Maciej SZANSER

Departament of Soil Ecology, Institute of Ecology, Polish Academy of Sciences,
Dziekanów Leśny near Warsaw, 05-092 Łomianki, Poland

ROOT PRODUCTION AND BIOMASS
OF ARRHENATHERETALIA MEADOWS OF DIFFERENT AGE

ABSTRACT: Root biomass and production in meadows of varying successional stages was analysed. The net production of root decreased along the successional age of the meadows. In two years old meadow the root biomass equalled that of the permanent one. Along the age gradient a decreasing share of live roots and a accumulation of dead root matter were observed. A new ley was characterized by the most intensive turnover of root biomass. In the sequence of meadows from youngest to permanent one the decomposition of root mass slowed down.

KEY WORDS: meadows biomass, production, roots, succession.

1. INTRODUCTION

The simplification of plant communities covers continually enlarging areas of grasslands. In temperate zone examples of such areas where this process occurs are fens, meadows, steppes and prairies (K a - jak 1985, R y c h n o v s k á 1985, T i - t l i a n o v a et al. 1990).

The diversity of vegetation in the habitats investigated in the present study is closely connected with the secondary succession and increases with the number of years since the meadow was established. In the majority of papers dealing with primary production of grasslands the assessment of the belowground parts is missing due to methodical difficulties, al- though these parts constitute 50–80% of the total plant biomass and during spring and late autumn they exceed even 90% (R y c h n o v s k á 1985). The below-ground production is therefore the main source of soil organic matter (P l e w - c z y ń s k a - K u r a ś 1974, T i l i a n - o v a 1977, T i t l i a n o v a et al 1990).

The present investgations aimed at evaluation the poorly known problem of the root production of meadows of different successional age. The attempt was also made at estimating the relationships between the root production and their biomass.

2. STUDY AREA

The analyses were carried out in the south-western part of the Suwałki Landscape Park (north-western Poland) on an outwash plain (Kajak 1997) Three moist meadows of the order Arrhenatheretalia, belonging to different stages of secondary succession were chosen. They represented: one year old meadow (new ley) (LA) sown in the preceeding autumn with *Dactylis glomerata* L., eight-year-old meadow (LC) and a permanent meadow (P) comprising the association *Anthylli Trifolietum montani*.

The examined meadows were situated on a typical brown soil (Kusińska, Łakomiec 1997).

The number of plant species and litter mass increased with the meadow age (Table 1). The increase of soil organic matter content and of the exchange capacity were also found. The nitrate-N content was the highest on meadow LC and the lowest on meadow LA (Table 2).

The study sites were mown once or twice a year and pastured. The investigations were conducted in years 1988–1989, except the meadow P, which was examined only in 1989. Samples were taken from ungrazed parts of the meadows.

The summer of 1989 was dryer than the preceeding one (Fig. 1).

Table 1. Characteristics of herbage in meadows under study (after Jankowski 1997a, b and unpubl.)

Taxonomy of meadow	One-year-old meadow LA	Eight-year-old meadow LC	Permanent meadow P
	Dactylis glomerata	Arrhenatherion	*Anthylli-trifolietum montani*
Herbage biomass (g dry wt m^{-2})	320	344	390
Litter thickness (cm)	1	2.5	2
Mean litter biomass (g dry wt m^{-2})	60	197	233
Number of plant species in association	4	31	35
Number of dominant species of the highest persistence	2	18	24

Table 2. Soil characteristic of examined meadows (for layer 0 –15 cm) (after Jankowski 1997a, and unpubl.). Meadow designation as in Table 1

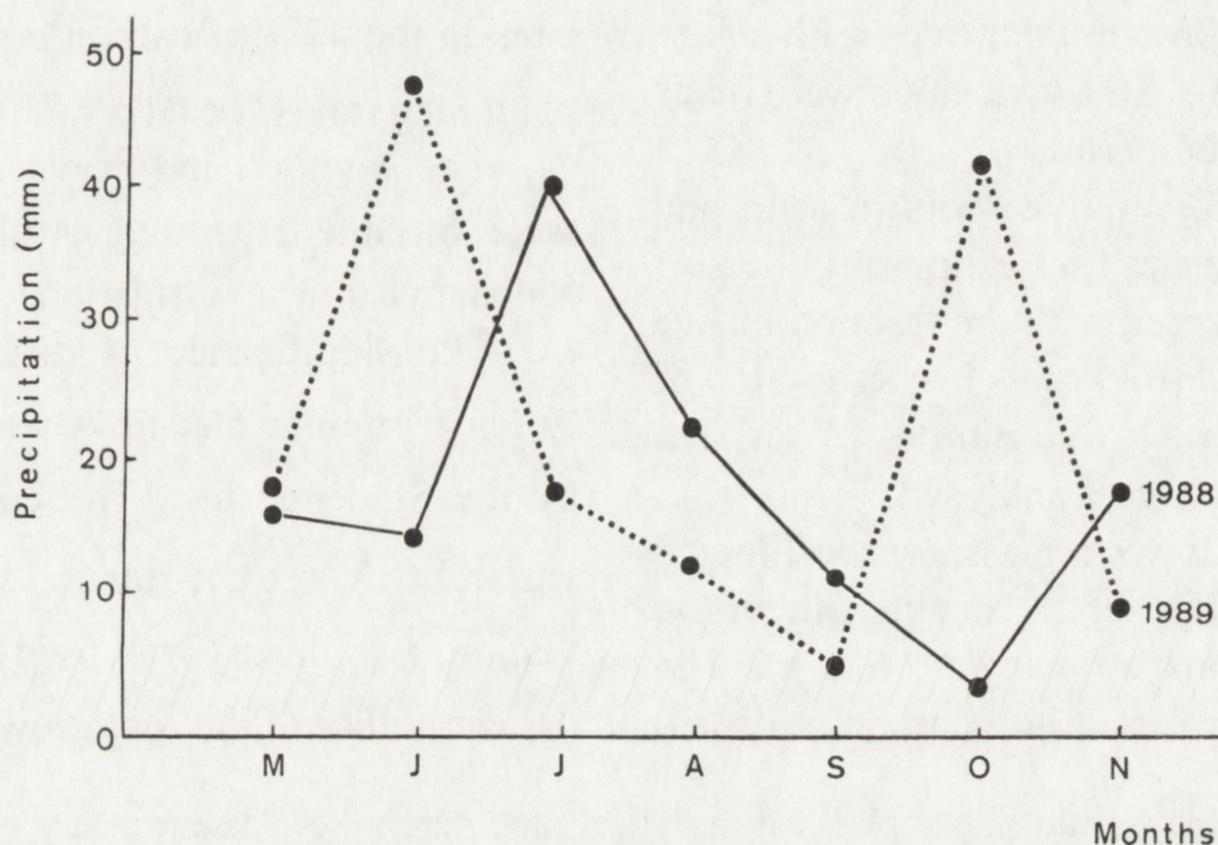| Soil characteristic	LA	LC	P
Organic matter content (%)	1.11	1.44	1.54
Soil sorption capacity (meq 100 g^{-1} dry wt of soil)	13.15	14.6	16.8
Content of N-NO$_3$ (mg 100 g^{-1} dry wt of soil)	0.04	0.9	0.3

Fig. 1. Course of precipitations (mm per month) on the examined area in 1988 and 1989

3. METHODS.

The root production was established experimentally by measuring the weight of roots ingrowing to sandy substrate in mesocosms of experimental design presented in K a j a k (1997). The sand on all examined meadows was of the same source. On each site 90 pits (in the form of a cylinder) of 200 cm³ area and 30 cm deep, were dug. The pits were ranged in 3 rows, 30 in each row, with the distance of 1 m between rows and 0.5 m between pits. The bags were made of steelon net of 0.28 mm mesh.

In the first experimental year (17 May 1988 – 10 February 1989) the root growth was analysed at the end of the experiment. The samples taken as whole sand bags were divided into two depth profiles: 0–10 cm and 10–20 cm. In the next experimental year (10 May 1989–11 October 1989) samples were taken from the depth 0–10 cm by soil coreer (10 cm²) every second month from pits. Method of destructive sampling was applied. Soil samples to determine root biomass were also taken in the vicinity of the pits, using the same sampler.

The roots were washed on sieves of 1 and 0.25 mm mesh sizes.

In samples both from sand and from soil three fractions of root biomass were distinguished: large (bR), medium (mR) and small (sR) roots. Among large parts the fraction forming an integral part of the plant was reckoned, which comprised live as well as dead roots in various phases of dying off and the dead ones. Medium and small fraction consisted of the dead material freely distributed in the substratum and held up on sieves of different mesh size. The applied partitioning of belowground plant biomass was used for the evaluation of the intensity of root dying off and of their separation from plants. Besides, the proportion of live roots (lR) was estimated in sand and soil samples. Live material was distinguished according to P l e w c z y ń s k a - K u r a ś (1974) and F i a l a (1987a), who indicate that young live beloground plant components were white, yellow with visible epi-

dermis, and brown older ones with suberized epidermis. Dead fractions were black and without epidermis.

The share of live roots in sand and soil was measured by estimating the surface area covered with the fraction of live (lR) and dead (dR) roots in the fraction of large roots (bR). Subsamples of an area of several cm^2 were analysed.

The total root mass was estimated gravimetrically after drying them at 105^{0}C to constant weight (4–8 h). The mass was converted into carbon units, as-

suming the 45% of carbon content in dry plant material (Ú l e h l o v á 1985).

The number and ways of analyses were variable depending on the site, season and year of investigation (Table 3).

The significance of differences between particular meadows was estimated by the Student t test. The coefficient of variability $V = s/\bar{x} \times 100$ (s – standard deviation, $\bar{x}$ – mean) was used to estimate the variability of the root growth rate.

Table 3. Characteristic of samples and analytical procedure (+ evaluation made, – evaluation not made)

Substratum	Date of sample collection	Sampling method	Number of samples per meadow			Layer analysed (cm)	Root fractions	Share of live roots
			LA*	LC*	P*			
Sand	10. Febr. 1989	from bags	20	9		0–10, 10–20	–	–
	7 Jul. 1989	from pits	20	19	20	0–10	–	+
	9. Aug. 1989	from pits	13	17	20	0–10	+	+
	11. Oct. 1989	from pits	20	20	19	0–10	+	+
Soil								
	9. Aug. 1989	from pits	19	16	17	0–10	+	+
	11. Oct. 1989	from pits	19	19	19	0–10	+	+

* Type of meadow as in Table 1.

4. RESULTS

4.1. ROOT PRODUCTION

The meadows under study differed in root growth rate (production) (Table 4). In the first year of experiment (1988/89) the daily root growth on the one year old meadow (LA) was significantly lower as compared to that of eight year old meadow (LC). This regularity occured in both sand layers, the upper (0–10 cm) and

the lower one (10–20 cm). In the next year the mean growth rate of roots was similar in all study sites. The differences were not significant. However significant differences between meadows occured in particular periods. In the youngest meadow (LA) during the spring and autumn the root growth rate was higher

Table 4. Root production (mean $\pm$ $s_{\bar{x}}$ in g dry wt m^{-2} day^{-1}) in sand mesocosms (layers 0–10 cm (a) and 10–20 cm (b))

Sites[a]	1988/89 from bags[b]	1989 from pits[b]			Average production rate
	17. May – 10. Febr.	10. May – 7 Jun.	7. Jun. – 9. Aug.	9. Aug. – 11. Oct.	10. May – 11. Oct
LA	a) 0.54 (±0.04)	0.89 (±0.43)	0.38 (±0.09)	0.48 (±0.11)	0.49 (±0.05)
	b) 0.21 (±0.03)				
LC	a) 0.77 (±0.12)	0.13 (±0.02)	1.02 (±0.12)	0.22 (±0.09)	0.46 (±0.05)
	b) 0.57 (±0.13)				
P		0.10 (±0.02)	0.61 (±0.09)	0.43 (±0.09)	0.43 (±0.05)
	Significance of differences between sites				
LA vs. LC	a) p < 0.05, n = 25	p < 0.05, n = 30	p < 0.001, n = 30	p < 0.001, n = 40,	n.s.
	b) p < 0.01, n = 24				
LA vs. P		p < 0.05, n = 40	p < 0.05, n = 39	n.s.	n.s.
LC vs. P		n.s.	p < 0.001, n = 37	p < 0.001, n = 39	n.s.

[a] Type of meadow as in Table 1;
[b] Bags and pits filed with sand, inserted into soil surface (15 cm depth).

than on meadows LC and P, while in summer it was lower than on older meadows (Table 4).

The lowest seasonal variation of root growth was observed on the youngest site (LA) (38%) and the highest one on meadow LC (87%), whereas the site P exhibited a medium variation (56%).

The comparison of all the meadows in vegetative season indicated that the coefficient of variation dependent on meadow age decreased during a season, from 98% in spring, 40% in summer to 30% in autumn.

The highest differences between meadows in root production, occured in spring. During the first month the root production expressed as biomass increment per day, was over 7 times higher on the new ley (LA) than on remaining meadows (Table 4). During the summer and autumn, the differences between meadows were not so important. In summer the root growth rate on older meadows (LC, P) exceeded that on the new ley (LA), however in autumn the most intensive growth was observed again on the latter (LA).

On comparison of the meadows as to the accumulated amount of carbon brought in with roots to the sand, the highest value of accumulation in autumn occured on young meadow (LA) and the lowest in the permanent meadow (P) (Fig. 2).

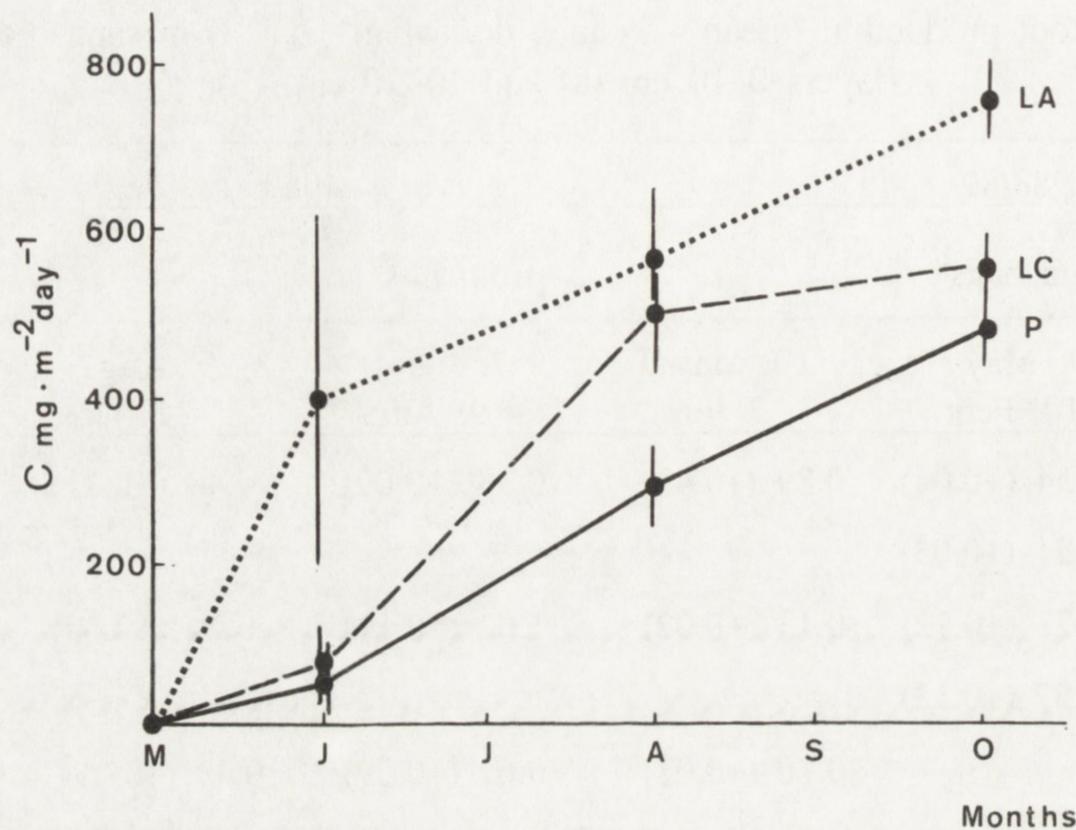On the new ley (LA) the root production was not only higher but also more regular, than on older meadows

Fig. 2. Root production rate in sand as accumulated carbon (in 1989)
LA – new ley, LC – eight years old ley, P – permanent meadow

(LC, P). The several year old meadow (LC) was characterized by the most variable pattern of root production, whereas the permanent one (P) exhibited the slowest root growth as compared to younger meadows (LA, LC).

4.2. ROOT BIOMASS

The examined meadows differed with respect to root biomass (Fig. 3). In summer the meadow LC showed a significantly lower belowground biomass (1150 g dry wt m^{-2}) than meadow LA (1555 g dry wt m^{-2}) and P (1550 g dry wt m^{-2}). In autumn, in comparison with summer, there was a decrease of belowground root biomass in all meadows, and the biomass was similar in all the sites (Fig. 3).

The root biomass in two year old meadow (LA) in 1989 was similar as in the permanent meadow, due to higher root growth rate in this meadow in some periods of this year (Fig. 2).

It should be emphasized as well that the root production in sand during the experiment was a very low fraction of the total root biomass in soil (5–7%) (Figs 3 and 4).

4.3. ROOT FRACTIONS IN SAND AND SOIL

In the root production in sand the fraction of large roots (bR) comprising a part of the plant was distinguished. This fraction included live, dying off and dead roots. On the other hand the dead root matter distributed seperately in sand consisted of the fraction of the finest roots (sR) (Fig. 4).

The lowest amount of large root fraction was found in meadow P in summer and in autumn as well (Fig. 4). Significant differences were found only between meadows LC and P in summer (n = 37, p < 0.02). The amount of fine roots was lower in the young meadow (LA) than in permanent (P) one. In contrast the amount of large roots was higher in new ley (LA).
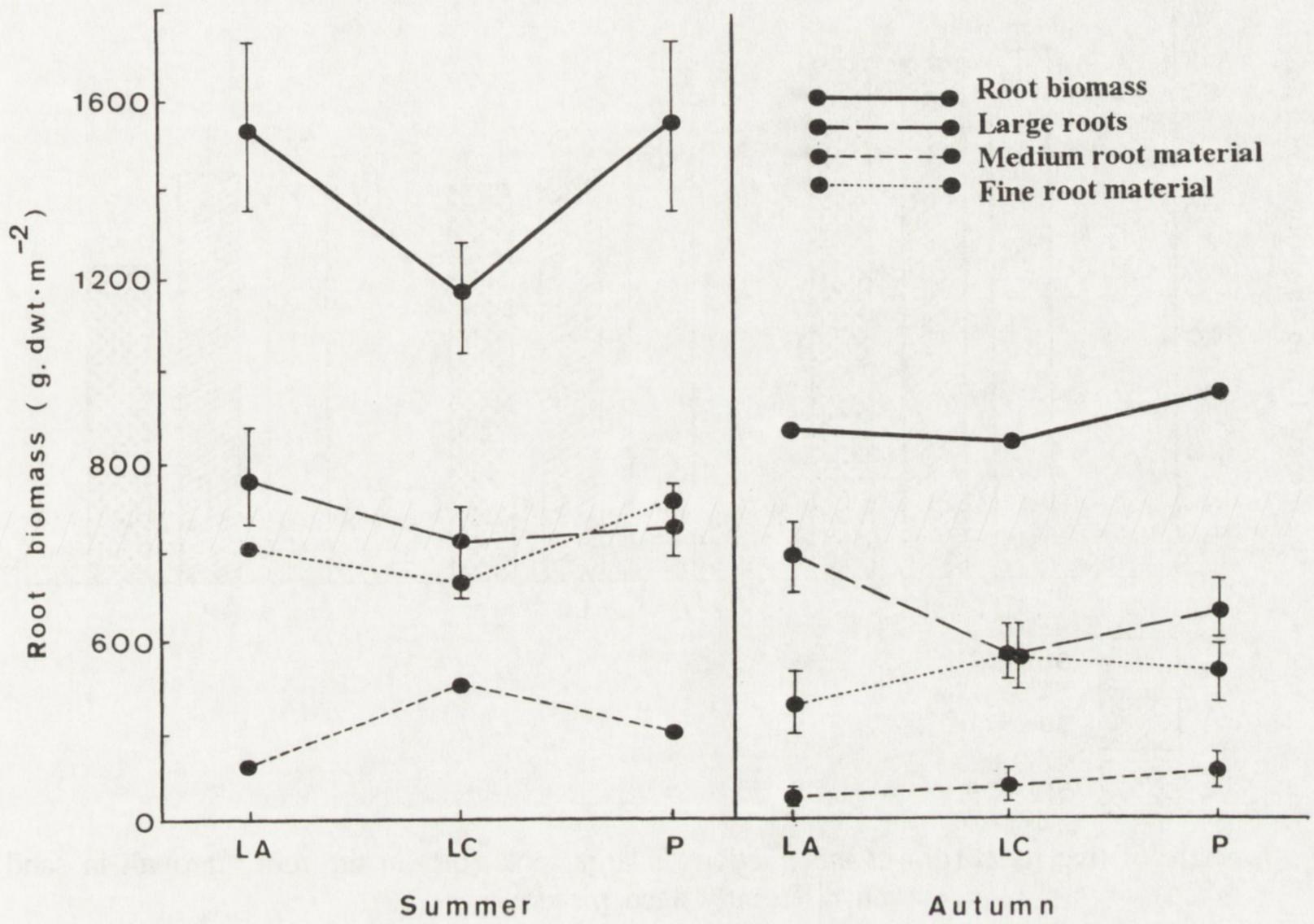
Fig. 3. Root biomass in soil on different aged meadows.
Denotations of sites as in Fig. 2

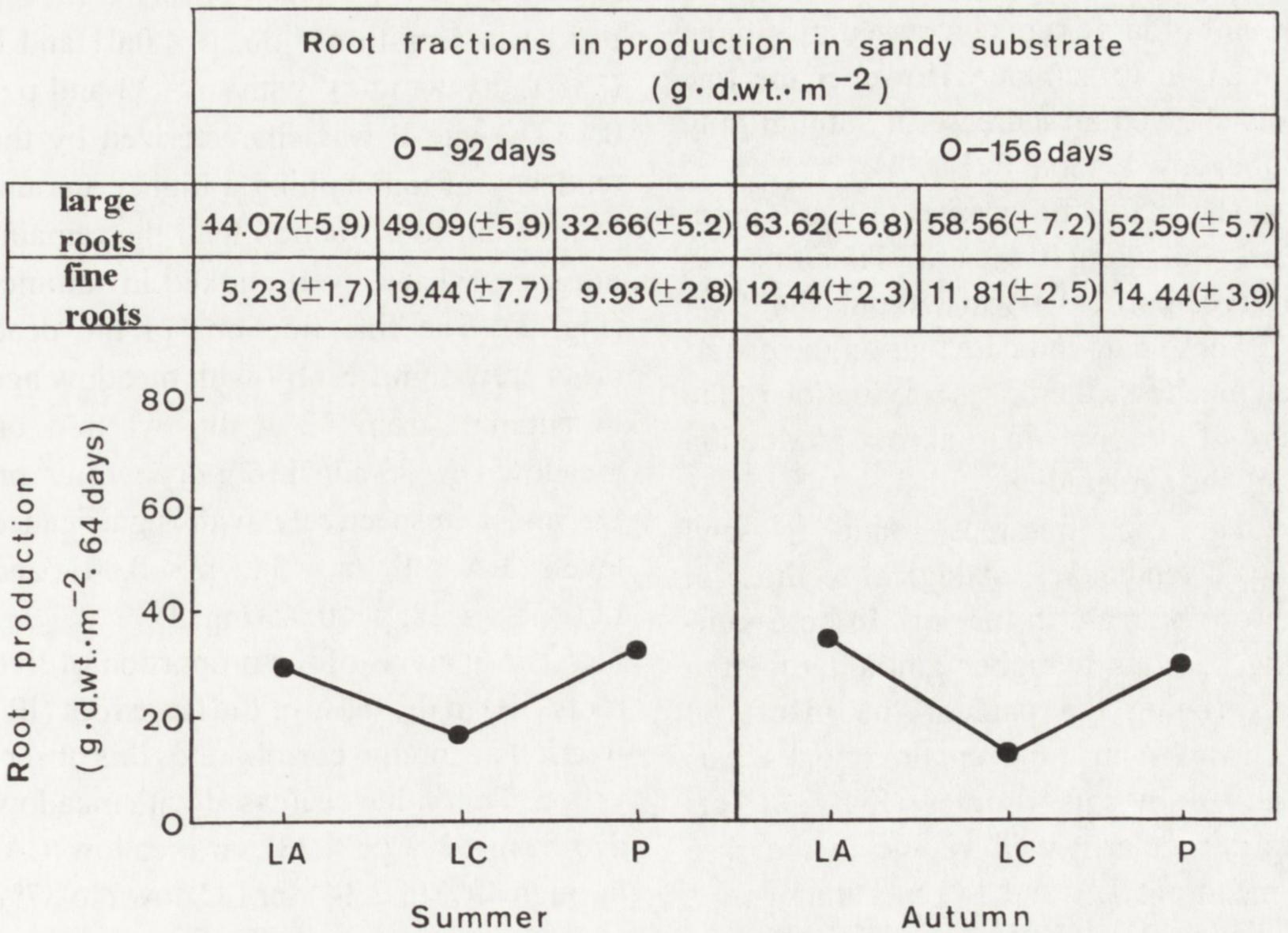| Root fractions in production in sandy substrate $(g \cdot d.wt. \cdot m^{-2})$					
	O – 92 days			O – 156 days		
large roots	44.07(±5.9)	49.09(±5.9)	32.66(±5.2)	63.62(±6.8)	58.56(±7.2)	52.59(±5.7)
fine roots	5.23(±1.7)	19.44(±7.7)	9.93(±2.8)	12.44(±2.3)	11.81(±2.5)	14.44(±3.9)

Fig. 4. Root fractions in sand.
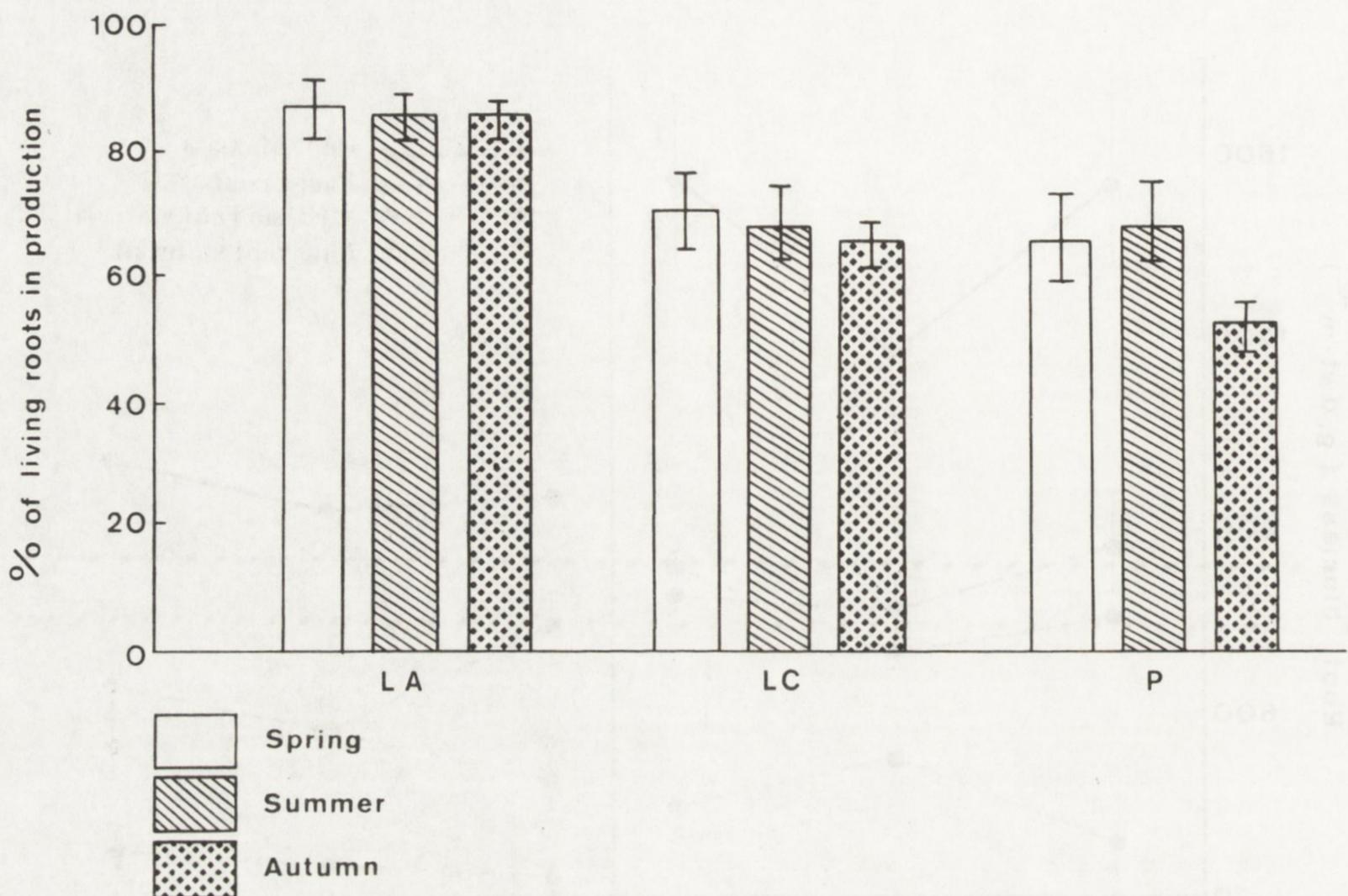Denotations of sites as in Fig. 2

Fig. 5. Share of live roots (lR) in the fraction of large roots (bR) in the root ingrowth in sand on differently aged meadows.
Denotations of sites as in Fig. 2.

But all these differences were not significant (Fig. 4). In all the meadows the amount of large roots increased in autumn in relation to summer. However the fine roots showed an increase in autumn only on meadow LA and P (Fig. 4).

The share of live roots in sand diminished with aging of meadows and this was observed particularly in autumn (Fig. 5).

These data indicate that on the examined meadows there was a reduction of the share of live roots in total root production along the age gradient.

The root fractions found in sand showed tendencies analogical to those in the root biomass in the soil. In both sampling seasons a higher amount of large roots (being the part of the plant) on meadow LA than on remaining ones, was observed in soil samples (Fig. 3). This was particularly well visible in the case of meadows LA and LC in autumn (n = 38, p < 0 .02). The fraction of dead roots (fine and medium ones) increased with meadow age. In autumn the site LA ex-

hibited a lower biomass of medium roots (243 g dry wt m^{-2}) than sites LC (377 g dry wt m^{-2}) with n = 36, p < 0.01 and P (335 g dry wt m^{-2}) with n = 33 and p < 0.1. The site P was characterized by the tendency of maintaining a higher amount of medium root fraction than the remaining sites, what is well marked in summer (Fig. 3). The fine fractions of the dead roots grew significantly with meadow age in autumn, from 62 g dry wt m^{-2} on meadow LA, 83 and 116 g dry wt m^{-2} on LC and P respectively with significance levels LA < P n = 34, p < 0.001 and LC < P, n = 38, p < 0.02 (Fig. 3).

The analysis of the proportion of live roots (lR) in the mass of the large root (lR) fraction in autumn corroborates this observation. This value decreased with meadow age from 53% (± 4.23) on meadow LA, through 49% (± 3.14) for LC down to 37% (± 2.4) for meadow P. On the permanent meadow P the percentage of live roots is significantly lower than on meadow LA,

with n = 33 and p < 0.01 and on LC, with n = 39 and p < 0.01.

These data allow to conclude that irrespective of the method used in fractination the roots, the highest share of live roots was observed on the youngest site (LA). Along the age gradient the share of dead roots increased in both, the medium and fine fractions.

4.4. ROOT MASS TURNOVER

The exchange rate of root mass on the meadows under investigation changed with their age. This parameter was examined by analysing:

1. ratio of large root biomass in soil, i.e. of the fraction containing live roots, to total belowground plant mass (bR/R).

2. ratio of surface occupied by live roots to total surface occupied by large roots (lR/bR). Basing upon the results of Fiala (1990) these above parameters were taken as the measure of root turnover.

3. ratio of the total carbon contributed by root production in sand to total carbon cotent in sand at the end of the experiment (C_r/C_s).

In all cases the values of analysed ratios decreased within the sequence of meadows from LA to P (Table 5.). It may be concluded that with meadow aging the proportion of dying off roots and retention of root derived carbon in the sand increased.

Table 5. Indices of root turnover on meadows under study (bR – large roots, lR – live roots, R – total root biomass, C_r – cumulative root increment as carbon, C_s – total carbon content in sand at the end of the experiment) (after Kusińska 1997)

Indices of turnover rate	Type of meadow		
	LA[*]	LC[*]	P[*]
bR/tR	0.56	0.48	0.46
lR/bR	0.53	0.48	0.37
C_r/C_s	8.64	5.12	4.22

[*]Denotations as in Table 1.

5. DISCUSSION

This paper presents a comparison between meadows differing as to the time since establishment. It was important to answer how much time would require the root biomass of a young meadow to attain the level of a permanent one.

It was found that already the meadow of the age of two years (LA) showed a belowground biomass resembling that of the permanent meadow (P). Other authors, dealing with this problem in relation to various grassy communities proved that the belowground plant biomass exhibits a growth during 2–4 years since the meadow establishment (Kacperska-Palacz, Pietruch 1970, Janus 1976, Rutkowska et. al. 1980).

The biomass ratio between below-ground parts (R) to aboveground ones (G) was considered, basing on data from this paper and those of Jankowski (1997b). This parameter depends on plant species, development phase, conditions of the habitat, way of exploitation as well as clearly on fertilization (Janus 1976). It was then important to verify how R/G would change with the age of examined meadows. This problem remains poorly known. The value R/G was the highest on young meadow LA amounting to 3.8. On the remaining meadows these values were lower, that is 2.9 for the meadow LC and 3.2 for meadow P.

This differentiation was even more pronounced when only large roots (bR) were taken into account, that is the fraction where live roots are included.. The values bR/G in the sequence of increasing meadow age were 2.1, 1.4, and 1.5 respectively. These data are situated within the R/G limits quoted by Fiala (1990) for various grassy communities. According to this author the analysis of the mass ratio of live roots to aboveground parts of plants affords a clearer picture of the relationship between both components of plant biomass than considering the total root mass comprising an important fraction of dead roots.

The present results indicate that on the new ley (LA) the root production prevailed over the aboveground production and along with meadow aging these parameters may attain an equillibrium. This interesting problem calls for futher investigations to confirm the above relationships.

The present results regarding the root biomass approximate those of Kotańska (1970) and Plewczyńska-Kuraś (1976) obtained for meadow associations of the order Arrhenatheretalia. On the other hand Pilarska et al.

(1981) found a much higher value of root mass in polluted area as compared with meadows discussed in present paper, of the same order Arrhenatheretalia. The probable reason of this fact might be the industrial pollution of the environment and consequently the accumulation of the dead root mass.

The data from Lithuania (Lapinskene 1986) regarding the grassy communities both exploited and natural, situated on slopes, also approximate the present results. To sum up, the present data concerning the root standing crop and biomass growth are generally similar to those found in the literature, concerning this geographic region.

The values of root production observed in the present investigations were very low in comparison to root biomass, presumably however the applied method might have influenced the results. Namely the production was estimated basing upon the weight of roots ingrowing to the bags or into the pits filled with sand during a definite time. Fiala (1986, 1987a) used a similar method, but the containers were filled with sieved soil changed monthly, and found a root production of 34% in relation to biomass. The data of the above quoted author may be high in relation to the reality due to to the application of exchange of containers with the substratum which provided constantly a new space for ingrowing roots and additional supply of mineral compounds. The application of a poor substratum such as sand in the experiment on meadows in present paper may have hindered to some extent the root growth. It had however the advantage of uniformity of the substratum on all experimental localities facilitating the estimation of the potential tendency of root growth.

According to Andrzejewska (1991) who used an analogical method as

in the present paper, the root production on two and three years old meadows newly founded on drained fens neared that on leys in present investigations. However the ratio of root production (P) to their biomass (R), which on peat meadows amounted to 0.3 (soil layer 0–15 cm) and in present paper to 0.08, may indicate a different rate of root turnover on both meadow types.

All quoted authors observed a lower production of roots than their biomass. The present results as well those obtained by Fiala (1986, 1987b), Bazi-levich and Shatohina (1976) and Andrzejewska (1991) indicate, that the mentioned method of estimation the root production may be useful in comparing different habitats.

The data concerning root turnover are of particular interest. After Speidel (1976) as much as 54% of roots lived shorter than one month on a meadow dominated by grass *Trisetum flavescens* and only 10–15% survived over 4 months. The ratio of long lived roots to short living ones was 1:4, the first root type appearing only during the second half of the year. Thus the root ingrowth in sand sampled in the autumn might be composed of long lived roots.

The root turnover may presumably vary according to the stage of succession of the meadows. The present data suggest that the turnover was the slowest on new ley (LA), the share of live root mass being there the highest. The formation of new biomass predominated over depositing dead mass, only fine fraction of dead roots (sR) was found. The level of dead root (mR + sR) matter in soil and of the share of dead roots (sR) in root ingrowth in sand increased with the age of meadows under study, while the root production showed decrease. It may suggest that the roots dying off progressed with the meadow age.

Thus the root decomposition might be slower in meadows older than new ley (LA).

A slower root decomposition on older meadows may be connected with the kind of roots and with their spatial distribution. Titlianova (1977) reports a decomposition in one year experiment, where the single species root decay proceeded faster than of three plant species mixed together. These plants were *Poa angustifolia* (loss of 48%), *Calamagrostis epigeios* (loss of 51%) and *Galatella biflora* (loss of 58%). When the species were mixed together the loss was only 41% of the root mass.

This observation suggest that if complexity of plant community becomes greater then root decomposition may be slowing down. Thus the suggestion about lower root turnover on permanent meadow (P) than 8 year old meadow LC is confirmed. If could be assumed that in new ley (LA) root biomass is mineralized at the higher rate, than in older meadows, it may be the reason, that the proportion of dead roots is lower there than in other sites. This is confirmed by the microbiological analysis of sand used in the experiment which showed greater number of bacteria and dehydrogenase activity on meadow LA than on older ones (Stefaniak et al 1997). Also the lowering ratio of root carbon to carbon in sand along the age gradient of meadows was observed. On the meadow LA decomposition of the litter placed on surface of the sand also went faster than on older sites (Bogdanowicz, Szanser 1997). These observations clearly show a picture that in sand on meadow LA mineralization processes went much faster than on older sites, with possibly quick dissappearance of dead roots and deposited carbon. Futher Tesařova's (1990) observation that root decomposition was faster on new than on permanent meadow confirms that

suggestion. Data presented in present paper agree with F i a l a ' s (1986) suggestion that younger meadows are characterised by a higher root production and turnover rate, than older grasslands.

Results obtained suggest that for obtaining more precise view into root dynamics, several carefully chosen methods must be applied together in such investigations.

6. CONCLUSIONS

1. The root production in sand decreased along the succession gradient i.e. from the youngest meadow with the most simple floristic composition, to a permanent one with the highest degree of plant species richness.

2. The young ley showed a stable root production during the vegetation season. The most variable belowground production was found in several years old meadow.

3. In the second year after establishment the root biomass on the new ley equalled the biomass in the permanent meadow. Along the meadow aging the

proportion of live roots decreased and that of dead roots increased.

4. Within the group of young roots that grew for several months, the proportion of dead fraction rose with the meadow age.

5. Accumulation of dead root mass with the meadow age resulted probably from the prevalence of root withering over their decomposition. Parallelly to meadow aging there occured an increasing retention of carbon, brought into the sand with roots. It is suggested that root turnover was the slowest on permanent meadow than on new ley.

7. SUMMARY

The investigations were carried out in the years 1988–1989 on Arrhenatheretalia meadows of different age situated in the Suwałki Landscape Park (N-E Poland) (Table 1 and 2). They aimed at estimating the root production and its relationship with total root biomass. The sites under study were one year old ley (LA) eight--year-old ley (LC) and permanent meadow (P). The production was evaluated experimentally, the root ingrowing to steelon bags or into pits, in both cases filled with sand. Bags filled with sand or sand samples from pits were analysed. The root biomass was estimated in soil samples (Table 3.). The samples were taken from two depths, 0–10 cm and 10–20 cm. The substratum was washed under running water on a set of sieves of 1.0 and 0.25 cm mesh size.

It was found that the root production in sand decreased according to the succession on meadows, that is from the youngest meadow with the simplest floristic composition, to the

permanent one with the highest degree of plant species diversity (Table 4, Fig. 2). The meadow LC exhibited the most variable root mass production. The root production made only 5.1–7.2% of the root mass in soil (Fig. 3, 4). In the second year of cultivation the root biomass in the new ley equalled that in the permanent meadow (Fig. 3). Along with meadow aging the share of live roots decreased (from 53% on the new ley, through 48% on older meadow, down to 37% on the permanent one) and that of dead roots rose in both, the root production in sand (Fig. 5) and in their biomass in soil.

It has been suggested that with the meadow aging increase of dead root mass resulted from the prevalence of root withering over root decomposition. The latter process also seems to be slower in permanent meadow than in younger ones. Along with meadow aging the growing accumulation of carbon, brought into the sand with roots was observed (Table 5).

8. POLISH SUMMARY

Badania przeprowadzono w latach 1988–1989 na różnowiekowych zespołach łąk Arrhenatheretalia na terenie Suwalskiego Parku Krajobrazowego (pn-wsch. Polska). Celem badań była ocena produkcji korzeni oraz relacji między tym parametrem a całkowitą biomasą korzeni na łąkach różniących się czasem trwania (łąka nowa LA, łąka ośmioletnia LC oraz łąka trwała P). Produkcję oceniono w eksperymencie gdzie korzenie wrastały do worków z siatki stylonowej lub dołków w obu przypadkach wypełnionych piaskiem. Do analiz pobierano odpowiednio worki wypełnione piaskiem lub próbki piasku pobieralnikiem. Biomasę korzeni oceniano w próbach glebowych pozyskanych pobieralnikiem. Próby o głębokości 0–10 i 10–20 cm oczyszczano z podłoża pod bieżącą wodą na zestawie sit o średnicy oczek 1.0 i 0.25 cm.

Stwierdzono, że produkcja korzeni w piasku malała w ciągu sukcesyjnym łąk tzn. od łąki najmłodszej o najprostszym składzie florystycz-nym do łąki trwałej o najwyższym stopniu zróżnicowania gatunkowego (tab. 4 i rys. 2). Łąka wieloletnia odznaczała się najbardziej zmienną produkcją masy korzeniowej. Produkcja korzeni stanowiła tylko 5.1–7.2% biomasy korzeni w glebie (rys. 3 i 4). Biomasa korzeni już w drugim roku uprawy na młodej łące dorównywała wielkością biomasie podziemnej na łące trwałej (rys. 3). Wraz ze starzeniem się łąk zmniejszał się udział żywych korzeni (od 53% na łące nowej poprzez 48% na łące wieloletniej do 37.% na łące trwałej), a powiększał się martwych zarówno w przyrostach w piasku (rys. 5) jak i w biomasie. Wyciągnięto wniosek, że wzrastająca wraz z wiekiem łąk masa martwych korzeni była wynikiem przewagi procesu obumierania korzeni nad ich rozkładem. Procesy rozkładu wydają się zachodzić wolniej na trwałej łące aniżeli na młodszych stanowiskach. Wraz ze starzeniem się łąk stwierdzono zwiększenie się retencji wniesionego przez korzenie węgla (tab. 5).

9. REFERENCES

1. Andrzejewska L. 1991 – Root production of some grass comunities on peat soil in river valleys of Biebrza and Narew – Pol. ecol. Stud.17,1–2: 57–67.
2. Bazilevich N. I., Shatohina N. G. 1976 – Opyt opredeleniya produkcii podzemnei massy v fitocenoze lugovoi stepi [In: Struktura funkcionirovaniya i evoluciya sistem biogeocenozov Baraby. II. Biogeocenoticeskiye procesy, Ed. R.V. Kovalev] – "Nauka"–Sibirskoye otdieleniye, Novosibirsk, 300–303.
3. Bogdanowicz L., Szanser M. 1997 – The decomposition of *Dactylis glomerata* grass litter in meadow ecosystems differing in age and management – Ekol. pol. 45: 647–663.
4. Fiala K. 1986 – Rocni produkce a rychlost obratu podzemni biomasy lučnich porostů ceskomoravske vrchowiny – Folia Phytotechnica – VEFT CSAV, Brno, 140–147.
5. Fiala K. 1987a – Rozlišeni živých a mrtvých kořenů [In: Metody studia travinných ekosystémů, Red. M. Rychnovská a kolektiv] – Academia Praha, 111–113.
6. Fiala K. 1987b – Stanovení ročni produkce kořenů [In: Metody studia travinných

ekosystémů, Red. M. Rychnovská a kolektiv] – Academia Praha, 120–121.
7. Fiala K. 1990 – Underground plant biomass of seminatural meadows and its variation according to ecological factors – Ekologia (CSRR), 9: 171–191.
8. Jankowski W. 1997a – The plant communities of meadows and pastures of Suwałki Landscape Park (north-eastern Poland) – Ekol. pol. 45: 587–607.
9. Jankowski W. 1997b – Floristic diversity of grassland swards in Suwałki Landscape Park (north-eastern Poland) in relation to use and age – Ekol. pol. 45: 619–632.
10. Janus E. 1976 – Wpływ deszczowania i nawożenia łąki na stosunki wodne gleby, rozmieszczenie korzeni oraz na zużycie wody i plonowanie [The influence of raining and fertilizing of the meadow on the water conditions of the soil, on the arrangement of the roots and the water consumption of the crop] – Zesz. probl. Post. Nauk Roln. 181: 379–425.
11. Kacperska-Palacz A., Pietruch B. 1970 – Wpływ koszenia i spasania na plon zielonej masy i rozmieszczenie organów podziemnych sześciu gatunków traw pastewnych [Effect of grazing and mowing

utilization upon green matter yield and dis-location of underground organs of plants in six fodder grass species] – Rocz. Nauk roln. ser. T. 77 : 377–388.

12. K a j a k A. 1985 – Immediate and remote ecological consequences of the peatland drainage – Pol. ecol. Stud. 11: 123–150.

13. K a j a k A. 1997 – Preface. Scope of stud-ies, experimental design, study area – Ekol. pol. 45: 581–585.

14. K o t a ń s k a M. 1970 – Morfologia i bio-masa podziemnych organów roślin w zbiorowiskach łąkowych Ojcowskiego Parku Narodowego [Morphology and biomass of the belowground organs of plants in grasslands communities of the Ojców National Park] – Stud. natur. Kraków, ser. A-4: 1–107.

15. K u s i ń s k a A. 1997 – Humification of grass litter on age differentiated meadows in the Suwałki Landscape Park (north-eastern Poland) – Ekol pol. 45: 665–671.

16. K u s i ń s k a A., Ł a k o m i e c I. 1997 – Content of humus fraction in the soils of age differentiated meadows in the Suwałk Landscape Park (north-eastern Poland) – Ekol. pol. 45: 609–618.

17. L a p i n s k e n e N. 1986 – Podzemnaya chast travianistyh rasteniy i fitocenozov v Litovskoj SSR – Mosklas, Vilnius, 175pp.

18. P i l a r s k a J., C i a n c i a r a S., U r b a n E., P r u s M. 1981 – Estimation of biologi-cal activity of soil complex in two grassland ecosystems in Upper Silesia – Pol. ecol. Stud. 7: 77–90.

19. P l e w c z y ń s k a - K u r a ś U. 1974 – An-alysis a sheep pasture ecosystem in the Pien-iny mountains (The Carpathians). IV. Biomass of the upper and underground parts of plants and of organic detritus – Ekol. pol. 22: 517–526.

20. P l e w c z y ń s k a - K u r a ś U. 1976 – Esti-mation of biomass of the underground parts of meadow herbage in the three variants of fertilization – Pol. ecol. Stud. 2: 63–74.

21. R u t k o w s k a B., S t a ń k o - B r ó d k o w a B., L e w i c k a E., D ę b s k a Z. 1980 – Kształtowanie się biomasy nadziemnej i podziemnej roślin na pastwisku wieloletnim i nowo zasianym [The formation of above-ground and underground biomass of plants on a permanent and newly sown up pasture] – Roczn. Nauk roln. ser. F, T. 80: 129–144.

22. R y c h n o v s k á M. 1985 – Primárni pro-dukce a vazba sluneční energie v porostech [In: Ekologie lučnich porostu, Eds. M. Rychnovská, E. Balátová-Tuláčková, B. Úlehlová, J. Pelikán] – Academia Praha, 125–158.

23. S p e i d e l B. 1976 – Primary production and root activity of a golden oat meadow with different fertilizer treatments – Pol. ecol. Stud. 2: 77–89.

24. S t e f a n i a k O., Ś l i z a k W., M a n i e w-s k a R., G o r l a c h K. 1997 – The impact of grass litter on the development of micro-organisms in the substrate – Ekol. pol. 45: 709–717.

25. T e s a ř o v a M. 1990 – Decomposition processes and carbon cycling in natural and man made grasslands – Ekologia (CSSR), 9: 207–216.

26. T i t l i a n o v a A. A. 1977 – Biologiceskiy krugovorot ugleroda v travianyh biogeo-cenozah – Izd. Nauka, Novosibirsk, 221pp.

27. T i t l i a n o v a A. A., Z l o t i n R. I., F r e n c h N. R. 1990 – Changes in structure and function of temperate – zone grasslands under the the influence of man [In: Managed Grasslands: Regional Studies, Ed. A. I. Breymeyer] – Amsterdam, Elsevier, 301–334.

28. Ú l e h l o v á B. 1985 – Koloběhy minerál-nich prvků [In: Ekologie lučnich porostu, Eds. M. Rychnovská, E. Balátová-Tuláčk-ová, B. Úlehlová, J. Pelikán] – Academia Praha, 219–238.