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IMPACT OF STARCH SEWAGE FERTILIZATION ON PHYTOCENOSES OF A FRESH PINE FOREST AND A CLEARING
II. MATTER AND NUTRIENT ECONOMY UNDER CONDITIONS OF SEWAGE FERTILIZATION[1]

ABSTRACT: Forest phytocenoses (a fresh pine forest and a clearing) were fertilized with starch sewage containing organic and inorganic compounds. Fertilization influenced physico-chemical properties of the soil as well as structure and magnitude of plant production. Three groups of species differing with respect to their tolerance to enhanced quantities of available nutrients were found to occur: (1) oligotrophic species, e.g. *Dicranum undulatum* and *Vaccinium vitis-idaea*, (2) mezotrophic species, e.g. *Vaccinium myrtillus* and *Trientalis europaea* and (3) eutrophic species, e.g. *Urtica dioica*, *Rubus idaeus* and *Stellaria media*. Contents of eight analyzed biogenic elements (Ca, Mg, K, Na, P, S, Cl, N) in biomass of the investigated plant species were different. The total content of elements in biomass of ground vegetation at the control forest amounted to 40 kg ha^{-1}, whereas in the fertilized area – to 116 kg ha^{-1} (ca. 3-fold increase). In the clear-cut control area, element content in biomass of ground flora was estimated to be 27 kg ha^{-1}, while in the fertilized clearing – 60 kg ha^{-1} (ca. 2-fold increase).

KEY WORDS: starch sewage fertilization, fresh pine forest, clearing, forest soil, ground flora production, element contents, ecological tolerance, nutrient accumulation by plants.

1. INTRODUCTION

Forests being the topmost systems within a hierarchy of terrestrial plant formations, are characterized by relatively the most stable state of ecological equilibrium. More and more frequently, forest ecosystems are threatened as they have been influenced by abiotic factors attributed lately to man's activity (antropopression). In this context, ecologists have often undertaken studies to meet requirements of reconstruction of destroyed ecological systems (Bradshaw and

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Chadwick 1980, Bradshaw 1983, Jordan et al. 1990, Di Casteri 1996, Van Driesche and Bellows 1996).

Mineral or organic fertilization may serve as an example of antropopression on forest sites. These problems have been discussed in numerous papers (e.g. Cybulko 1965, Sopper and Sagmuller 1966, Poncet 1970, Baule and Fricker 1973, Keller 1971, Hüser 1972, Sopper and Kardos 1972 a, b, 1973, Sommer and Fassbender 1975, Olszowski 1976 a, b, c, Wells 1991, Kaunisto 1992, Sundström 1992, Moilanen 1993, Vasander et al. 1993).

The results presented in this article concern the impact of organic fertilization (with starch sewage) on matter and nutrient economy in two soil-plant systems: a fresh pine forest and a clearing. The objectives of this work were: (1) to reveal changes in forest soils subjected to sewage fertilization, (2) to estimate ground flora production in the examined forest phytocenoses, (3) to find concentrations of biogenic elements in plant biomass, (4) to assess nutrient accumulation in particular populations of herbaceous plants growing under conditions of starch sewage fertilization.

Characteristics of the study area and principles of the fertilization experiment performed within so called soil-plant (forest) starch sewage treatment works have been presented elsewhere (Dyguś 1997).

2. MATERIALS AND METHODS

2.1. SOIL STUDIES

Soil samples were taken after four-year period of fertilization. A total of 63 soil samples were collected from the humus horizon of mineral soil (A_1), i.e. from the layer 5–25 cm subjacent to rhizosphere of native or secondary species of herb layer dominating in a phytocenosis.

The samples were oven-dried at 30–40° C, and then analyzed for soil pH in H_2O – electrometrically, hydrolytic (titratable) acidity (H_h) – by Kappen's method, contents of base cations (S): Ca^{2+}, K^+ and Na^+ – by flame photometrical method, Mg^{2+} - by atomic absorption method (exchange cations were extracted with 1 m solution of NH_4Cl at pH = 6.8), cation exchange capacity (T) was figured out from the formula S + H_h, base saturation (V_s) – from the percentage proportion of S to T, content of total carbon C_{tot} in % – by Turin's method, N_{tot} content – by Kiejdahl's method, and C : N ratio – by simple calculation.

2.2. ESTIMATION OF GROUND FLORA PRODUCTION

Simultaneously to examination of the soil, studies on ground flora production were performed.

Production was estimated according to Traczyk's method (1967a, b) having been based upon increments of individual plants and densities of particular species. Average individual increment of abovegrond parts of ground vegetation was obtained from the quotient of the total biomass and densities of particular populations. To assess the densities, aboveground shoots (individuals) were scored. To attain this, 100 random tossings of 0.1 m^2 ring or 40 measurements by means of wooden fork of an area of 0.25 m^2 were performed. Thus, shoot numbers (densities) of particular plant populations were obtained over 10 m^2 of ground. Multiplying the density by the average individual increment, net primary production of aboveground parts of the entire population of a given species was figured out. The sum of aboveground production of shoots of all populations constitutes the total aboveground production of vascular plants.

Belowground biomass of ground vegetation was evaluated on the basis of root density of a given species in a cuboid of 500 cm^2 (25 x 20 cm) basal area and a height of 30 cm. In order to attain this, 10 samples were taken at random.

To assess primary production of dwarf shrubs (*Vaccinium myrtillus*, *V. vitis-idaea*, *Rubus idaeus*), current year's shoots and rhizomes were separated from perennial ones (Moszyńska 1973, 1983).

Bryophyte biomass was estimated from 10 randomly chosen plots, each of 0.1 m^2. Bryophyte production was assumed to account for 1/3 part of their total biomass (Traczyk and Traczyk 1967, Mälkönen 1975).

The plant material collected was dried to a constant weight at 70–80° C, and weighed to an accuracy of 0.01 g.

2.3. CHEMICAL ANALYSES OF PLANT MATERIAL

The plants (17 species) collected in the full of the growing season (July) were dried at 65-70°C to a constant weight. Having separated the aboveground parts from belowground ones, the material was homogenized. Samples of every species (in total 130 samples), each of 1 g of dry weight, were burnt at 530° C, and ash was dissolved in 20% hydrochloric acid. Then, after quantitative filtration, the extract was analyzed for Ca, K and Na by flame photometrical method, Mg – by atomic absorption method, N_{tot} – by Kiejdahl method, P - colorimetrically, Cl – argentometrically in separate samples digested with an addition of CaO, and S – nephelometrically. All the results are given in mg 100^{-1} g of dry weight.

2.4. DETERMINATION OF ELEMENT CONTENT IN BIOMASS OF GROUND VEGETATION

Element contents in primary production of ground vegetation were expressed by the product of production and concentration of an element for each of the species considered. A similar procedure concerning elemental contents in plant biomass was employed by e.g. Höhne (1962, 1963) and Traczyk (1985, 1995).

3. RESULTS

3.1. CHANGES IN PHYSICO-CHEMICAL SOIL PROPERTIES CAUSED BY SEWAGE FERTILIZATION

The experiment was performed in soil environment (fresh pine forest), mainly brown podzolic soils with mor or moder-mor type of humus. Forest floor horizon (ectohumus) (A_o) reached 8 cm of thickness. Humus horizon of the mineral soil (A_1) derived from weakly loamy or loose sand reached typically 17 cm of thickness. Underneath (to ca. 50–70 cm), there was a rusty-brown-coloured horizon (B_{v1}) derived from weakly loamy sand and containing no organic-mineral complexes. At times, there was a transition layer A_2 separating A_1, where some symptoms of podzolization occurred. Yellow-coloured horizon of parent rock (C) made up of loose sand occurred typically below 50–70 cm.

Changes in soil properties are expressed by changes in values of the analytical indices found for the rooting zone of herbaceous plants (5–25 cm) (Tables 1 and 2).

The soil at the forest control plot was highly acidic. Four-year sewage fertilization has increased pH under the native vegetation by 0.6 units, and under the secondary community – by 0.8 units.

The treatments applied to the forest phytocenosis have raised base saturation so that cation exchange capacity was also increased. Owing to the soil enrichment in organic matter, trophic status of the site has been improved (Table 1).

After 4 years of fertilization, soil pH in the clearing was higher by 0.7 units when compare with the control. Contents of base cations were, however, reduced which resulted in lower cation exchange capacity of the soil (Table 2).

Table 1. Properties of the soil in the rooting zone (5–25 cm) of ground flora in the forest phytocenosis (the values are means for all the investigated species)

Indices	Control	Fertilization	
	Forest species		Non-forest species
pH_{H_2O}	3.4	4.0	4.2
Ca^{++} (meq. 100 g^{-1} of soil)	1.50	3.29	3.84
Mg^{++} (meq. 100 g^{-1} of soil)	0.23	0.67	0.97
K^{+} (meq. 100 g^{-1} of soil)	0.14	1.13	1.45
Na^{+} (meq. 100 g^{-1} of soil)	0.07	0.24	0.36
S (meq. 100 g^{-1} of soil)	1.94	5.33	6.62
H_h (meq. 100 g^{-1} of soil)	18.93	19.79	21.17
T (meq. 100 g^{-1} of soil)	20.87	25.12	27.79
V (%)	9.30	21.20	23.80
C_{org} (%)	6.34	8.57	12.46
N_{tot} (%)	0.27	0.51	0.82
$C_{org} : N_{tot}$	23.48	16.80	15.20

Symbol description: S – base cations, H_h – hydrolytic (titratable) acidity, T – cation exchange capacity (S + H_h), V – base saturation ($V = \frac{S \cdot 100}{T}$).

3.2. EFFECT OF FERTILIZATION ON PHYTOMASS

The total production of ground flora (above- and belowground parts) at the control forest area amounted to 1426.5 kg ha^{-1}. The greatest contribution to the annual production was characteristic of mosses (60%), especially of two dominant species: *Pleurozium schreberi* and *Dicranum undulatum* that produced about

Table 2. Properties of the soil in the rooting zone (5–25 cm) of ground flora in the clearing phytocenosis (the values are means for all the investigated species)

Indices	Control	Fertilization
	Forest species	Clearing species
pH_{H_2O}	3.7	4.4
Ca^{++} (meq. 100 g^{-1} of soil)	1.35	1.08
Mg^{++} (meq. 100 g^{-1} of soil)	0.82	0.19
K^{+} (meq. 100 g^{-1} of soil)	0.24	0.46
Na^{+} (meq. 100 g^{-1} of soil)	0.08	0.10
S (meq. 100 g^{-1} of soil)	2.49	1.83
H_h (meq. 100 g^{-1} of soil)	21.23	6.26
T (meq. 100 g^{-1} of soil)	23.72	8.09
V (%)	10.50	22.60
C_{org} (%)	8.20	1.98
N_{tot} (%)	0.36	0.14
C_{org} : N_{tot}	22.78	14.14

See Table 1 for symbol description

854 kg ha^{-1}. Among vascular plants, the dominant was *Vaccinium myrtillus* producing 325 kg ha^{-1} (Table 3).

After 4 years of sewage fertilization, production of forest species was almost 10 times lower which mainly resulted from the complete extinction of bryophytes. Forest species were replaced by anthropogenic plants. The greatest contribution to the production of the latter plants was found for nitrophilous species, i.e. *Urtica dioica* (50%), *Rubus idaeus* (22.7%) and *Senecio sylvaticus* (8.5%). Forest species accounted for slightly more than 10%. The total production of ground vegetation at the fertilized plot amounted to 1299.5 kg ha^{-1} (Table 3). This value is very close to that estimated for control understory.

Ground flora of the clearing was dominated by mosses (60%). Moreover, the dwarf shrub *Vaccinium myrtillus* appeared to be an important contributor (25.2%) (Table 4).

Following four years of fertilization, species typical of fresh pine forest have not longer contributed to understory production. Nevertheless, production was almost 2 times higher owing to the development of species from the class Epilobietea angustifolii, namely *Calamagrostis epigeios* (43.7%), *Epilobium angustifolium* (34.1%), *Rubus idaeus* (12.7%) and others (9.5%) (Table 4).

3.3. AN EFFECT OF FERTILIZATION ON NUTRIENT ECONOMY

With the aim of evaluating the role of herbaceous plants in the process of nutrient absorption, elemental concentrations in the examined material were necessary to assess. Therefore, above- and belowground biomass of the dominant species was chemically analyzed. The material included characteristic and accompanying species from the class Vaccinio-Piceetea and species charac-

Table 3. Primary production of ground flora in forest phytocenosis (total above- and belowground parts)

Species	kg ha^{-1}	%	Species	kg ha−1	%
Control			Fertilization		
*Pleurozium schreberi**	542.5	38.0	*Urtica dioica*	650.2	50.0
Vaccinium myrtillus	324.9	22.8	*Rubus idaeus*	294.7	22.7
*Dicranum undulatum**	311.1	21.8	*Senecio sylvaticus*	110.3	8.5
Deschampsia flexuosa	54.3	3.8	*Deschampsia flexuosa*	102.8	7.9
Convallaria majalis	48.3	3.4	*Stellaria media*	80.5	6.2
Calamagrostis arundinacea	48.2	3.4	*Vaccinium myrtillus*	22.4	1.7
Melampyram pratense	41.9	2.9	*Calamagrostis arundinacea*	8.7	0.7
Luzula pilosa	18.1	1.3	*Trientalis europaea*	8.4	0.6
Vaccinium vitis-idaea	17.6	1.2	*Epilobium angustifolium*	8.4	0.6
Trientalis europaea	7.8	0.5	*Convallaria majalis*	1.6	0.1
*Hylocomium splendens**	6.8	0.5			
Remaining species	5.0	0.4	Remaining species	11.5	0.9
Total	1426.5	100.0	Total	1299.5	100.0

*mosses.

Table 4. Primary production of ground flora in clearing phytocenosis (total above- and belowground parts)

Species	kg ha^{-1}	%	Species	kg ha−1	%
Control			Fertilization		
*Pleurozium schreberi**	361.8	46.7	*Calamagrostis epigeios*	543.3	43.7
Vaccinium myrtillus	195.7	25.2	*Epilobium angustifolium*	424.4	34.1
*Dicranum undulatum**	102.2	13.2	*Rubus idaeus*	157.3	12.7
Epilobium angustifolium	45.8	5.9			
Deschampsia flexuosa	31.4	4.0			
Anthoxanthum odoratum	8.3	1.1			
Remaining species	29.9	3.9	Remaining species	118.7	9.5
Total	775.1	100.0	Total	1243.7	100.0

* mosses.

teristic of the secondary associations. The analyses comprised such biogenic elements as nitrogen, phosphorus, potassium, calcium, magnesium, sodium, chlorine and sulphur. The results are given in mg 100^{-1} g dry wt.

The results obtained have served mainly as a background for assessing ecological tolerance ranges of plant species to enhanced nutrient availability under conditions of intensive organic fertilization.

Typical oligotrophic species, i.e. *Vaccinium vitis-idaea*, *Melampyrum pratense*, *Luzula pilosa* and all the forest bryophytes appeared to be intolerant of excess nutrients. These species were extinct already after first or second year of the treatment (Table 5).

An extended tolerance was found for mezotrophic species, e.g. *Vaccinium*

Table 5. Mean nutrient contents in species of ground flora characterized by the lack of tolerance to fertilization (extinct following fertilization)

Element (mg 100^{-1} g dry wt)		*Vaccinium vitis-idaea*	*Melampyrum pratense*	*Luzula pilosa*	*Dicranum undulatum**	*Pleurozium schreberi**	*Hylocomium splendens**
Ca	a	365	740	270	255	230	300
	b	123	432	225	–	–	–
Mg	a	118	223	191	123	108	100
	b	34	195	91	–	–	–
K	a	528	1210	1920	710	720	460
	b	254	515	550	–	–	–
Na	a	14	42	20	19	16	25
	b	9	30	14	–	–	–
P	a	68	225	133	200	180	160
	b	36	170	77	–	–	–
S	a	98	128	36	136	119	212
	b	26	78	170	–	–	–
Cl	a	4	8	661	0	0	0
	b	0	0	40	–	–	–
N	a	720	860	530	1720	1480	1870
	b	500	490	300	–	–	–
Σ	a	1915	3436	3761	3163	2853	3127
	b	982	1910	1467	–	–	–
Σa + b		2897	5346	5228	3163	2853	3127

a – aboveground parts, b – belowground parts, *mosses.

myrtillus (Table 6). The quantities of elements accumulated in the aboveground parts of that dwarf shrub were two times lower in case of calcium and magnesium, and two or several times higher for phosphorus and chlorine, respectively, when compare with the values obtained at the non-fertilized area. Other mezotrophic species, such as *Convallaria majalis*, *Trientalis europaea*, *Deschampsia flexuosa* and *Calamagrostis arundinacea* appeared to be tolerant of elevated soil nutrient concentrations. Element contents in these herbaceous species increased at least two times following fertilization (Table 6).

After four years of fertilization with sewage, forest species were no longer important in the process of nutrient absorption. Such functions were taken over by eutrophic species forming the secondary nitrophilous associations in place of the forest species being extinct (Dyguś 1997). The secondary nitrophilous community appeared to be more efficient in nutrient accumulation from the fertilized site. Concentrations of essential nutrients in tissues of the plants fertilized with sewage were 3-6 times higher than those found for forest species growing under identical conditions. The species (extremely nitrophilous and potassium-demanding) included *Senecio sylvaticus*, *Urtica dioica*, *Epilobium angustifolium*, *Rubus idaeus* and *Stellaria media* (Table 7).

Table 6. Mean nutrient contents in species of ground flora characterized by an extended tolerance to fertilization (present in course of fertilization)

Element (mg 100^{-1} g dry wt)		*Vaccinium mytrilis*		*Convallaria majalis*		*Trientalis europaea*		*Deschampsia flexuosa*		*Calamagrostis arundinacea*	
		C	F	C	F	C	F	C	F	C	F
Ca	a	456	225	395	605	415	390	173	223	150	237
	b	123	110	190	228	75	135	105	265	128	228
Mg	a	89	43	258	155	373	268	28	105	82	91
	b	21	80	43	98	45	84	9	55	21	53
K	a	498	610	2045	4095	1760	3740	1160	2995	1698	2992
	b	277	275	468	1055	838	1800	430	685	230	630
Na	a	20	34	25	37	24	69	21	43	15	42
	b	7	32	20	22	28	76	16	22	14	49
P	a	86	155	144	415	140	400	83	392	147	427
	b	51	115	90	485	82	315	65	335	57	295
S	a	51	48	79	80	97	214	57	100	24	142
	b	26	48	55	113	53	118	55	93	51	130
Cl	a	9	60	296	740	382	590	204	960	453	620
	b	45	59	0	30	125	120	70	60	36	30
N	a	1120	1240	1320	2910	1480	3560	1350	3150	1560	2050
	b	1070	1370	1550	3520	720	950	1080	2490	1690	2020
Σ	a	2329	2415	4562	9037	4671	9231	2076	7968	4129	6531
	b	1620	2080	2416	5551	1966	3598	1830	4005	2227	3435
Σa + b		3949	4495	6978	14588	6637	12829	3906	11973	6356	9966

C – Control, F – Fertilization; a – aboveground parts, b – belowground parts.

3.4. NUTRIENT ACCUMULATION IN BIOMASS OF GROUND FLORA AFFECTED BY SEWAGE FERTILIZATION

Assessment of element contents in plant biomass was based upon production of native (natural) and secondary (anthropogenic) phytocenoses as well as elemental concentrations in populations constituting particular communities (see Sections 3.2 and 3.3). The quantities of accumulated elements are given in kilograms per hectare (kg ha^{-1}).

The examined understory of the non-fertilized forest phytocenosis accumulates 40.5 kg ha^{-1} of all the elements analysed. Out of that amount, 14.9 kg ha^{-1} fall to vascular plants, and 25.5 kg ha^{-1} – to bryophytes. The secondary forest community – developed as a result of fertilization – accumulated 3 times more nutrients (Table 8).

Contents of the eight analysed nutrients in annual primary production differed among the populations and communities considered (Table 8).

Nitrogen. Forest understory (control) was found to contain 20.6 kg of that element in newly produced biomass per ha. The respective values for bryophytes and vascular plants (mainly *Vaccinium myrtillus*) amounted to 13.5 and 7.1 kg ha^{-1}.

Table 7. Mean nutrient content in species of the secondary ground flora (massive appearance in course of fertilization)

Element (mg 100^{-1} g dry wt)		*Senecio sylvaticus*	*Epilobium angustifolium*	*Rubus idaeus*	*Calamagrostis epigeios*	*Stellaria media**	*Urtica dioica*
Ca	a	735	660	430	185	510	930
	b	710	343	290	172	–	455
Mg	a	210	320	140	88	525	260
	b	155	980	75	51	–	168
K	a	7940	4400	1870	3245	8280	5608
	b	10560	2317	705	830	–	2870
Na	a	169	77	55	39	159	55
	b	267	102	36	53	–	72
P	a	865	610	265	395	840	615
	b	710	296	275	285	–	630
S	a	218	135	70	98	203	168
	b	230	95	49	158	–	123
Cl	a	830	280	30	66	470	190
	b	620	310	10	20	–	60
N	a	3740	3620	2210	2070	3400	3300
	b	2210	1920	1400	2140	–	2450
Σ	a	14707	10122	5070	6186	14387	11126
	b	15462	6363	2840	3709	–	6828
Σa + b		30169	16485	7910	9895	14387	17954

a – aboveground parts, b – belowground parts, *no data for belowground parts.

Fertilized plants (secondary community) accumulated 36.7 kg of nitrogen per ha, i.e. almost 2 times more than moss-dwarf shrub layer of the forest control plot. Major part of nitrogen was retained in tissues of *Urtica dioica* (19.9 kg ha^{-1}), *Rubus idaeus* (6.7 kg ha^{-1}), *Senecio sylvaticus* (3.5 kg ha^{-1}) and *Stellaria media* (3.0 kg ha^{-1}).

Phosphorus. Forest vegetation at the control plot assimilated 2.1 kg of that nutrient per ha, with bryophytes being the most efficient – 1.6 kg ha^{-1}. The secondary community fixed 3 times larger amounts of that element with *Urtica dioica* accumulating the highest quantity (3.9 kg ha^{-1}).

Calcium. The forest understory (control) was found to contain 4.0 kg ha^{-1} of calcium. This element was mainly absorbed by bryophytes (2.1 kg ha^{-1}), as well as *Vaccinium myrtillus* (1.1 kg ha^{-1}) and *Melampyrum pratense* (0.3 kg ha^{-1}) from among the herbaceous plants. The secondary community of the fertilized site accumulated 2.5 times more calcium than the forest community at the control plot, with *Urtica dioica* (6.7 kg ha^{-1}), *Senecio sylvaticus* (1.6 kg ha^{-1}) and *Rubus idaeus* (1.2 kg ha^{-1}) being the most important sinks.

Magnesium. Pool of magnesium gained annually by ground vegetation at the control plots amounted to 1.5 kg ha^{-1}.

Table 8. Nutrient contents in annual production of ground flora species in the forest phytocenosis (total above- and belowground parts)

Species	Ca	Mg	K	Na	P	S	Cl	N	Σ	%
	kg ha^{-1}									
Control										
*Pleurozium schreberi**	1.24	0.59	3.91	0.09	0.98	0.65	0.00	8.03	15.49	38.3
*Dicranum undulatum**	0.79	0.38	2.21	0.06	0.62	0.40	0.00	5.35	9.81	24.3
Vaccinium myrtillus	1.14	0.27	1.25	0.14	0.23	0.27	0.05	4.00	7.35	18.2
Convallaria majalis	0.16	0.07	0.86	0.01	0.08	0.04	0.16	0.56	1.94	4.8
Melampyrum pratense	0.30	0.10	0.49	0.02	0.09	0.05	0.00	0.41	1.46	3.6
Deschampsia flexuosa	0.07	0.01	0.42	0.02	0.04	0.03	0.07	0.73	1.39	3.4
Calamagrostis arundinacea	0.11	0.01	0.27	0.01	0.04	0.03	0.01	0.59	1.07	2.6
Luzula pilosa	0.05	0.03	0.24	0.00	0.02	0.01	0.07	0.07	0.49	1.2
Vaccinium vitis-idaea	0.06	0.02	0.07	0.00	0.01	0.02	0.01	0.12	0.31	0.8
Trientalis europaea	0.02	0.02	0.12	0.00	0.01	0.01	0.02	0.10	0.30	0.7
*Hylocomium splendens**	0.02	0.01	0.03	0.00	0.01	0.01	0.00	0.13	0.21	0.5
Remaining species	0.01	0.00	0.06	0.00	0.01	0.00	0.05	0.50	0.63	1.6
Total	3.97	1.51	9.93	0.35	2.14	1.52	0.44	20.59	**40.45**	100.0
Fertilization										
Urtica dioica	6.74	2.01	28.84	0.39	3.92	1.11	1.89	19.92	64.82	55.8
Rubus idaeus	1.20	0.56	6.40	0.12	0.81	0.19	0.28	6.65	16.21	14.0
Senecio sylvaticus	1.57	0.17	7.46	0.16	0.59	0.22	0.98	3.53	14.68	12.6
Stellaria media	0.56	0.31	6.26	0.08	0.60	0.14	0.37	2.99	11.31	9.7
Deschampsia flexuosa	0.14	0.07	2.10	0.03	0.24	0.08	0.87	2.29	5.82	5.0
Epilobium angustifolium	0.05	0.02	0.31	0.00	0.04	0.01	0.03	0.26	0.72	0.6
Trientalis europaea	0.02	0.02	0.24	0.00	0.03	0.03	0.04	0.23	0.61	0.5
Calamagrostis arundinacea	0.02	0.01	0.24	0.00	0.03	0.02	0.05	0.18	0.55	0.5
Vaccium myrtillus	0.04	0.01	0.11	0.00	0.04	0.01	0.00	0.27	0.48	0.4
Convallaria majalis	0.01	0.00	0.06	0.00	0.01	0.00	0.01	0.05	0.14	0.1
Remaining species	0.03	0.01	0.30	0.00	0.04	0.02	0.07	0.29	0.76	0.7
Total	10.38	3.19	52.32	0.78	6.35	1.83	4.59	36.66	**116.10**	100.0

*mosses.

Just as in case of calcium, majority of that nutrient was retained in bryophytes (1.0 kg ha^{-1}), as well as in *Vaccinium myrtillus* (0.3 kg ha^{-1}) and *Melampyrum pratense* (0.1 kg ha^{-1}). The secondary community acquired two times greater amounts (2.7 kg ha^{-1}) than the native one. The greatest quantities were found to be accumulated by *Urtica dioica* (2.0 kg ha^{-1}) and *Rubus idaeus* (0.6 kg ha^{-1}).

Potassium was the most common nutrient in biomass of ground vegetation. Considerable amounts of this element were also found to be accumulated by non-fertilized plants (9.9 kg ha^{-1}), mainly by mosses *Pleurozium schreberi* (3.9 kg ha^{-1}) and *Dicranum undulatum* (2.2 kg ha^{-1}) as well as by populations of *Vaccinium myrtillus* (1.3 kg ha^{-1}) and *Convallaria majalis* (0.9 kg ha^{-1}). In case of the fertilized community, the 5-fold increase in accumulation of that essential nutrient took place. It was mainly retained in populations of *Urtica dioica* (28.8 kg ha^{-1}) and *Stellaria media* (6.3 kg ha^{-1}), and species characteristic of the class Epilobietea angustifolii, especially *Senecio sylvaticus* (7.5 kg ha^{-1}) and *Rubus idaeus* (6.4 kg ha^{-1}).

Sodium. Among the examined nutrients, sodium appeared to be the least abundant. The non-fertilized phytocenosis contained merely 0.4 kg of Na ha^{-1}. There was, however, the 2-fold increase in Na content in biomass of the fertilized (secondary) community.

Chlorine. Newly produced biomass of forest understory retained merely 0.4 kg of this element per ha. The greatest amounts were found in *Convallaria majalis* tissues (0.2 kg ha^{-1}). Bryophytes contained trace quantities of that element. Secondary community, in turn, accumulated up to 4.6 kg of Cl ha^{-1}, i.e. 10 times more than the amount found for the control plot (!).

Sulphur. Sulphur was a relatively more abundant element than sodium or chlorine (1.5 kg ha^{-1}). It is mostly retained in bryophyte phytomass (1.1 kg ha^{-1}). Secondary (fertilized) communities retained approximately the same amounts of sulphur (1.8 kg ha^{-1}).

At the control clearing, the total contents of biogenic elements in understory biomass was 27.0 kg ha^{-1} (Table 9). Plant species typical of forests accumulated 20.0 kg of elements per ha, with *Vaccinium myrtillus* (5.9 kg ha^{-1}) and *Pleurozium schreberi* (10.1 kg ha^{-1}) being the main contributors. The most abundant elements assimilated by the community of the control clearing included nitrogen (11.5 kg ha^{-1}), potassium (8.7 kg ha^{-1}),

Table 9. Nutrient contents in annual production of ground flora species in the clearing phytocenosis (total above- and belowground parts)

Species	Ca	Mg	K	Na	P	S	Cl	N	Σ	%
	kg ha^{-1}									
Control										
*Pleurozium schreberi**	0.93	0.30	2.90	0.07	0.50	0.36	0.08	4.98	10.12	37.5
Vaccinium myrtillus	0.71	0.40	1.42	0.05	0.21	0.14	0.39	2.60	5.92	22.0
*Dicranum undulatum**	0.23	0.11	0.64	0.03	0.15	0.10	0.13	1.62	3.01	11.2
Epilobium angustifolium	0.31	0.12	1.18	0.02	0.15	0.07	0.14	1.04	3.03	11.2
Deschampsia flexuosa	0.04	0.02	0.24	0.00	0.04	0.02	0.05	0.43	0.84	3.1
Anthoxanthum odoratum	0.05	0.01	0.13	0.00	0.05	0.04	0.05	0.11	0.44	1.6
Remaining species	0.23	0.03	2.23	0.05	0.13	0.03	0.18	0.73	3.61	13.4
Total	2.50	0.99	8.74	0.22	1.23	0.76	1.02	11.51	**26.97**	100.0
Fertilization										
Calamagrostis epigeios	0.73	0.38	9.01	0.07	1.23	0.52	1.94	8.27	22.15	36.8
Epilobium angustifolium	3.09	0.90	5.66	0.23	1.48	0.27	0.65	7.93	20.21	33.6
Rubus idaeus	1.44	0.31	3.05	0.08	0.48	0.09	0.17	4.03	9.65	16.0
Remaining species	0.37	0.29	3.10	0.06	0.52	0.20	0.30	3.32	8.16	13.6
Total	5.63	1.88	20.82	0.44	3.71	1.08	3.06	23.55	**60.17**	100.0

*mosses.

calcium (2.5 kg ha^{-1}) and phosphorus (1.2 kg ha^{-1}). Among non-forest species growing there, *Epilobium angustifolium* had the highest total nutrient content (3.0 kg ha^{-1}).

Nutrient accumulation by plants growing at the fertilized clearing amounted to 60. 2 kg ha^{-1} (Table 9). The highest contents were found for *Calamagrostis epigeios* (22. 2 kg ha^{-1}), *Epilobium angustifolium* (20.2 kg ha^{-1}) and *Rubus idaeus* (9.7 kg ha^{-1}). Abundant elements included nitrogen 23.6 kg ha^{-1}) and potassium (20.8 kg ha^{-1}), whereas calcium (3.7 kg ha^{-1}), phosphorus (3.7 kg ha^{-1}) and chlorine (3.1 kg ha^{-1}) were less abundant. The least abundant elements were magnesium (1.9 kg ha^{-1}), sulphur (1.1 kg ha^{-1}) and sodium (0.4 kg ha^{-1}). The total nutrient content in plant biomass of the fertilized clear-cut area was 2 times higher than that found for the control (untreated) plot.

4. DISCUSSION

Fertilization of the forest ecosystem, i.e. supplying it with an additional pool of biogenic elements, has disturbed that relatively stable and integrated system. The disturbance comprised both structural and functional inseparable constituents of the ecosystem. Succession toward nutritionally-demanding communities (Dyguś 1997), increasing productivity of ground vegetation, and changes in matter economy were found to occur. These are the phenomena, which have frequently been interpreted by ecologists as being typical of anthropogenic ecosystems (Stugren 1976, Trojan 1978, 1984, Bradshaw and Chadwick 1980, Odum 1982, Jordan et al. 1990).

Initially, the effects of fertilizers applied to the phytocenoses of the forest and clearing pointed out homeostasis of those systems to be destroyed. This was, however, followed by a rapid ecological compensation effect (Trojan 1984). Functions of the broken links were taken over by other phytocenotic structures. Mosses were replaced by short-growing synanthropic species (e.g. *Stellaria media*), while the forest dwarf shrub-grass community – by tall-growing synanthropic species (e.g. *Urtica dioica*). However, that newly developed understory is characterized by an apparent stability; self-controlling (self-regulating) mechanisms are being progressively weaker.

According to Obmiński (1977), not only stand structure but also ground vegetation plays a significant role in forest-forming processes. Attention has been paid to the significance of forest understory by numerous authors (Ovington 1956, 1962, Reiners and Reiners 1970, Izdebski et al. 1977, Czerwiński and Traczyk 1985 e). Minor vegetation plays a substantially greater role as a nutrient "consumer" than biomass producer. It appears that despite a relatively low contribution of ground flora to the total production of a forest phytocenosis (ca. 25%), it accounts for almost 40% of nutrients retained in phytomass of the entire forest ecosystem (Holmen 1964, Mälkönen 1975).

Under conditions of soil fertilization, cation exchange capacity and base saturation are of outstanding importance. According to Puchalski and Prusinkiewicz (1975), these are the factors responsible for buffering capacity of the soil. The highest buffering capacity is characteristic of soils rich in colloids (heavy soils), while the lowest one – of soils poor in colloids (sandy soils).

The results of soil chemical analyses (Section 3.1) and soil studies performed by Czępińska-Kamińska and Janowska (1992) indicate an increase in fertility of the soils treated with organic sewage. This is manifested mainly by the increase in base saturation. However, particle-size distribution of the illuvial horizon and parent rock should also be taken into account. In forests, these are usually derived from weakly loamy or loose sands so that the soil is subject to nutrient leaching and has limited cation exchange capacity.

All sorts of fertilization and irrigation basically tend towards intensifying plant productivity. The use of fertilizers in forestry practice has mainly been considered in connection with stand crop production (Baule 1973, Baule and Fricker 1973), whereas significance of understory production has been ignored. In this work – dealing with ground flora production – considerable importance of mosses as biomass producers has been revealed. Mosses constituted as much as 60% of ground flora production in either phytocenosis examined. Fertilization caused mosses to disappear. Although herb layer production was equalized (forest) or even doubled (clearing) following fertilization, species composition and structure of the secondary community was completely altered (Dyguś 1997).

Primary production of herbaceous plants in oligotrophic forest sites subjected to fertilization may even be comparable to production of fertile riparian sites (Aulak 1970, Traczyk 1971), willow shrubberies or alder-carrs (Traczyk 1971, Polakowski and Endler 1985).

Nutrient contents in biomass of particular plant species growing in the same patch of a community (under the same site conditions) were different. Chemical composition of those plants depends on specific genetic features and, to a lesser extent, on site fertility (Czerwiński and Pracz 1995 a, b, c, d). The above observation may concern species characteristic of a given plant community, i.e. those showing wide ecological tolerance to changes in site conditions. Certain plant species occur under various site conditions, and their chemical composition depends to a high degree upon the site fertility. This usually comprises species showing considerable ecological tolerance to site conditions, which has been revealed for several species fertilized with sewage rich in mineral as well as organic compounds (see Section 3.3).

Functional changes occurring in the fertilized phytocenoses were shown through evaluation of possibilities of nutrient accumulation in plant biomass. According to Traczyk (1995) the possibilities are testified by the following regularities. Eutrophic, rich communities of deciduous forests, where numerous species of rapid phenological rhythm occur, are characterized by high rate of organic matter transformations, considerable production and large quantities of essential nutrients. On the contrary, phytocenoses of coniferous forests accumulate nutrients in biomass of perennial and long-living species (dwarf shrubs).

The problems relevant to nutrient accumulation by plants have been discussed by numerous authors. Pre-cursor German investigations (Höhne 1962, 1963) call for special attention. The studies comprised a comparison of element contents, magnitude of herb layer production and nutrient accumulation per hectare of ground area among different forest communities.

In Poland, alike studies were performed by Traczyk (1985, 1995), who applied a term "phytosorption" to express elemental contents in plant biomass.

Numerous other studies have comprised e.g. nutrient accumulation in certain feed crops and industrial plants (Czerwiński et al. 1985 a, b), mineral nutrient contents in grassland vegetation (Czerwiński et al. 1978 a, b, Czerwiński and Traczyk 1985 a, b, c), sorption capacity and matter economy within species or communities characteristic of forest (Izdebski and Popiołek 1975, Izdebski et al. 1976, Zimka and Stachurski 1976 a, b, Izdebski 1978, Marrs 1978, Moszyńska 1983, Czerwiński and Traczyk 1985 e, Zimka 1989, Traczyk (ed.) 1995) and mire ecosystems (Czerwiński and Traczyk 1985 d, Sieber-Rost and Jahn 1988, Wilpiszewska 1990).

Quantities of nutrients retained in plant biomass depend upon e.g. site fertility, physiological adaptations of species to nutrient uptake and, above all, upon plant productivity. These are the three fundamental parameters that could be regarded as being factors determining nutrient accumulation by plants. In natural communities, the factors are moderately dynamic. An opposite takes place in case of sites subjected to various anthropogenic factors such as industrial pollution, fertilization and others. Such factors modify productivity, concentrations and nutrient accumulation by plants' populations.

An example of the modifying effect of anthropopression on plants is given by changes in nutrient economy following fertilization of the forest phytocenoses investigated in this work. A response of certain understory species to starch sewage fertilization seems to be noteworthy. It has been shown that e.g. calcium and magnesium uptake by *Vaccinium myrtillus* is two times lower when compare the fertilized phytocenosis with the non-fertilized one. Reduced accumulation of calcium and magnesium by that dwarf shrub growing on nutritionally improved sites has also been recorded by Moszyńska (1983). Furthermore, extremal nitrophytes, e.g. *Urtica dioica*, *Epilobium angustifolium*, *Senecio sylvaticus*, *Stellaria media*, under conditions of starch sewage fertilization exhibit uncommonly great possibilities of nutrient accumulation, sometimes even incomparably higher than recorded on natural sites (Czerwiński and Traczyk 1985 a, b, c, d, e, Czerwiński and Pracz 1995 a, b, c, d, e, Dyguś and Traczyk 1995 a, b, Kotowska and Traczyk 1995, Pasternak-Kuśmierska and Traczyk 1995 a, b, Traczyk et al. 1995).

Several-years functioning of so called soil-plant sewage treatment works has led to plant "filter" formation consisting of nutrient-demanding species. These are species typical of nitrophilous communities, mainly from the class Artemisietea, Epilobietea angustifolii and Chenopodietea (Dyguś 1997). However, a question arises – how much, if any, sewage may be added to maintain an efficient operating of that natural filter? It results from the studies on biogenic element accumulation by plants affected by sewage fertilization that the doses should be at least 10 times lower; it concerns such elements as nitrogen, phosphorus, potassium, calcium and magnesium. In case of such elements as chlorine, sodium and sulphur, the contents in starch sewage were shown to be about 100 times (!) greater than plant's demands (Table 10).

Contents exceeding threshold values have become the major limiting factors and the main cause of eutrophication and, as a consequence – the cause of homeostasis destruction in the fertilized forest site.

Quantities of nutrients taken up by ground vegetation, though extremely nitrophilous, are so low as sewage treatment in forest sites seems to be questionable. This will not be any different when we take into account an index of nutrient accumulation by pine stand, which has considerably lower value than that of nitrophilous herb layer having been developed as a result of fertilization (Dyguś, in preparation). Furthermore, cation exchange capacity of the soil under coniferous forest sites is limited (cf. Section 3.1).

Table 10. The comparison between elements added with sewage and elements accumulated in biomass of ground vegetation

Element	Forest			Clearing		
	kg ha^{-1} $year^{-1}$		%	kg ha^{-1} $year^{-1}$		%
	a	b	c	a	b	c
N	499	36.7	7.4	499	23.6	4.7
P	81	6.3	7.8	81	3.7	4.6
K	882	52.3	5.9	882	20.8	2.4
Ca	255	10.4	4.1	255	5.6	2.2
Mg	96	3.2	3.3	96	1.9	2.0
Na	60	0.8	1.3	60	0.4	0.7
Cl	495	4.6	0.9	495	3.1	0.6
S	154	1.8	1.2	154	1.1	0.7
Σ	2522	116.1	4.6	2522	60.2	2.4

a – amount of element added with sewage; b – amount of element accumulated in biomass of ground flora; c – estimated per cent of element uptake by ground flora.

5. CONCLUSIONS

1. Sewage treatment of poor environment of forest (sandy) soils – with weakly developed sorption complex – does not guarantee purifying the sewage to such a degree as to avoid nutrient leaching from the fertilized system to e.g. ground water.

2. The increase in plant production following fertilization of the poor forest site is comparable to production of fertile sites, e.g. riparian, alder-carrs or willow shrubberies. However, the secondary community developed as a result of artificial enrichment of the site is characterized by an "ecological disharmony" within the "site – vegetation" system.

3. Quantities of nutrients taken up by the fertilized species depended upon their selectivity and tolerance to modifications of site conditions; species characterized by a narrow ecological tolerance were extinct; species of a wide tolerance range were still present or some new species appeared as a result of changes in site conditions.

4. Possibilities of accumulating nutrients by the secondary (nitrophilous)

ground flora, despite its high nutrient demands, are too limited as to accumulate the load of elements, especially that of potassium, nitrogen and chlorine added along with sewage.

5. Intensive fertilization, all sorts of industrial impacts as well as numerous of other antropopression forms strongly affect ecosystems, which results in adverse effects on matter economy and biogeochemical cycles; this has always led to undesirable alterations, disturbances or even destruction of ecological systems at various levels of their organisation.

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6. SUMMARY

This work presents results of studies concerning physico-chemical properties of the soil, matter economy and nutrient accumulation in two forest phytocenoses (a fresh pine forest and a clearing) under conditions of four-year fertilization with starch sewage rich in organic as well as inorganic compounds.

The study area comprised so called soil-plant (forest) sewage treatment works located in a fresh pine forest (*Peucedano-Pinetum*, Mat 1962, 1973).

Fertilization increased cation exchange capacity of the soil under the forest phytocenosis (Table 1), whereas a decrease in cation exchange capacity was found in the clearing phytocenosis (Table 2).

After four years of sewage fertilization, production of typical forest ground flora was almost completely declined in both examined phytocenoses. Forest species were replaced by nitrophilous ones belonging to the classes Artemisietea, Chenopodietea, Epilobietea angustifolii and Molinio-Arrhenatheretea (Tables 3 and 4).

Three groups of species exhibiting different responses to enhanced nutrient concentrations in the site were distinguished: (1) those characterized by the lack of tolerance to elevated contents of biogenic elements, e.g. *Dicranum undulatum*, *Vaccinium vitis-idaea*, *Melampyrum pratense* – extinct as affected by fertilization (Table 5); (2) those characterized by an extended tolerance to elevated contents of biogenic elements in the site, e.g. *Vaccinium myrtillus*, *Convallaria majalis*, *Trientalis europaea* – still present in course of fertilization (Table 6) and (3) species showing considerable ability to take up nutrients from the site, e.g. *Urtica dioica*, *Senecio sylvaticus*, *Stellaria media* – dynamically expanding in course of fertilization (Table 7).

Populations and communities of the investigated plants accumulated different amounts of elements (N, P, K, Ca, Mg, Na, Cl, S) in annually produced tissues. Contents of all the analysed nutrients in biomass of the control forest phytocenosis amounted to 40 kg ha^{-1}. Out of this quantity, 15 kg ha^{-1} was retained in vascular plants, and 25 kg ha^{-1} – in mosses. In the secondary forest community – developed as a result of fertilization – the total nutrient content was 116 kg ha^{-1}, i.e. almost 3 times higher (Table 8). The total nutrient content in the control part of the clearing phytocenosis was assessed to be 27 kg ha^{-1}. Plant biomass of the fertilized clearing contained, in turn, 60 kg of nutrients per ha, i.e. over 2 times more than found for the non-fertilized area (Table 9).

On the basis of the results concerning nutrient accumulation by plants, a very low efficiency of sewage purification from nutrients has been revealed (Table 10).

7. POLISH SUMMARY

W pracy przedstawiono wyniki badań dotyczące właściwości fizykochemicznych gleb, gospodarowania materią oraz akumulacji pierwiastków w dwóch fitocenozach leśnych (borowej i porębowej) w warunkach czteroletniego nawożenia bogatymi w związki organiczne i mineralne ściekami przemysłu krochmalniczego.

Obiektem badań była tzw. glebowo-roślinna (leśna) oczyszczalnia ścieków przemysłu krochmalniczego zlokalizowana na powierzchniach boru świeżego (*Peucedano-Pinetum*, Mat 1962, 1973).

Nawożenie w fitocenozie borowej wpłynęło na wzrost pojemności sorpcyjnej gleb (tab. 1), natomiast w fitocenozie porębowej stwierdzono obniżenie pojemności sorpcyjnej (tab. 2).

Po czterech latach nawożenia ściekami produkcja runa borowego w obydwu badanych fitocenozach obniżyła się znacznie. Produkcję w nawożonych fitocenozach przejęły gatunki nitrofilne z klas: Artemisietea, Chenopodietea, Epilobietea angustifolii i Molinio-Arrhenatheretea (tab. 3 i 4).

Wyodrębniono trzy grupy gatunków różniące się reakcją na podwyższoną koncentrację składników pokarmowych w siedlisku: (1) cechujące się brakiem tolerancji na zwiększoną ilość biogenów, np. *Dicranum undulatum*, *Vaccinium vitis-idaea*, *Melampyrum pratense* – wyginęły w czasie nawożenia (tab. 5); (2) gatunki o zwiększonej tolerancji na podwyższoną koncentrację biogenów w siedlisku, m.in. *Vaccinium myrtillus*, *Convallaria majalis*, *Trientalis europaea* – były stale obecne w trakcie nawożenia (tab. 6) oraz (3) gatunki o dużej zdolności do pobierania składników pokarmowych z siedliska, np. *Urtica dioica*, *Senecio sylvaticus*, *Stellaria media* – rozprzestrzeniały się dynamicznie w trakcie nawożenia (tab. 7).

Akumulacja każdego z ośmiu nutrientów (N, P, K, Ca, Mg, Na, Cl, S) w rocznej produkcji analizowanych populacji i zbiorowisk roślinnych przebiegała odmiennie. Zawartość wszystkich analizowanych nutrientów w biomasie kontrolnej fitocenozy borowej wyniosła 40 kg ha^{-1}. Na rośliny naczyniowe przypadło z tego 15 kg ha^{-1}, a na mchy 25 kg ha^{-1}. W leśnym zbiorowisku zastępczym – wykształconym pod wpływem nawożenia – zawartość całkowita nutrientów wyniosła 116 kg ha^{-1}, tj. prawie 3-krotnie więcej (tab. 8). Zawartość całkowitą nutrientów w kontrolnej części fitocenozy porębowej oceniono na 27 kg ha^{-1}. Natomiast na porębie nawożonej zawartość całkowita nutrientów wyniosła 60 kg ha^{-1}, tj. ponad 2-krotnie więcej niż na powierzchni nie nawożonej (tab. 9).

Na podstawie uzyskanych wyników dotyczących gromadzenia nutrientów przez roślinność wykazano bardzo niski stopień oczyszczania ścieków ze składników pokarmowych (Tab. 10).

8. REFERENCES

1. Aulak W. 1970 – Studies on herb layer production in the *Circaeo-Alnetum* Oberg. 1953 association – Ekol. pol. 18: 411–427.
2. Baule H. 1973 – Nawożenie w praktyce leśnictwa światowego [Fertilization in the world forestry practice] – Las Pol. 13–14: 27 pp.
3. Baule H., Fricker C. 1973 – Nawożenie drzew leśnych [Fertilization of forest trees] – PWRiL, Warszawa, 315 pp.
4. Bradshaw A. D. 1983 – The reconstruction of ecosystems – Journal of Applied Ecology, 11: 1–17.
5. Bradshaw A. D., Chadwick M. J. 1980 – The Restoration of Land – Blackwell Scientific Publications, Oxford, London, Edinburgh, Boston, Melbourne, 317 pp.
6. Casteri Di F. (Ed.) 1996 – Biodiversity, science and development. Towards a new partnership – CAB International, International Union of Biological Sciences, 644 pp.
7. Cybulko T. 1965 – Z badań nad mineralnym nawożeniem borówki czernicy (*Vaccinium myrtillus* L.) rosnącej w warunkach naturalnych [Investigation on the mineral fertilization of bilberry (*Vaccinium myrtillus* L.) growing under natural conditions] – Roczn. WSR, Poznań, Leśn. 27: 45–54.
8. Czerwiński Z., Pracz J. 1995 a – Content of mineral components in the overground parts of the herb layer plants in *Tilio-Carpinetum* communities – Pol. ecol. Stud. 21: 139–152.

9. Czerwiński Z., Pracz J. 1995b – Content of mineral components in the herb layer plants of the alderwood *Carici elongatae-Alnetum* – Pol. ecol. Stud. 21: 171–176.
10. Czerwiński Z., Pracz J. 1995c – Content of mineral elements in the overground parts of herb layer plants in the *Sphagno girgensohnii-Piceetum* community – Pol. ecol. Stud. 21: 195–203.
11. Czerwiński Z., Pracz J. 1995d – Contents of mineral elements in the overground parts of herb layer plants in the community of *Vaccinio uliginosi-Pinetum* Kleist 1929 – Pol. ecol. Stud. 21: 221–226.
12. Czerwiński Z., Pracz J. 1995e – Content of mineral elements in the overground parts of herb layer plants in the community of *Sphagno-Caricetum rostratae* Steffen 1931 – Pol. ecol. Stud. 21: 237–242.
13. Czerwiński Z., Traczyk T. 1985a – Contest of mineral nutrients and ionic equilibrium in grassland plants of the Jorka River watershed – Pol. ecol. Stud. 11: 371–380.
14. Czerwiński Z., Traczyk T. 1985b – Contents and accumulation of mineral nutrients in roots of grassland plants of the Jorka River watershed – Pol. ecol. Stud. 11: 381–391.
15. Czerwiński Z., Traczyk T. 1985c – Accumulation of mineral nutrients in overground and underground parts of grassland plants of the Jorka River watershed – Pol. ecol. Stud. 11: 393–403.
16. Czerwiński Z., Traczyk T. 1985d – Chemical composition and accumulation of mineral compounds in plants of Lake Jorzec – Pol. ecol. Stud. 11: 405–421.
17. Czerwiński Z., Traczyk T. 1985e – Contents of mineral nutrients in xylem of some trees and in herb layer plants from forest communities covering the Jorka River watershed – Pol. ecol. Stud. 11: 423–431.
18. Czerwiński Z., Traczyk T., Pracz J. 1978a – Chemical composition of meadow postgathering residues and mineral fertilization – Pol. ecol. Stud. 4: 259–265.
19. Czerwiński Z., Traczyk T., Pracz J. 1978b – The dynamics and chemical composition of surface detritus in meadow ecosystems – Pol. ecol. Stud. 1: 267–281.
20. Czerwiński Z., Traczyk T., Wilpiszewska I. 1985a – Accumulation of mineral elements in cereal plants – Pol. ecol. Stud. 11: 349–360.
21. Czerwiński Z., Traczyk T., Wilpiszewska I. 1985b – Contents and accumulation of mineral elements in some fodder and industrial crops – Pol. ecol. Stud. 11: 361–370.
22. Czępińska-Kamińska D., Janowska E. 1992 – Kierunki przemian właściwości fizykochemicznych i chemicznych gleb pod wpływem nawadniania ściekami komunalnymi [The course of changes in physico-chemical and chemical properties of the soil affected by irrigation with municipal waste water] – Prace IBL, ser. B, nr spec.: 54–68.
23. Driesche Van R. G., Bellows T. S. 1996 – Biological control – Chapman and Hall, International Thomson Publishing Company, 539 pp.
24. Dyguś K. H., Traczyk T. 1995a – Phytosorption of nutrients in the herb layer of the *Vaccinium uliginosi-Pinetum* Kleist 1929 community – Pol. ecol. Stud. 21: 227–230.
25. Dyguś K. H., Traczyk T. 1995b – Nutrient accumulation by vascular plants in a transition bog, *Sphagno-Caricetum rostratae* Steffen 1931 – Pol. ecol. Stud. 21: 243–248.
26. Dyguś K. H. 1997 – Impact of starch sewage fertilization on phytocenoses of a fresh pine forest and a clearing. I. Vegetation changes as an effect of sewage fertilization – Ekol. pol. 45: 531–553.
27. Holmen H. 1964 – Forest ecological studies on drained peat land in the province of Uppland, Sweeden, parts I–III – Stud. Forest. suec. 16, 303 pp.
28. Höhne H. 1962 – Vergleichende Untersuchungen über Mineralstoff - und Stickstaffgehalt sowie Trockensubstanzproduktion von Waldbodenpflanzen – Arch. Forstwest. Berlin, 11, 10: 1085–1141.
29. Höhne H. 1963 – Der Mineralstoff – und Stickstoffgehalt von Waldbodenpflanzen in Abhängigheit von Standort – Arch. Forstwest. Berlin, 12, 8: 791–805.
30. Hüser R. 1972 – Problematik der Ausbringung von ausgefaulten Klärschlamm in den Wald – Allgemeine Forstzeitschrift. Jg. 27, 9–10, 150 pp.
31. Izdebski K. 1978 – Materiały do badań nad zawartością substancji mineralnych i azotu u wybranych gatunków runa leśnego [Materials for studies on the content of mineral substances and nitrogen in selected

species of the herb layer] – Ann. Univ. Mariae Curie-Skłodowska, C. 33, 16: 203–216.

32. Izdebski K., Kimsa T., Kozak K., Michna E., Popiołek Z., Strączek A., Zienkiewicz A. 1977 – The effect of habitat in two forest ecosystems on the productivity of pine stands in Central Roztocze – Ekol. pol. 25: 89–105.

33. Izdebski K., Kimsa T., Strączek A. 1976 – Dynamika zawartości niektórych składników mineralnych w runie i glebie wybranych zbiorowisk borowych Roztocza Środkowego [Dynamics of some mineral nutrients in herb layer and the soil of selected forest communities of central Roztocze] – Ann. Univ. Mariae Curie-Skłodowska, C, 31, 3: 69–78.

34. Izdebski K., Popiołek Z. 1975 – Dynamika zawartości przyswajalnego fosforu i potasu w roślinach i glebie zespołów borowych na Roztoczu Środkowym [Dynamics of assimilable phosphorus and potassium in plants and soil of forest associations of central Roztocze] – Ann. Univ. Mariae Curie-Skłodowska, C, 30, 15: 101–112.

35. Jordan III W. R., Gilpin M. E., Aber J. D. (Eds) 1990 – Restoration ecology. A synthetic approach to ecological research – Cambridge University Press, Cambridge, New York, Port Chester, Melbourne, Sydney, 342 pp.

36. Kaunisto S. 1992 – Effect of potassium fertilization on the growth and nutrition of Scots pine – Suo, 43: 45–62.

37. Keller T. 1971 – Der Einfluss der Stickstoffernährung auf den Gaswechsel der Fichte – Allgemeine Forst und Jagdzeitung, 142: 189–193.

38. Kotowska J., Traczyk T. 1995 – Phytosorption of nutrients in the herb layer of the *Sphagno-girgensohnii-Piceetum* Pol. 1962 community – Pol. ecol. Stud. 21: 205–211.

39. Mälkönen E. 1975 – Annual primary production and nutrient cycle in some Scots Pine Stands – Commun. Inst. Forest. Fen. 84: 1–88.

40. Marrs R. H. 1978 – Seasonal changes and multivariate studies of the mineral element status of several members of the Ericaceae – J. Ecol. 66: 829–834.

41. Moilanen M. 1993 – Lannoituksen vaikutus männyn ravinnetilaan ja kasvuun Pohjos-Pohjanmaan ja Kainuun soilla [Effect of fertilization on the nutrient status and growth of Scots pine on drained peatlands in nothern Ostrobothnia and Kainuu] – Folia For. 820: 1–37.

42. Moszyńska B. 1973 – Methods for assessing production of the upper parts of shrubs and certain perennial plants – Ekol. pol. 21: 359–367.

43. Moszyńska B. 1983 – Some problems on ecology of *Vaccinium myrtillus* L. in pine forest communities – Pol. ecol. Stud. 9: 565–643.

44. Obmiński Z. 1977 – Ekologia lasu [Forest ecology] – PWN, Warszawa, 473 pp.

45. Odum E. P. 1982 – Podstawy ekologii [Fundamentals of ecology] – PWRiL, Warszawa, 660 pp.

46. Olszowski J. 1976 a – The effect of fertilization on a pine forest ecosystem in an industrial region. I. Forest stand volume increment – Ekol. pol. 24: 285–297.

47. Olszowski J. 1976 b – The effect of fertilization on a pine forest ecosystem in an industrial region. V. Chemical properties of the soils – Ekol. pol. 24: 331–344.

48. Olszowski J. 1976 c – The effect of fertilization on a pine forest ecosystem in an industrial region. VI. Biological activity of the soils – Ekol. pol. 24: 345–358.

49. Ovington J. D. 1956 – Studies of the development of woodland conditions under different trees. The mineral composition of the ground fora – Ecol. 44: 597–604.

50. Ovington J. D. 1962 – Quantitative ecology and woodland ecosystems – Adv. ecol. Res. 1: 103–192.

51. Pasternak-Kuśmierska D., Traczyk T. 1995 a - Phytosorption of nutrients by the herb layer of the *Tilio-Carpinetum* Tracz. 1962 community – Pol. ecol. Stud. 21: 153–162.

52. Pasternak-Kuśmierska D., Traczyk T. 1995 b – Phytosorption of nutrients by the herb layer of the *Carici elongatae-Alnetum* Koch 1926 community – Pol. ecol. Stud. 21: 177–183.

53. Polakowski B., Endler Z. 1985 – Primary production of herb layer in forest and shrub communities of the Jorka River watershed – Pol. ecol. Stud. 11: 321–336.

54. Poncet A. 1970 – Renovation des eaux urbaines usees en fertilisation forestiere par irrigation – Revue Forestiere Francaise, 22: 85–88.

55. Puchalski T., Prusinkiewicz Z. 1975 – Ekologiczne podstawy siedliskoznawstwa leśnego [Ecological foundations of

forest habitat science] – PWRiL, Warszawa, 463 pp.
56. Reiners W. A., Reiners N. M. 1970 – Energy and nutrient dynamics of forest floor in three Minuesota forests – J. Ecol. 58: 497–519.
57. Siebert-Rost K., Jahn G. 1988 – Veränderungen der Waldbodenvegetation während der letzten Jahrzehnte – Eignung zur Bioindication von Immisionswirkungen – Forst und Holzwirt 4: 75–81.
58. Sommer U., Fassbender H. W. 1975 – Möglichkeiten der Abwasserverrieselung in Waldbeständen – Allgemeine Forst Zeitschrift, Jol. 30, 22: 469–471.
59. Sopper W. E., Kardos L. T. 1972 a – Effects of municipal waste water disposal on the forest ecosystem – J. Forestry, 70: 612–616.
60. Sopper W. E., Kardos L. T. 1972 b – Municipal Wastewater Aids Revegetation of Strip-Mined, Spoil Banks – J. Forestry, 70: 612–616.
61. Sopper W. E., Kardos L. T. (eds.) 1973 – Recycling Treated Municipal Wastewater and Sludge through Forest and Crop – land The Pennsylvania St. Un. Press, Un. Park and London, 479 ss.
62. Sopper W. E., Sagmuller C. J. 1966 – Forest vegetation growth responses to irrigation with municipal sewage effluent – Pan American Soil Conservation Congress Proceeding Sao Paulo, Brasil, 639–647.
63. Stugren B. 1976 – Zasady ekologii ogólnej [Principles of general ecology] – PWN, Warszawa, 209 pp.
64. Sundström E. 1992 – Growth response of black spruce five years after drainage and fertilization in the Clay Belt of northern Ontario, Canada – Proc. 9th Int. Peat Congr., Int. Peat Soc., Swed Nat. Comm., Uppsala, 2: 434–444.
65. Traczyk H. 1971 – Relation between productivity and structure of the herb layer in associations on The Wild Apple-Tree Island (Masurian Lake District) – Ekol. pol. 19: 333–363.
66. Traczyk H., Traczyk T. 1967 – Tentative estimation of the production of herb layer – Ekol. pol. A, 15: 832–835.
67. Traczyk T. 1967 a – Propozycja nowego sposobu oceny produkcji runa [A proposed new way of estimating the production of the forest herb layer] – Ekol. pol. B, 13: 241–247.
68. Traczyk T. 1967 b – Studies on herb layer production estimate and the size of plant fall – Ekol. pol. A, 15: 837–867.
69. Traczyk T. 1985 – The role of plant subsystem in matter flow in the agricultural landscape – Pol. ecol. Stud. 11: 445–466.
70. Traczyk T. (ed.) 1995 – Structural features production and phytosorption of the herb layer in the chosen plant communities of the Masurian Landscape Park – Pol. ecol. Stud. 21: 91–256.
71. Traczyk T., Czerwiński Z., Kotowska J., Pasternak-Kuśmierska D., Dyguś K. H. 1995 – Summary of the study results on the phytosorption of nutrients in the herb layer of chosen plant communities in the Masurian Landscape Park – Pol. ecol. Stud. 21: 249–256.
72. Trojan P. 1978 – Ekologia ogólna [General ecology] – PWN, Warszawa, 419 pp.
73. Trojan P. 1984 – Ecosystem homeostasis – Dr W. Junk Publishers, The Hague (Boston) Lancaster, PWN, Warszawa, 132 pp.
74. Vasander H., Kuusipalo J., Lindholm T. 1993 – Vegetation changes after drainage and fertilization in pine mires – Suo 44: 1–9.
75. Wells E. D. 1991 – Efects of refertilization of an 18-year-old Japanese larch (*Larix leptolepis*) peatland in western Newfoundland, Canada [In:] Jeglum J. K., Overend R. P. (eds) – Peat and peatlands – diversification and innovation – Can. Soc. Peat Peatlands, 1: 129–138.
76. Wilpiszewska J. 1990 – Productivity and chemical valorization of mire vegetation in postglacial agricultural landscape – Ekol. pol. 38: 3–72.
77. Zimka J. R. 1989 – Analysis of processes of element transfer in forest ecosystems – Pol. ecol. Stud. 15: 135–212.
78. Zimka J. R., Stachurski A. 1976 a – Regulation of C and N transfer to the soil of forest ecosystems and the rate of litter decomposition – Bull. Acad. pol. Sci., Cl. II, 24: 127–132.
79. Zimka J. R., Stachurski A. 1976 b – Vegetation as a modifier of carbon and nitrogen transfer to soil in various types of forest ecosystems – Ekol. pol. 24: 493–514.