22	5	2	1.5	4.3	3.8	52.1	0.02	0.13	0.02	0.04
Field layer	1.2	0.056	21	0.9	3	8	5	4	3.7	5.6	3.7	-	0.09	0.33	0.03	0.03
Total below-ground	18.6	0.317	-	7.4	12	172	27	12	17.7	30.1	23.8	163.1	0.20	0.82	0.18	0.18
TOTAL ABOVE-AND BELOW-GROUND	132.6	1.123	-	17.9	280	731	114	72	66.9	82.1	38.9	273.6	1.19	3.52	0.96	0.69

Table 4. Comparison of the element distribution in the biomass of a mixed forest of *Quercus robur* and *Corylus avellana* in Linnebjer, Sweden, with that in neighboring beech forests along a fertility gradient in southernmost province in Sweden.

Forest type		Base saturation %	Basal area m^2·ha^{-1}	C t·ha^{-1}	N	P	Na	K	Ca	Mg	Mn	Fe	S
					kg·ha^{-1}								
Oak	*Oxalis*	21	31	114	81	49	11	268	559	87	60	15	53
Beech	*Mercurialis*	60	31	156	83	55	24	465	924	121	2	6	59
	Lamium	22	31	159	106	85	32	460	663	105	111	15	68
	Deschampsia	12	30	119	64	65	17	318	478	85	29	5	65

From: Oak (Andersson, 1970b); Beech (Nihlgård & Lindgren 1977).

lity in the form of exchangeable amounts in soil and in total biomass. Other elements such as P, Mn and Fe are dependent on the degree of solubility, which is regulated by soil pH. Sulfur to some extent reflects atmospheric deposition.

5.3. Amounts of Elements in Litterfall and Surface Litter

In order to analyse the circulation of elements, data on yearly litterfall (L) and the dynamics of the surface litter (SL) were used (**Table 5**).

The nitrogen content in the annual litterfall was 69 kg·ha^{-1}. The other elements were present in the following descending order: Ca, Si, Mg, K, S, Mn, P, Fe and Na, in amounts ranging from 41 to 0.9 kg·ha^{-1}·yr^{-1}. The surface litter comprised 6.0 t·ha^{-1} organic matter, or 2.8 t·ha^{-1} of carbon with a nitrogen content of 107 kg·ha^{-1}. The other elements occurred in the following descending order: Ca, Si, S, Mg, Mn, K, P, Fe and Na, in amounts ranging from 59 to 0.8 kg·ha^{-1}.

Some readily mobile elements, such as K and Na, had a decomposition rate (k-value) of approx. 50%, indicating that half the litterfall amount was turned over during one year. Other elements such as Si had a slow turnover rate of 14%, while the rest had intermediate values.

5.4. Amount of Elements in Precipitation, Throughfall and Interception

Input of elements was the result of precipitation measured in the open field (In), and of not measured dry deposited, aerosols (A) (**Table 6** and see **Figure 1**).

Content of elements (kg·ha^{-1}) in incoming precipitation (In), throughfall (T) and interception (Diff = canopy − leached fraction) in a mixed forest of *Quercus robur* and *Corylus avellana* in Linnebjer, Sweden (**Table 6**).

Through fall (T) was measured and the difference between In and T (Diff) indicated leached (positive values)

Table 5. Content of organic matter and elements in litterfall (L) and surface litter (SL) and decomposition factor k (L/L + SL) of a mixed forest of *Quercus robur* and *Corylus avellana* in Linnebjer, Sweden, April 1966-March 1967.

Period	Fraction	Org. matter	C	N	Na	K	Ca	Mg	Mn	Fe	Si	P	S
		kg·ha^{-1}											
April 66-June 66	Twigs	245	120	3.72	0.06	0.34	1.88	0.27	0.18	0.04	0.45	0.16	0.23
	Leaves	53	26	1.71	0.01	0.15	0.43	0.12	0.04	0.01	0.16	0.06	0.07
	Budscales	310	152	6.17	0.04	0.52	2.79	0.60	0.26	0.07	0.70	0.36	0.27
	Misc.	8	4	0.08	0	0.02	0.04	0.02	0.01	0	0.02	0.01	0.02
July 66-Sept. 66	Twigs	238	117	2.52	0.06	0.34	2.06	0.20	0.14	0.09	0.57	0.13	0.22
	Leaves	212	104	4.37	0.08	0.82	1.90	0.44	0.29	0.04	0.58	0.24	0.27
	Budscales	204	100	4.06	0.03	0.79	1.83	0.39	0.17	0.05	0.48	0.24	0.18
	Misc.	174	85	4.11	0.05	0.31	1.81	0.33	0.16	0.05	1.70	0.27	0.16
Oct. 66-Nov. 66	Twigs	87	43	0.85	0.02	0.13	0.65	0.08	0.06	0.03	0.17	0.04	0.07
	Leaves	1491	151	17.59	0.10	2.27	13.69	2.32	2.13	0.32	6.26	0.79	1.43
	Budscales	110	54	2.19	0.02	0.19	0.99	0.21	0.09	0.03	0.26	0.13	0.10
	Misc.	49	24	1.01	0.02	0.15	0.46	0.12	0.05	0.21	0.59	0.08	0.10
Dec. 66-March 67	Twigs	465	228	5.07	0.09	0.46	3.15	0.29	0.20	0.14	2.41	0.21	0.56
	Leaves	1048	514	14.29	0.27	0.66	9.46	0.74	0.58	0.58	6.37	0.61	1.65
	Budscales	0	-	-	-	-	-	-	-	-	-	-	-
	Misc.	38	19	0.87	0.01	0.05	0.28	0.03	0.02	0.06	0.56	0.05	0.09
Total	Twigs	1035	508	12.16	0.23	1.27	7.74	0.84	0.58	0.30	3.60	0.54	1.08
	Leaves	2840	1375	38.66	0.46	3.90	25.48	3.62	3.04	0.95	13.37	1.70	3.42
	Budscales	624	306	12.42	0.09	1.50	5.61	1.20	0.52	0.15	1.47	0.73	0.55
	Misc.	269	172	6.07	0.08	0.53	2.59	170	0.24	0.32	2.87	0.41	0.37
Total litterfall (L)		4768	2321	69.31	0.86	7.20	41.42	7.36	4.38	1.72	2.31	3.38	5.42
Surface litter (SL)		6010	2825	107	0.75	6.63	58.92	8.65	7.30	3.43	128.07	4.47	13.86
Finer fractions		4400	1985	99	0.60	5.00	44.92	7.39	6.29	2.77	118.20	3.87	12.07
Branches		1670	840	7.8	0.15	1.63	14.00	1.29	1.01	0.66	9.87	0.60	1.79
TOTAL LITTER (L + SL)		10,778	5146	176.3	1.61	13.83	100.34	16.04	11.68	5.15	149.38	7.85	19.28
k-value		0.44	0.45	0.39	0.53	0.52	0.41	0.46	0.38	0.20	0.14	0.43	0.28

or absorbed elements (negative values) in the canopy. The Diff value also included possible dry deposited aerosols (A). What were possibly overlooked were elements from A that had been absorbed into the leaves. This can be the case e.g. for NO_3 and NH_4ions.

The amount of precipitation in the year of measurement (1967) was 644 mm. The amount captured by the canopy, interception, was 168 mm. The input of elements with rain was in decreasing order: Cl, S, N, Na, Ca, Mg, K, Mn and P in amounts ranging from 23 to 0.04 kg·ha^{-1}·yr^{-1}. The through fall contained in decreasing order: Cl, K, S, N, Na, Ca, Mg, Mn and P, in amounts ranging from 55 to 1.5 kg·ha^{-1}·yr^{-1}. The higher values show the most readily motile elements.

Special consideration needs to be given to deposition of sulfur and nitrogen. The open field received inputs of 11.0 kg S ha^{-1}·yr^{-1} and 9.4 kg N ha^{-1}·yr^{-1}. The through fall contained 34.3 S and 22.3 N kg·ha^{-1}·yr^{-1}. Over time, these amounts would contribute to acidification of the soil and one-sided fertilisation of the forest. The study area was located in a rural landscape not far from urban areas, which may explain the very high level of S, but also the unexpectedly high level of N. The levels observed were lower than those reported for the north-west of the region at the time (Nihlgård 1972). Since then, S deposition has strongly decreased and the Slevel in the open field today is approx. 5 kg·ha^{-1}·yr^{-1}. The present day N deposition rate is approximately 10 kg·ha^{-1}·yr^{-1} (Pihl-Karlsson et al. 2012).

5.5. Soil Organic Matter and Exchangeable Mineral Content

The organic matter of the soil (SOM) was estimated to 288 t·ha^{-1}, with a carbon content of 108 t·ha^{-1} and a nitrogen content of 12 t·ha^{-1} (**Table 7**). The exchangeable (Exch) amounts in an extraction with ammonium acetate (Am-Ac) were in decreasing order: Ca, P, Mg, K, Na and Mn.

Table 6. Content of elements (kg·ha^{-1}) in incoming precipitation (In), throughfall (T) and interception (Diff = canopy-leached fraction) in a mixed forest of *Quercus robur* and *Corulys avellana* in Linnebjer, Sweden.

Period	Precipitation		Na	K	Ca	Mg	Mn	Cl	S	P	N_{tot}	pH
	type	mm	kg·ha^{-1}									
2-24/12 1966	In	81.5	2.23	0.19	0.83	0.29	0.02	3.88	1.60	0.006	0.97	5.2
	T	68.2	7.95	1.92	2.92	1.04	0.21	12.58	4.74	0.015	1.17	4.8
	Diff	−13.3	+5.72	+1.73	+2.09	+0.75	+0.19	+8.70	+3.14	+0.009	+0.20	
25/12 1966-24/1 1967	In	65.5	1.79	0.08	0.42	0.25	0	4.00	1.11	-	1.14	4.9
	T	55.1	2.71	1.25	1.40	0.58	0.14	4.51	3.26	-	1.10	4.7
	Diff	−10.4	+0.92	+1.17	+0.98	+0.33	+0.14	+0.51	+2.15	-	−0.04	
25/1-21/2 1967	In	32.0	0.54	0.04	0.31	0.10	0	1.27	0.10	0.001	1.16	4.4
	T	25.1	nd	2.19	1.81	0.65	0.16	8.59	3.77	0.003	2.67	6.2
	Diff	−6.9	nd	+2.15	+1.50	+0.55	+0.16	+7.32	+3.67	+0.002	+1.51	
22/2-6/3 1967	In	5.0	0.02	0	0.05	0.01	0	0.16	0.03	0	0.01	4.7
	T	4.9	0.38	0.16	0.27	0.11	0.03	0.69	0.82	0	0.04	4.7
	Diff	−0.1	+0.36	+0.16	0.22	+0.10	+0.03	+0.53	+0.79	0	+0.03	
7-24/3 1967	In	31.5	0.23	0.04	0.35	1.63	0	2.42	0.99	0.001	0.04	4.6
	T	29.1	0.43	0.62	1.11	5.16	0.13	4.33	2.65	0.002	0.15	4.7
	Diff	−2.4	+0.20	+0.58	+0.76	+3.53	+0.13	+1.91	+1.66	+0.001	+0.11	
25/3-6/5 1967	In	37.0	0.90	0.06	0.30	1.57	0	2.51	0.93	0.001	1.64	5.0
	T	27.1	1.06	0.54	1.17	2.49	0.10	2.16	2.19	0.011	3.06	5.9
	Diff	−9.9	+0.26	+0.48	+0.87	+0.92	+0.10	−0.35	+1.26	+0.010	+1.42	
7-19/5 1967	In	42.0	0.14	0.13	0.26	0.05	0.01	0.50	0.56	0.001	0.49	5.5
	T	32.5	0.73	0.56	0.70	0.23	0.12	2.01	1.56	0.004	0.98	5.4
	Diff	−9.5	+0.59	+0.43	+0.44	+0.18	+0.11	+1.51	+1.00	+0.003	+0.49	
20/5-19/6 1967	In	37.5	0.13	0.14	0.30	0.09	0.04	1.17	0.88	0.012	0.69	5,1
	T	27.6	0.78	12.35	1.08	0.90	0.30	2.47	2.07	1.158	3.65	6,1
	Diff	−9.9	+0.65	+12.21	+0.78	+0.81	+0.26	+1.30	+1.19	+1.146	+2.96	
20-30/6 1967	In	48.5	0.14	0.05	0.36	0.05	0.02	0.48	0.53	0.003	0.07	5.5
	T	34.3	0.86	2.35	0.79	0.35	0.12	2.06	1.60	0.051	0.93	5.8
	Diff	−14.2	+0.72	+2.30	+0.43	+0.30	+0.10	+1.58	+1.07	+0.048	+0.86	
1-16/7 1967	In	74.5	0.15	0.07	0.68	0.07	0.16	1.09	1.09	0.002	0.64	5.0
	T	49.8	0.94	2.32	0.84	0.34	0.16	2.78	2.13	0.031	2.95	5.0
	Diff	−24.7	+0.79	+2.25	+0.16	+0.27	0	+1.69	+1.04	+0.029	+2.31	
17/7-18/8 1967	In	42.0	0.22	0.17	0.34	0.07	0.01	2.01	0.29	0.002	0.24	5.6
	T	34.3	0.67	2.58	0.76	0.29	0.11	2.73	1.09	0.078	1.88	6.1
	Diff	−7.7	+0.45	+2.41	+0.42	+0.22	+0.10	+0.72	+0.80	+0.076	+1.64	
19/8-29/9 1967	In	38.0	0.25	0.10	0.30	0.08	0.04	1.58	0.67	0.003	0.60	5.8
	T	20.6	0.49	2.91	0.68	0.26	0.13	3.51	1.57	0.119	1.74	6.8
	Diff	−17.4	+0.23	+2.81	+0.38	+0.18	+0.09	+1.93	+0.90	+0.116	+1.14	
30/9-13/10 1967	In1	61.5	0.42	0.14	0.49	0.13	0.03	0.71	1.18	0.004	0.95	nd
	T	43.8	1.08	5.02	1.40	1.04	0.24	2.39	4.12	0.066	1.28	5.9
	Diff	−18.7	+0.66	+4.88	+0.91	+0.91	+0.21	+1.68	+2.94	+0.062	+0.33	
14/10-1/11 1967	In	20.5	0.43	0.05	0.16	0.05	0.01	0.03	0.53	0.001	0.47	5.1
	T	10.4	0.35	1.11	0.71	0.41	0.19	2.47	1.55	0.002	0.32	6.2
	Diff	−10.1	−0.08	+1.06	0.55	+0.36	+0.18	+2.44	+1.02	+0.001	−0.15	
2-21/11 1967	In	26.5	0.11	0.03	0.18	0.32	0.02	0.21	0.50	0.002	0.33	5.1
	T	14.9	0.27	1.50	0.64	0.27	0.13	1.37	1.28	0.003	0.42	5.7
	Diff	−11.6	+0.16	+1.47	+0.46	−0.05	+0.11	+1.16	+0.78	+0.001	+0.09	
TOTAL	In	643.5	7.71	1.29	5.33	4.76	0.36	23.02	10.99	0.039	9.44	–
	T	476.7	18.70	37.38	16.28	13.83	2.27	54.65	34.43	1.543	22.34	–
	Diff	−166.8	+10.99	+36.09	+10.95	+9.07	+1.91	+31.63	+23.44	+1.504	+12.90	

1) Estimated; nd = not determined.

6. Discussion

Element cycling is currently a central theme in ecosystem ecology (Ågren & Andersson 2012, Andersson 1970a). The main results of the present study are summarised in **Table 8**. The yearly biomass increase indicates that at the time of measurement, the Linnebjer forest ecosystem is still in an aggradation or accumulation phase (Bormann & Likens 1979). Tree biomass increased yearly by 6.6 $t \cdot ha^{-1}$ or 3.1 $t \cdot ha^{-1}$ carbon. The other elements accumulated in the order: N > Ca > Mg > K > Mn > Si > P, in amounts ranging from 29 to 1.8 $kg \cdot ha^{-1}$ yearly. The litterfall returned elements to the soil. 14% - 53% was decomposed and returned to the ecosystem over the year. It can thus be assumed that the exchangeable pool of elements was slightly increasing. The atmospheric deposition of sulfur observed was sufficient to cause acidification of the forest soil. The nitrogen input should have had a fertilising effect, leading to increased forest growth.

The results reported deal with plant biomass, primary production and mineral cycling. Earlier the two first properties have been reported, but the mineral cycling not. As the results still are valid and can serve as reference material, it is considered essential to have them published. The cycling of carbon, nitrogen and sulfur are elements, which are affected by a changing climate and deposition. Repeated investigations make it possible to address questions like the forest as a source or sink for carbon.

The result of plant biomass and production are less affected by time as the methods are considered as more or less the same today. Chemical methods and techniques have changed more. The results related to chemistry and reported are, however, considered as "robust" and will allow being used for comparisons. Even if "modern" chemical methods are used, the final results are depending on the quality of the data from the estimation of plant biomass and production.

In a follow up paper, results from an investigation of sampling in vegetation and soil after fifty years will be reported.

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Table 7. Distribution of elements in soil organic matter (SOM) and amount in an extraction with ammonium acetate (Am-Ac.Exch) in the soil profile of a mixed forest of *Quercus robur* and *Corylus avellana* in Linnebjer, Sweden.

Fraction	Organic matter	C	N	C/N	Na	K	Ca	Mg	Mn	P
	$t \cdot ha^{-1}$			ratio	$kg \cdot ha^{-1}$					
Soil organic matter 0 - 60 cm	288	108	12.0	9	-	-	-	-	-	-
Am-Ac. Exch 0 - 40 cm	-	-	-	-	221	226	532	242	55	256

Table 8. Distribution of organic matter and chemical elements in some important above-ground functional fractions and turnover characteristics of a mixed forest of *Quercus robur* and *Corylus avellana* in Linnebjer, Sweden.

Symbol	Fraction	Biomass	C	N	C/N	Na	K	Ca	Mg	Fe	Mn	P	Si
		$t \cdot ha^{-1}$			ratio	$kg \cdot ha^{-1}$							
PP	Yearly primary production	12.8	6.33	0.165	38	1.17	49.4	66.8	24.1	1.51	13.6	9.6	27.3
ΔB	Yearly biomass increase	6.6	3.06	0.029	106	0.26	8.9	20.3	14.0	0.42	8.3	1.8	2.8
L	Yearly litterfall	4.8	2.32	0.070	33	0.86	7.2	41.4	7.4	1.72	4.4	3.8	21.3
CL	Canopy leached fraction	-	-	0.013	-	10.99	36.1	11.0	9.1	-	1.4	1.5	-
R	Input by rain	-	-	0.009	-	7.71	1.3	5.3	4.8	-	0.4	<0.1	-
SL	Surface litter	6.1	2.83	0.110	26	0.75	6.6	58.9	8.7	3.43	7.3	4.5	128
SOM	Soil organic matter	288	108	12	9	-	-	-	-	-	-	-	-
Exch	Exch. in soil	-	-	-	-	221	226	532	242	-	55	421	-
	PP-ΔB	6.2	3.27	0.136	-	0.91	40.4	46.5	10.8	1.09	5.3	7.5	24.6
	L + CL	-	-	0.11	-	11.74	43.3	54.4	16.4	-	6.3	5.3	-
	L/L + SL	0.44	0.45	0.39	-	0.53	0.52	0.41	0.46	0.33	0.38	0.46	0.14

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