EKOLOGIA POLSKA (Ekol. pol.)	43	3–4	205–215	1995

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CHEMICAL COMPOSITION OF EARTHWORM CASTS IN DIFFERENT HABITATS OF POLAND

ABSTRACT: Earthworms deposited on soil surface from 2.7 to 19.3 kg dry mass casts per m^2 in different habitats of the Masurian Lakeland in a wet year of 1984. These casts were characterized by pH about 6.4 and C/N close to 10.3. They were markedly enriched with nitrogen, phosphorus and potassium forms readily available to plants, and with exchangeable cations. The enrichment of casts with calcium occurred in habitats with soil pH lower than 6, enrichment with phosphorus was high in habitats with low contents of this nutrient (0.8–1.6 mg P_2O_5 x 100^{-1} g soil) and lower in others. Rich in nutrients were casts from areas where dung was the source of food for earthworms.

KEY WORDS: earthworms, casts, chemical composition.

1. INTRODUCTION

There is a large body of literature on earthworm casts, although not totally consistent. It is known that the contents of nitrogen, phosphorus, and exchangeable cations typically are higher in casts than in the surrounding soil (Edwards and Lofty 1972). It is also known that these nutrients are in the form readily available to plants (Syers et al. 1977, Sharply and Syers 1979, Kale and Krishnamorthy 1980), and even that casts contain growth substances of plants (Nielsen 1965, after Syers and Springett 1983). A rapid growth of industrial earthworm cultures rises interest in the possibility of applying casts as fertilizer. In this situation, conclusions based on comparing data on chemical properties of casts in different habitats can prove to the useful.

The objective of the paper is an analysis of chemical composition of earthworm casts, and comparison of the results with those of similar earlier studies (Czerwiński et al. 1974, Pętal et al. 1977).

2. STUDY AREA AND METHODS

The study was conducted in the Masurian Lakeland. Soils of these areas belong to typical brown soils derived from boulder clay with admixture of sand. There were four study sites: (1) 5-ha pasture located in a large (over 100 ha) complex of pastures owned by a farm specialized in cattle breeding (State Agricultural Farm). These areas were fertilized and sown with timothy grass (*Phleum pratense* L.); (2) a 0.6-ha fresh meadow of the order Arrhenateretalia. As this meadow was not managed, it was subject to succession, and invaded by seedlings of willows and alders; (3) a young, about 50-years-old alder wood invading old pastures; and (4) a largely transformed lime-hornbeam forest. In addition to hornbeams, also a lime alley was preserved. Elders were growing in the shrub layer, and *Aegopodium podagraria* L., *Galeobdolon luteum* Huds., and *Urtrica dioica* L. in the herb layer.

Numbers of earthworms were estimated using the formalin method (Satchell 1969). Each 0.25-m^2 sample was flooded with 9 l of 0.3% formalin three times. Ten such samples were taken at a time. Casts were collected from ten 250 cm^2 metal rings permanently present at each site. Each month they were collected four times at two-day intervals, dried to a constant weight, and weighed. Chemical analyses comprised estimates of the content of organic carbon using the Tiurin method, total nitrogen by the Kiejdahl method, phosphorus and potassium available to plants by the Egner-Rhiem method, exchangeable cations by the photometric method, and pH in H_2O by the electrometric method. Chemical analyses of soil were made by averaging the results from three subsamples taken from one, mixed soil sample. Differences among samples taken in this way did not exceed 0.01.

The chemical composition of casts collected in the field was compared with that of cultured earthworms. The cultured earthworms were kept in plastic 2-l containers filled with sift soil. These were 5 *Lumbricus terrestris* L. or 10 *Aporrectodea caliginosa* Sav. individuals per container. They were supplied with grass turned yellow taken from the study meadow, or with fallen alder leaves, or with cattle dung after one day-exposure on the pasture. Casts were collected once a week four times in each diet variant.

3. RESULTS

The material from earthworm cultures was used to analyse differences in the chemical composition of casts between *L. terrestris* and *A. caliginosa*, and also among three different diets of *L. terrestris* (Table 1). In all casts, the percentage of organic carbon was a little higher than in the soil used in the culture, whereas the percentage on nitrogen was lower (consequently, C/N ratio was higher). Among exchangeable cations, the content of potassium was higher, whereas the contents of calcium, sodium and magnesium were lower. Only reduction in the contents of Ca, Na, and Mg was statistically significant ($p < 0.1$). The results for C, N, and K, although not significant, were consistently lower in all experiments. Similarly, differences in the chemical composition of casts of *L. terrestris* and *A. caliginosa* were not significant. In the experiment with different diets, only casts of earthworms fed on cattle dung significantly differed in their chemical composition from those earthworms fed on grass or leaves – they had the highest contents of C, N, and K.

Table 1. Chemical composition of casts of cultured earthworms
Exchangeable cations (in mg 100 g^{-1} soil)

Parameters	C (%)	N (%)	C : N	K	Ca	Na	Mg
Control soil	1.10	0.115	9.6	11.5	102	8.8	11.0
			Casts				
L. terrestris	1.26	0.096	13.1	12.0	53.6	4.2	5.3
SD (n = 9) ±	0,06	0.007		0.8	3.5	0.5	0.9
A. caliginosa	1.24	0.101	12.3	12.5	66.0	5.7	6.0
SD (n = 3) ±	0.14	0.020		1.9	16.4	1.5	3.4
			Casts *L. terrestris*				
Diet : leaves	1.21	0.095	12.7	11.2	69.3	5.5	6.2
SD (n = 3) ±	0.17	0.018		1.0	19.0	1.9	4.5
Grass	1.23	0.091	13.5	12.0	46.7	3.7	4.0
SD (n = 3) ±	0.05	0.026		1.7	6.4	0.4	2.1
Dung	1.35	0.109	12.5	15.5	5.2	4.8	8.0
SD (n = 3) ±	0.21	0.003		1.4	1.3	1.1	3.3

A comparison was made of the mean content of nutrients in the top soil layer (0–5 cm) and in casts collected from four sites of the Masurian Lakeland (Table 2). In almost all samples, casts were richer in nutrients than the surrounding soil. This was the case of organic carbon and potassium, as well as nutrients the contents of which were reduced in the casts of cultured earthworms, that is, nitrogen, magnesium, and sodium. Only the content of calcium in casts from the three sites, except from the lime-hornbeam site, was lower than, or equal to its content in the soil (Table 2).

Differences in chemical composition between the casts and the soil varied from site to site. Casts from the meadow with low contents of carbon and exchangeable cations (except for calcium) were most enriched with carbon and potassium available to plants. In the pasture, the content of Ca in casts was reduced, and the content of other nutrients was increased. The most pronounced

Table 2. Chemical composition of casts collected from habitats of the Masurian Lakeland
s – soil (0–5-cm layer), c – casts; (exchangeable cations in mg 100 g^{-1})

Elements and compounds	Pasture A		Meadow B		Alder wood C		Lime-hornbeam forest D	
	s	c	s	c	s	c	s	c
C (%)	2.20	2.98	1.96	4.02	4.84	5.20	1.56	2.47
N (%)	0.161	0.275	0.201	0.315	0.502	0.541	0.193	0.291
K	20.5	24.0	15.5	19.0	11.7	12.3	16.5	20.0
Ca	82	68	164	164	282	267	50	82
Na	3.6	3.6	6.4	6.8	10.4	10.7	2.4	4.4
Mg	6.5	10.3	6.5	12.2	11.3	13.1	4.5	10.6
P_2O_5	29.0	48.5	12.2	16.5	11.5	14.2	15.0	21.0
K_2O	34.7	43.5	2.0	20.0	8.0	10.0	9.5	18.2

changes were observed on the lime-hornbeam site, which was the poorest one; the content of all exchangeable cations was high, and the content of K_2O in casts was twice that in the soil. In the alder wood, the most fertile habitat, percentage differences in chemical composition between the casts and the soil were lowest.

In the alder wood, also seasonal changes in the composition of casts were observed (Table 3). Over the study period, differences in the carbon content in soil were 1.4% and in casts 1.7%. The respective figures for nitrogen were 0.21 and 0.11%. The contents of K_2O in the soil and the casts differed by a factor of 2. The value of C/N is an indicator of the decomposition of organic matter. That is why it decreased in both the soil and the casts from May to September (as litter decomposition proceeded) and slightly increased in October with the appearance of new litter fall. The direction of changes in C/N in the casts implies that in May earthworms consumed heavily decomposed alder litter. In September, the availability of this food was likely to be reduced and earthworms fed on more decomposed organic matter. C/N was reduced to 9.1 and increased again at the beginning of the autumn leaf fall.

Table 3. Seasonal changes in chemical composition of casts in the alder wood
Explanation as in Table 2

Months	C (%)		C : N		K_2O		P_2O_5	
	s	c	s	c	s	c	s	c
May	5.25	5.94	10.3	11.4	8	10	12.9	12.2
June/July	4.84	5.20	9.4	10.2	8	10	11.5	14.2
August	5.02	5.32	8.8	10.2	4	10	15.5	14.2
September	5.28	4.74	8.7	9.1	5	12	10.2	15.8
October	6.18	6.43	9.4	10.2	8	20	19.1	23.8

The dynamics of casts decomposition is shown in Figure 1. The highest rate of cast deposition typically occurred at the end of June, and there was no a straightforward correlation between this rate and numbers of earthworms, or factors affecting their activity, such as temperature and sum of precipitation.

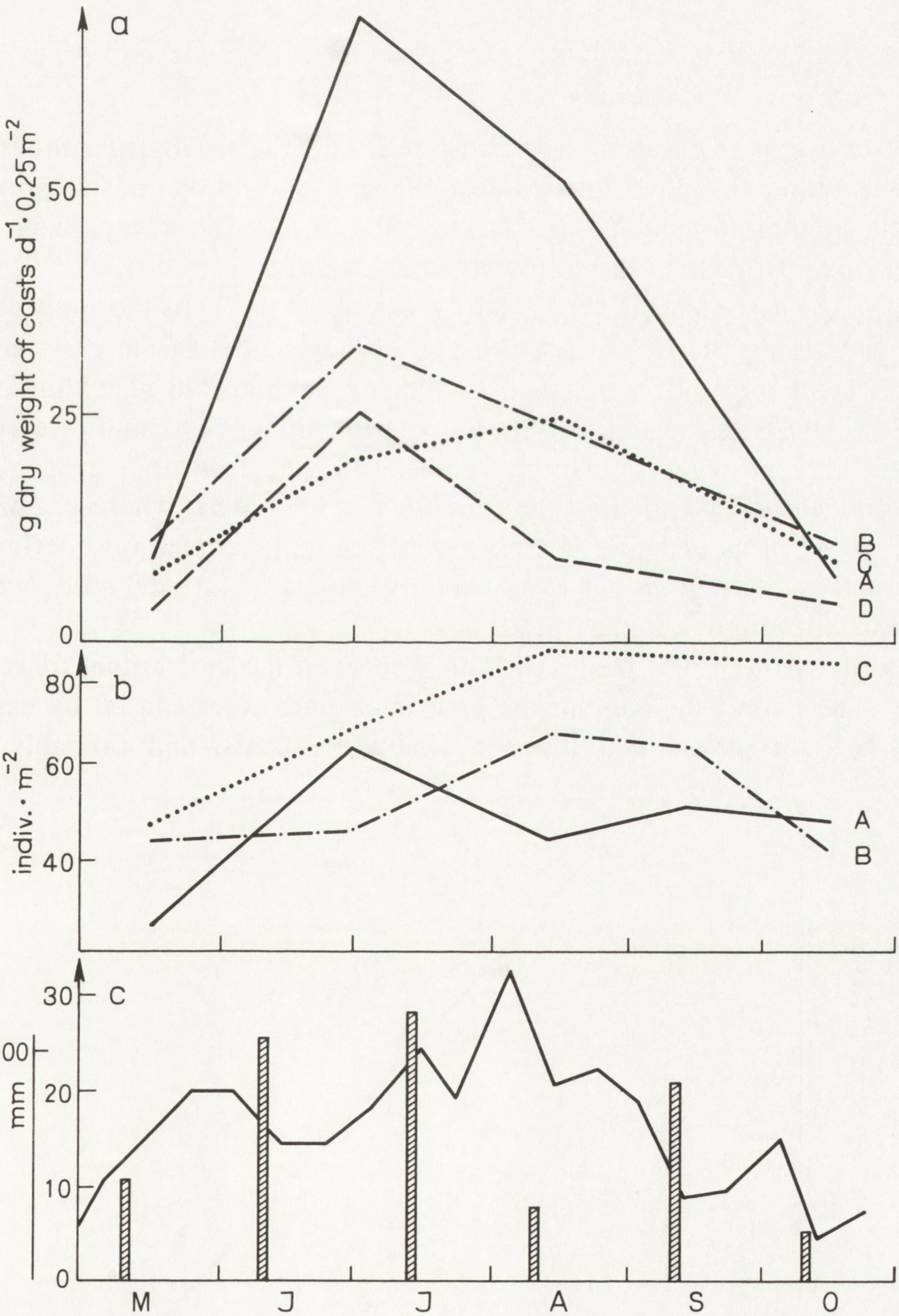

Fig. 1. Dynamics of surface casting of earthworms in several habitats of the Masurian Lakeland, compared with temperature and precipitation
A – pasture, B – meadow, C – alder wood, D – lime-hornbeam forest, a – seasonal changes in cast weight, b – dynamics of earthworm numbers (indiv. m^{-2}), c – mean temperature of 10-day periods in °C and monthly sum of precipitation in mm

After multiplying the mean daily mass of casts deposited on the surface by the length of seasonal earthworm activity (6 months) we will get the following amounts of casts: 19.3 kg dry wt per m^2 per season in the pasture, 10.8 kg in the meadow, and 2.7 kg in the lime-hornbeam forest.

4. COMPARISON OF DATA FOR NINE HABITATS

The results of this study were compared with the results of similar studies conduced on three meadows located near Warsaw, and on two pastures located in the Small Pieniny Mountains (Pętal et al. 1977). The comparison of nine habitats (Table 4) leads to the following conclusions:

The pH of casts tends to 6.4, and C/N is about 10.3. In the hind part of *L. terrestris* intestines, pH is 6.6 (Laverack 1963), so pH of the casts is similar. In the habitats compared, the casts pH averaged 6.4 and ranged within 1.6 units. Changes in the pH of the soil passing through the alimentary canal of earthworms increased with growing deviation of the soil pH from 6.6 (Fig. 2). This relationship can be described by the formula $y = 3.5 - 0.5x$, where y – difference between pH of casts and pH of soil, x – pH of soil; correlation coefficient $r = -0.78$, $p = 0.01$. Change in pH is particularly important for acid soils, where this factor can limit microbiological processes.

A similar pattern was observed with respect to the enrichment of casts with nutrients. The poorer the habitat, the greater changes were caused by casts. This was the case of phosphorus forms available to plants, and probably also of

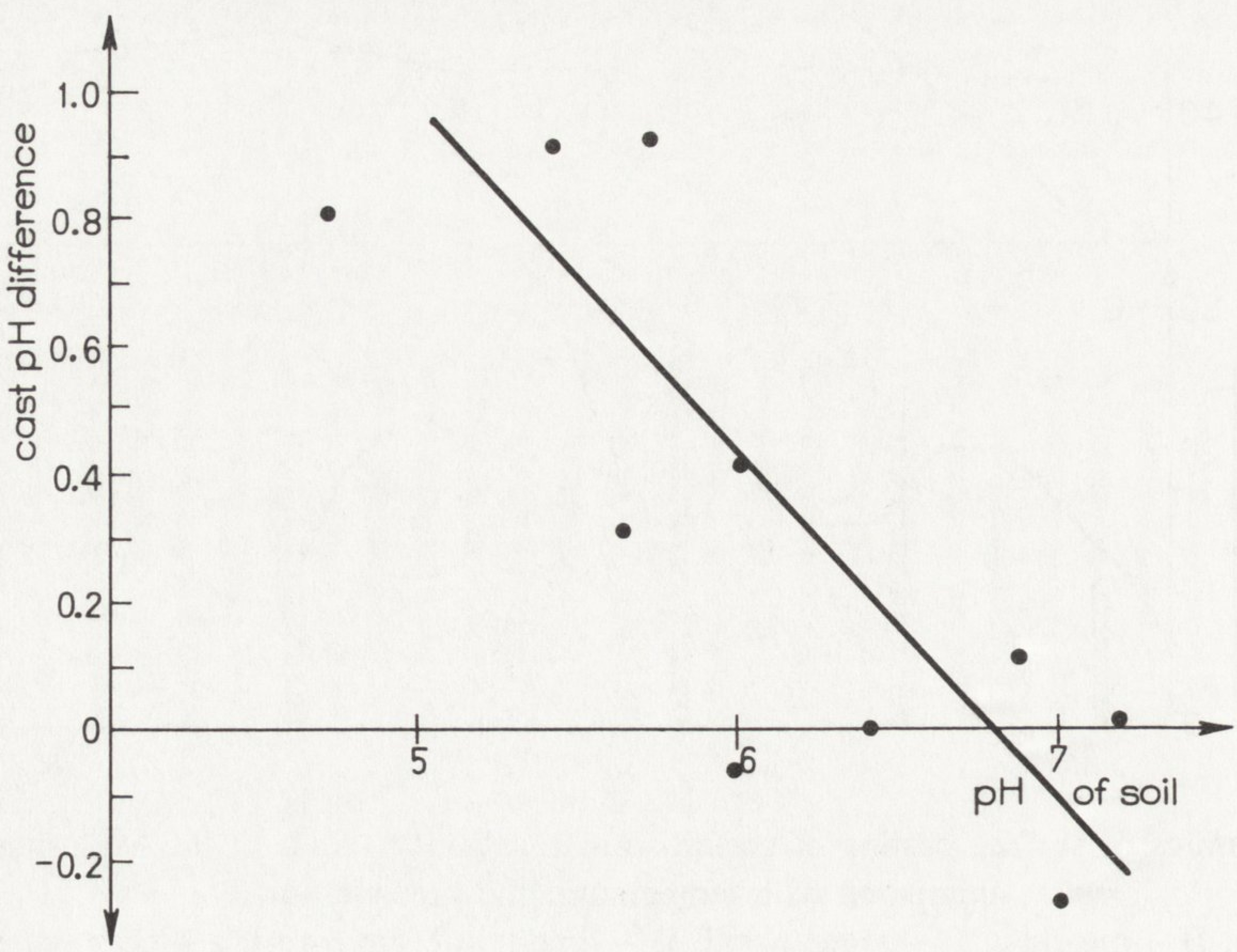

Fig. 2. Relation of changes in the acidity of casts to the acidity of surrounding soil (measured as a difference between cast pH and soil pH)

potassium (Fig. 3). The correlation between the content of this form of phosphorus in casts and in the soil was not statistically significant, but another relationship can be observed. In habitats poor in phosphorus, containing 0.8–1.6 mg P_2O_5 x 100 g^{-1} soil, its content in casts increased by a factor of 4 to 17 (Table 4). In the remaining habitats, where P_2O_5 content in soil ranged from 11.5 (or even from 6.6 mg, Czerwiński, unpublished data) to 33.2 mg 100 g^{-1} soil, the increase of its content in the casts was 23–67%. The relationship between the phosphorus content in the soil and in the casts can be described by the formula log y = 2.0054 – 0.60x, where y is the ratio of P_2O_5 content in casts to its content in soil, and x is P_2O_5 content in soil in mg x 100 g^{-1} ($p = 0.01$, $r = -0.90$). The enrichment of casts with K_2O was less pronounced. Its content was from 1.3 to 7 times that in soil, and the correlation was not significant. As the content of nutrients in casts did not seem to tend to a constant values, it is probable that the diet of earthworms was changed. Characteristically, those very high contents of both phosphorus (increase by a factor of 10, from 1.3 to 13.4 mg x 100 g^{-1} soil) and potassium (7-time increase from 9.4 mg to 64 mg x 100^{-1} soil) occurred in the pasture. Presumably, the additional source of these nutrients was dung supplementing the diet of earthworms.

Among the exchangeable cations, calcium behaved in a different way than other nutrients. Its content in casts was often lower than in the soil. It was so because earthworms use this nutrient to neutralize body liquids. In the study habitats, the content of calcium increased at pH 5.4 and 5.6, whereas in more alkaline habitats, Ca content did not change or it decreased.

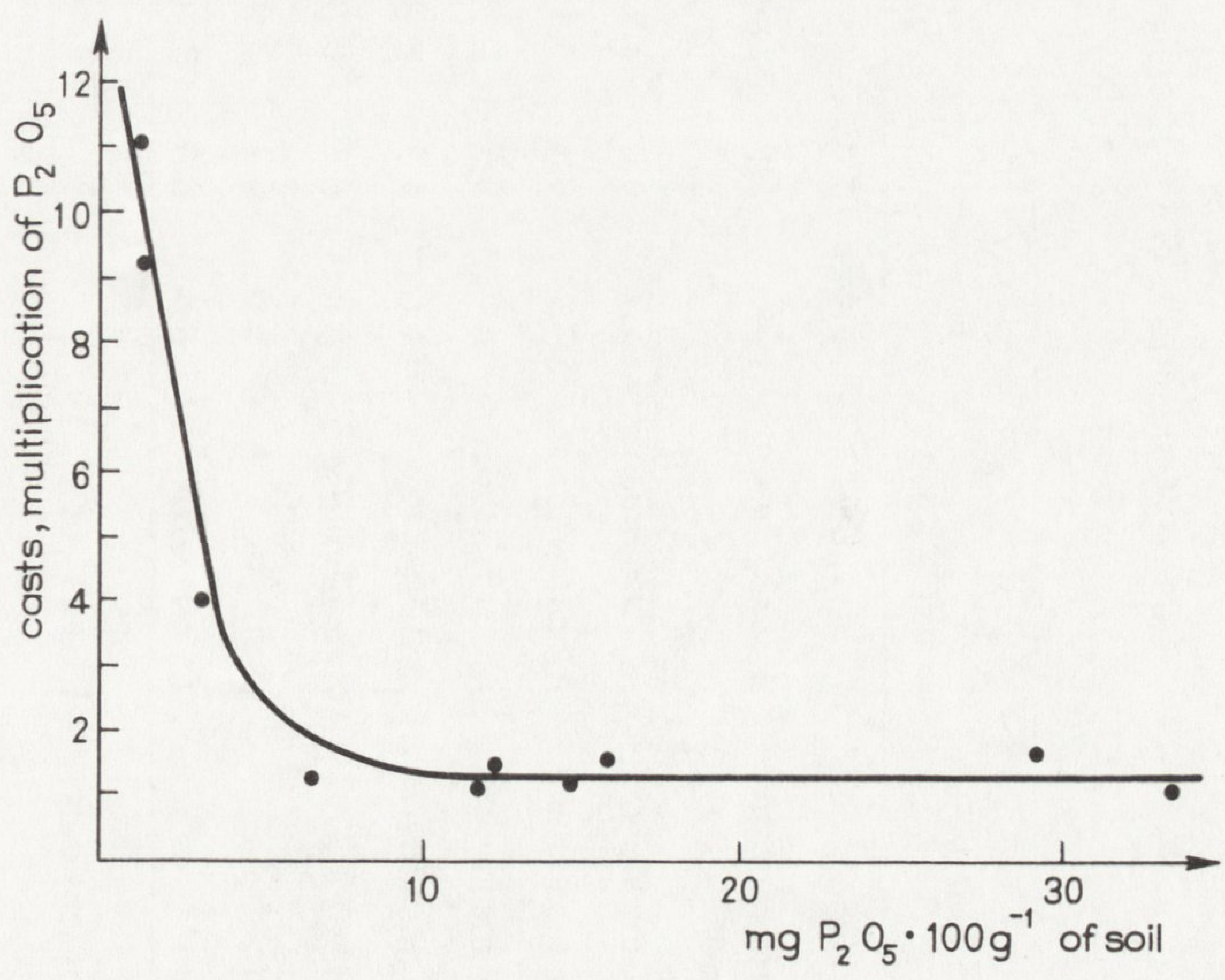

Fig. 3. Relationship between P_2O_5 contents in soil and in casts expressed as a multiplication

Table 4. Comaprison of the chemical composition of casts in several habitats of Poland
Explanations as in Table 2

Habitat	Dominant species	pH		C (%)		N (%)		C : N		P_2O_5		Ca	
		s	c	s	c	s	c	s	c	s	c	s	c
Alder wood*	*L. terrestris*	6.9	7.0	4.84	5.20	0.50	0.54	9.3	9.6	11.5	14.2	262	267
Lime-hornbeam forest*	*A. caliginosa*	5.6	5.9	1.56	2.47	0.19	0.29	8.1	8.5	15.0	21.0	50	82
Fresh meadow**	*A. caliginosa*	5.7	6.6	1.93	3.80	0.22	0.36	8.8	10.5	1.3	13.4		
Fresh meadow**	*A. caliginosa*	7.1	7.1	3.31	3.65					33.2	35.6		
Fresh meadow**	*A. caliginosa*	4.7	5.5	2.33	3.49					15.6	26.0		
Fresh meadow*	*A. rosea*	7.0	6.7	1.96	4.02	0.20	0.32	12.8	9.8	12.2	16.5	164	164
Pasture*	*A. caliginosa*	5.4	6.3	2.70	4.82	0.28	0.48	9.6	10.0	0.8	8.7	188	220
Pasture**	*A. rosea*	6.0	6.4	2.59	4.84	0.31	0.46	8.3	10.4	1.6	6.6	304	270
Pasture**	*L. terrestris*	6.4	6.0	2.20	2.90	0.16	0.28	13.7	10.8	29.0	48.5	82	68

*Present data. ** Pętal et al. 1977.

The contents of the remaining exchangeable nutrients increased in casts various rates. This process was probably affected by the rate of leaching.

In the material presented here, different species of earthworms predominated (Table 4), but this had no effect on the chemical composition of casts. Chemical composition of the soil itself was most important. Additional food resources available to earthworms on the pastures dung had a similar effect on the chemical composition of casts, although different earthworm species predominated in these habitats.

5. DISCUSSION

Chemical analyses were made by using standard methods applied in agriculture. This ensured the utility of the results but, on the other hand, only gross changes could be analysed. The culture was primarily developed to learn how to distinguish between casts of two earthworm species in the field. This failed, however, it is easy to identify cast-stoppers closing entrances to large corridors of *L. terrestris*, but casts of young individuals of this species and of other earthworm species remained indistinguishable.

The weight of the casts collected in the field was probably overestimated, as the removal of a cast-stopper must stimulated production of another one to maintain suitable microclimate in the corridor.

The results from the earthworm culture and from the field data support the earlier suggestions (Edwards and Lofty 1972) that casts are not always richer in minerals than the surrounding soil. Presumably, such enrichment does not take place at low nitrogen content and a high utilization of this nutrient for growth of organisms, as it was the case in the culture.

Earthworms used in the experiment different in their habitat and food preferences. *L. terrestris* occur deep in the soil but they feed on litter, whereas *A. caliginosa* live and feed in the soil. In the culture, both these species had to use the same food. In this situation, no clear differences were found in chemical composition of their casts, except that casts of *L. terrestris* had slightly lower contents of nitrogen and exchangeable cations than those of *A. caliginosa*. This implies a higher utilization of nutrients by *L. terrestris* (and indirectly indicates that the food supplied in the experiment was proper for this species).

Lack of significant differences in chemical composition of casts between the two species in combination with the fact that change in diet accounted for differences, provide evidence that diet has a greater effect on the quality of casts than species-specific differences in physiology.

Seasonal differences in the composition of casts (Table 3) were related to changes in the rate microbiological processes in the habitat (Kozlovskaja 1965) and also to changes in the diet of earthworms, which in turn was related to differences in food availability.

The weight of the casts collected in the Masurian Lakeland is large compared to that known from the literature. The highest values are similar to those found in Britain (Edwards and Lofty 1972), and the lowest values noted in the lime-hornbeam forest are only slightly lower than those found in fertile, abundant in earthworms pastures of the Pieniny Mountains (Czerwiński et al. 1974).

The weights of casts and their chemical composition compared to those of the soil were such that a difference of 0.1% in nitrogen content between casts and the top soil layer corresponded to 190 kg ha^{-1}, that is, to the nitrogen input at a high rate of mineral fertilizing. This nitrogen mass is added gradually, with a highest rate in the middle of the growing season, that is, in June. The utilization of nitrogen supplied in this way can be much efficient than when it is supplied in a single dose. This is also the case of the addition of other nutrients, and the figures obtained in this study emphasize the importance of earthworms in restoring nutrients in the upper soil layer.

6. SUMMARY

The weight of casts deposited by earthworms on the soil surface of four habitats in the Masurian Lakeland ranged from 2.7 kg dr wt per m^2 per season in the lime-hornbeam forest to 19.3 kg dr wt per m^2 on the pasture. Typically, casts were deposited at a highest rate in June (Fig. 1). The chemical composition of casts in the earthworm culture depends on the diet. If dung is the source of food, the contents of C, N, K, and Mg are higher in casts than in the surrounding soil, whereas the content of Ca is lower (Table 1). The study habitats differed with respect to differences in chemical composition between casts and the surrounding soil. These differences were largest in the poorest habitat, that is, in the lime-hornbeam forest (Table 2). Chemical composition of casts, and especially the decomposition index C/N showed seasonal variation (Table 3).

Analogical data from the Small Pieniny Mountains and from region of Warsaw also show that changes caused in the habitat by earthworm casts are increasingly better pronounced with declining habitat fertility (Table 4). Changes in pH can be described by the formula $y = 3.5 - 0.5x$, where y is difference between pH of casts and pH of soil, and x is pH of 0–5-cm soil layer (Fig. 2). The content of P_2O_5 varies according to the formula $\log y = 2.0054 - 0.6x$, where y is the ratio of phosphorus content in casts to its content in soil, and x is the content of phosphorus in soil (in mg x 100 g^{-1} soil) (Fig. 3). Enrichment of casts with calcium occurred only in habitats with pH > 5.6, and their C/N was about 10.3.

7. POLISH SUMMARY

Ciężar koprolitów wydalanych przez dżdżownice na powierzchni gleby w czterech siedliskach Pojezierza Mazurskiego wynosił od 19,3 kg s.m. m^{-2} na sezon na pastwisku do 2,7 kg s.m. m^{-2} w grądzie. Koprolity na ogół najintensywniej odkładane były w czerwcu (rys. 1). W hodowli skład chemiczny koprolitów zależy od rodzaju podawanego pokarmu. Jeśli dżdżownice karmi się nawozem, koprolity wykazują wyższą niż otaczająca gleba zawartość C, N, K i Mg, a niższą zawartość Ca (tab. 1). W każdym z badanych siedlisk odmienne były różnice między składem chemicznym koprolitów i otaczającej gleby – największe w najuboższym siedlisku, czyli w grądzie (tab. 2). Skład chemiczny koprolitów, a głównie wskaźnik rozkładu C/N, zmienia się w czasie sezonu (tab. 3).

Z porównania przytoczonych danych z analogicznymi danymi dla Małych Pienin i okolic Warszawy wynika także, że zmiany spowodowane w siedlisku przez koprolity są tym silniejsze, im uboższe jest siedlisko (tab. 4). pH zmienia się zgodnie z równaniem y = 3,5 – 0.5x, gdzie y = pH koprofitów, x to pH 0–5 cm warstwy gleby (rys. 2), zawartość P_2O_5 zgodnie z równaniem log y = 2,0054 – 0,6x, gdzie y jest równe stosunkowi zawartości fosforu w koprolitach do jego zawartości w glebie, a x – zawartości fosforu w glebie (w mg x 100 g^{-1} gleby) (rys. 3). Wzbogacanie koprolitów w wapń następuje tylko w siedliskach o pH powyżej 5,6, ich wskaźnik C/N jest bliski 10,3.

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(*Received after revising 20 February 1995*)