CENTRUM VOOR AGROBIOLOGISCH ONDERZOEK

Wageningen

THE EFFECT OF EARTHWORMS (LUMBRICIDAE) AND "GRASS SICKNESS" ON THE PRODUCTIVITY OF GRASSLAND.

M. Hoogerkamp

CABO-verslag nr. 52

1984

Contents page

1 INTRODUCTION

Young grassland is frequently considered more productive than old grassland (e.g. Ahlgren, 1952; Garstang, 1978 and Hoogerkamp, 1974). This is partly so, because in the comparisons of old and young grasslands, young grasslands were used with a better botanical composition and a better fertilizer status than the old grasslands.

In our research a study was made to see if such differences in productivity also occur, if both types of grassland have a good botanical composition and both are well-managed. However, in these comparisons young reseeded grassland should be distinguished from young grassland sown after other crops. The differences that may occur are e.g. in the organic matter content of the soil, in the risk of the occurrence of rotation problems ("grass sickness") and those in the size of the earthworm population. Alternating grassland with arable crops may reduce all three aspects.

In earlier research (Hoogerkamp, 1974) suggestions were obtained that rotation diseases and pests ("grass sickness") might be important. Therefore more research was done under controlled conditions (glass-houses and growth chambers) and in the field. Furthermore, data collected for other purposes were tested on this hypothesis.

Possible "grass sickness" problems can be reduced by applying crop rotation and if diseases and pests are involved, by applying chemical products against the causing organisms. However, both these methods can reduce the earthworm population.

Few data are available on the effect of earthworms on the agricultural value of grassland. In the new IJsselmeerpolder O. Flevoland, where earthworms were hardly present in the grassland, this aspect was studied.

2 PURPOSE AND DESIGN OF THE STUDY

2.1 Effect of the preceding crop

Although crop rotation diseases and pests are well-known in most arable and horticultural crops, little is found about these problems in the grassland literature; legumes excepted. Grassland even is quoted as one of the crop examples in which these problems do not occur. Often the rotation with arable crops is considered harmful to grassland (Arens, 1971 and Klapp, 1954).

However, the mycological, entomological, nematological and physiological literature mentions all kind of diseases, pests and other damages of grasses, which might be decreased by crop rotation (e.g. Cook & York, 1980; Couch, 1962; Dwarshuis, 1975; Sampson & Western, 1954 and Turgeon, 1982).

Earlier findings of Hoogerkamp (1974) indicated that crop rotation problems in grassland were involved.

In the present research the problem of "grass sickness" was studied in various ways:

a) by comparing the productivity of young reseeded with that of old grassland; both with a good botanical composition (mostly field experiments);
b) by comparing the productivity of young grassland sown in arable soil with that of grassland sown in grassland soil (pot and field experiments);
c) by comparing the productivity in the first and in the second year (and sometimes more years) of grassland sown in arable soil and in grassland soil.

The greatest difficulty in this study was to separate the negative effects of arable crops as a preceding crop to grassland (lower organic matter content and reduced earthworm activity) from positive effects, if any.

Reseeding of grassland : reseeding was always started from grassland with a good botanical composition (mainly *Lolium perenne*). The old grass sward was usually destroyed with a rotavator (depth some 12 cm); immediately afterwards *Lolium perenne* was sown. Comparable old grassland was always present. On one experimental field (E12) direct-reseeding was compared with sowing after a fallow period of three months. A pot experiment was done with grassland soil, which before sowing was kept for 0, 8, 15, 29 en 57 days at 12^{o}C or 20^{o}C.

Sowing after arable crops : the effect of arable crops as a preceding crop to grassland was studied in different ways: a) by testing the findings collected for other purposes; b) by the layout of experimental fields with different rotations and c) by growing grass under more or less controlled conditions (glasshouses and growth chambers). In these latter experiments Mitscherlich pots or plastic pots (contents 7 and 1.3 l and heights 21 and 11.6 cm, respectively) were filled with soil from arable fields and grassland fields (usually from the layer 0-10 cm) situated near each other. In total 21 of these experiments were done. Sometimes more than two fields were compared per experiment. Besides differences in the preceding crop, other variables were included in the different experiments: temperature, depth of sowing, moisture content, fertilizer N, fertilizer K, addition of sod rests, grass species and varieties of *Lolium perenne*. In these pot experiments *Lolium perenne* was mostly used.

To study the underground plant parts often some additional pots were included, of which the plants were rinsed at the relevant time. Sometimes, however, plastic tubes were used. These tubes were made of transparent plastic, 50 cm long and with a cross-section of 3.5 x 3 cm^2; they were covered with black plastic and placed at an oblique angle, so that root growth could be followed at one side.

Effect of nematicides with or without fungicides: in various experiments indications were obtained that especially nematodes and to a less extent fungi were involved in the present crop rotation problems. In five pot experiments and on eight experimental fields fungicides or nematicides were applied. The relevant pesticides were usually applied before sowing the grass seed and, if possible, incorporated in the soil (some 12 cm).

Table 1 gives a short description of the experimental fields.

Table 1. Details of the experimental fields; z = sandy soil; kl = clay soil; n = nematicide; f = fungicide; g = grass; m = maize; zk = summer oilseed rape; bk = forage rape; afr = marigolds; y. = year. The number of replicates was mostly 4.

Exp.no. and soil type	date (re)seeding	preceding crop(s)	pesticides applied[4]	N fertilizer (kg N ha^{-1} per year 1st year	2nd year
E 1 (z)	69-09-05[1]	g	-	219/275/320	200/274/341
E 2 (z)	69-09-05[1]	g	-	101/126/176	59/129/204
E 3 (z)	77-09-07	g	1n/2f/1n+2f	100/200/400/600	90/180/360/540
E 4 (z)	79-09-21	g	1n/1f/1n+1f	94/188/376/564	105/210/420/630
E 5 (kl)	76-09-24	g	1n+2f/1n	441/604	520/715
E 6 (kl)	78-10-10	g	1n+2f/1n	300/413	-
E 7 (kl)	76-09-24[2]	g	1n+2f	-	139/332
E 8 (kl)	78-10-10	g	1n+2f	127/320	-
E 9 (z)	78-11-03[3]	g	1n	-	-
E 10 (z)	76-03-23	2y.m	-	131/173/217/256	125/231/342/440
		1y.g/1y.m	-	131/173/217/256	125/231/342/440
		2y.g	-	131/173/217/256	123/231/342/440
E 11 (z)	76-03-23	2y.m	-	131/173/217/256	125/231/342/440
		1y.g/1y.m	-	131/173/217/256	125/231/342/440
		2y.g	-	131/173/217/256	125/231/342/440
E 12 (z)	79-09-26	g	1n+1f	420	-
		zk[5]	-	420	-
		bk[5]	-	420	-
		afr[5]	-	420	-

[1] reseeding repeated on 70-08-21; [2] the same on 77-04-27; [3] reseeding failed; [4] fungicides: captafol and thiram; nematicides: aldicarb and oxamyl; [5] interim crops on grassland for three months.

The experimental fields E3, E4 and E12 were only mown, the other experimental fields were mostly grazed.

2.2 Effect of earthworms

Old grassland usually has a well-developed soil fauna, for both the number of species and the total number and biomass; earthworms (Lumbricidae) with respect to weight often forming the major part of it in W. Europe (Dunger, 1964; Tischler, 1955a and 1955b and Voisin, 1960). Eijsackers (in: Hoogerkamp et al., 1983) reports as an average for old grassland some 500 specimens per m^2 and 2500 kg biomass per ha. Doeksen (1969) mentions some 200 per m^2 and a live weight of 2000 kg ha^{-1} as normal, Klapp (1971) reports as an average for productive grassland 400 specimens per m^2 and a biomass of 1000-2000 kg ha^{-1} and Tischler (1955b) 200-300 specimens per m^2. However, wide differences may occur both spatially and temporally.

Earthworms may have an effect on the productivity of grassland. This is especially so, when the effect of anthropogenous soil tillage carried out before sowing is no longer active.

Although much work has been done on the effect of earthworms on soil fertility (e.g. Edwards & Lofty, 1977 and Satchell & Martin, 1981), there are relatively few experiments in which the influence of earthworms on the agricultural quality of grassland was demonstrated. In New Zealand where the relevant, benificial species were lacking most findings have been collected and reported.

In the new IJsselmeerpolders an opportunity occurred to study the effect of earthworms on grassland. In these polders earthworms hardly occurred in the first years after reclamation.

For this reason earthworms were inoculated patchwise in a number of fields. The grasslands involved were situated on a field of a private farm near the border of O. Flevoland (Biddinghuizen) and on farms used by agricultural institutions near Lelystad and Swifterbant. On the former field about 3000 earthworms were inoculated in a spot of some dm^2 in the spring of 1971, by the staff of what used to be ITBON (now RIN) at Arnhem; i.e. 2790 Allolobophora caliginosa and 244 Lumbricus terrestris. On the other fields usually some 10.000 earthworms were inoculated per ha in spots varying from 1/4-1 ha; this was done in 1971 and successive years and Lumbricus rubellus was mainly used, together with rather many Allolobophora caliginosa and some specimens of Lumbricus terrestris and Allolobophora longa. In the period 1976 - 1983 the effect was studied in more detail of earthworms on grassland in a number of these fields, mainly those situated on the "ir A.P. Minderhoudhoeve" at Swifterbant.

The soil of the experiment at Biddinghuizen was a light, very fine sandy loam soil; that of the experiments near Lelystad and Swifterbant a light clay soil. The grassland was mainly intensively used (3-4 LSU ha^{-1} and 300-550 kg fertilizer N ha^{-1}).

The relevant fields were sown in the years 1970 en 1971 with a Lolium perenne dominant grass seed mixture (54% Lolium perenne, 14% Festuca pratensis, 16% Phleum pratense and 16% Trifolium repens or 62% Lolium perenne, 18% Festuca pratensis and 20% Phleum pratense). In the first years this seeding resulted in a sward mainly (80-85%) consisting of Lolium perenne, with some (5 to 10%) Phleum pratense and some (5%) Festuca pratensis.

On a number of these fields the botanical composition and bearing capacity were noted. The gross yields were measured on four fields and two fields in 1981 and 1982, respectively. In 1982 four N-fertilizer levels were applied (0, 135, 270 and 405 kg ha^{-1} per year).

Moreover, a pot experiment was carried out in 1981 in which Mitscherlich pots were filled with about 5.16 kg of soil from the layer 0-20 cm; on the treatment without earthworms, including the mat (A0-layer). The earthworms were removed from the soil with a screen 0.7 cm mesh size. The mat and roots were clipped and mixed through the soil; the above-ground parts of the grass were removed. The pots were dressed with phosphate and potassium and sown with Lolium perenne. Four fertilizer N levels were applied, corresponding with 0, 100, 300 and 500 kg N ha^{-1}; these amounts were divided into four equal dressings which were successively applied at sowing and immediately after harvesting the first three cuts. The grass was harvested once a month (cutting height 2 cm); at the last harvest the stubble and root weights were also measured.

In 1981 the C and N contents were measured in the layers 0-2, 2-5, 5-10 and 10-20 cm in two fields and in the treatment without earthworms also in the mat layer; this was done after the methods of Kurmies and Kjeldahl, respectively. The soil was sieved before the relevant analysis; the mesh size was 2 mm. In one of these fields the volume weights of the soil were also measured in the layers 0-5, 5-10 and 10-20 cm.

General

When the field experiments were grazed all the treatments and variants mostly were available to the cattle at the same time and together. When the field was cut, the whole experimental field was cut on the same day. The yields were measured by cutting strips with a mowing machine just before pasturing the cattle or just before cutting; sometimes the strips were protected by cages against grazing animals. The following variables were measured: fresh grass yield, dry matter yield with or without the crude protein yield (= N-Kjeldahl x 6.25).

The botanical composition of the grass sward was recorded in several ways: the number of tillers per 0.25 dm^2 (about 50 samples), the frequency of species (about 100 samples of some 0.25 dm^2 each), or the dry weight percentages (one sample mostly composed of about 50 subsamples) (De Vries, 1949). Sometimes the coverage of the soil (by the separate species) was estimated in the field or established by the point quadrat method.

In the pot experiments, at a number of times after sowing, the number of seedlings, the number of leaves per plant, the length of the plants, the length of the longest primary and secondary roots, root weight (dry and fresh), with or without the shoot weight (dry or fresh) were measured. These variables were also measured in some of the field experiments.

3 RESULTS

3.1 Reseeding grassland with a good botanical composition

On most experimental fields a closed grass sward was obtained, mainly consisting of Lolium perenne. On E_1, E_2, E_7 and E_9 the (first) resowing was a failure. The grass sward on E_7 was almost entirely destroyed by larvae of the frit fly (Oscinella frit) and on E_9 the young grass sward was killed off by frost (sown on 3 November). On E_1 and E_2 the first reseeding failed, because of reasons unknown.

On most of the experimental fields and also as an average the gross dry matter yields in the first year, were somewhat lower of the reseeded grassland than those of the old grassland (Table 2).

Table 2. Gross dry matter yields (t ha^{-1}) on the old (=O) and on the young grassland in the first year after reseeding (=H). If different letters have been placed behind comparable yields the differences are significant.

			N-fertilizer level									
			N1		N2		N3		N4		Average	
			O	H	O	H	O	H	O	H	O	H
E 1		1971	7.0	6.0	7.5	6.9	7.3	7.0			7.3 (a)	6.6 (a)
E 2		1971	6.1	5.8	7.4	6.6	8.1	7.3			7.2 (a)	6.6 (a)
E 3	autumn	1977[1)]	1.3	-	1.1	-	1.1	-	1.0	-	1.1	-
		1978	8.9	7.0	9.6	9.4	12.8	12.8	12.9	14.0	11.1 (a)	10.8 (a)
	total	1977/78	10.2	7.0	10.7	9.4	13.9	12.8	13.9	14.0	12.2 (a)	10.8 (b)
E 4		1980	7.7	5.2	10.6	8.8	15.9	13.5			11.4 (a)	9.2 (b)
E 5		1977	11.9	12.2	11.1	12.4					11.5 (a)	12.3 (a)
E 6	spring	1979	3.2	-[2)]	3.5	-[2)]					3.4	-
	rest	1979	7.2	6.3	6.4	6.7					6.8 (a)	6.5 (a)
	total	1979	10.4	6.3	9.9	6.7					10.2 (a)	6.5 (b)
E 8	spring	1979	1.7	-[2)]	2.2	-[2)]					2.0	-
	rest	1979	6.1	5.1	8.2	6.7					7.2 (a)	5.9 (b)
	total	1979	7.8	5.1	10.4	6.7					9.2 (a)	5.9 (b)
E12		1980	10.6	10.4							10.6 (a)	10.4 (a)
Average extra cut											0.8	-
Average rest											9.1	8.5
Average total											9.9	8.5

[1)] In autumn the N dressings were not yet varied; [2)] the first cut consisted almost completely of Stellaria media.

When the first cut is excluded, the difference in the average dry matter yields was somewhat greater (88 : 100 instead of 93 : 100). If the yield of the old grassland, harvested before the reseeded grassland was producing again, was included, this difference was still greater.

In the second year hardly any differences in the gross dry matter yield occurred any more; the dry matter yields on the old and on the reseeded grassland averaged 10.2 and 9.9 t ha^{-1}.

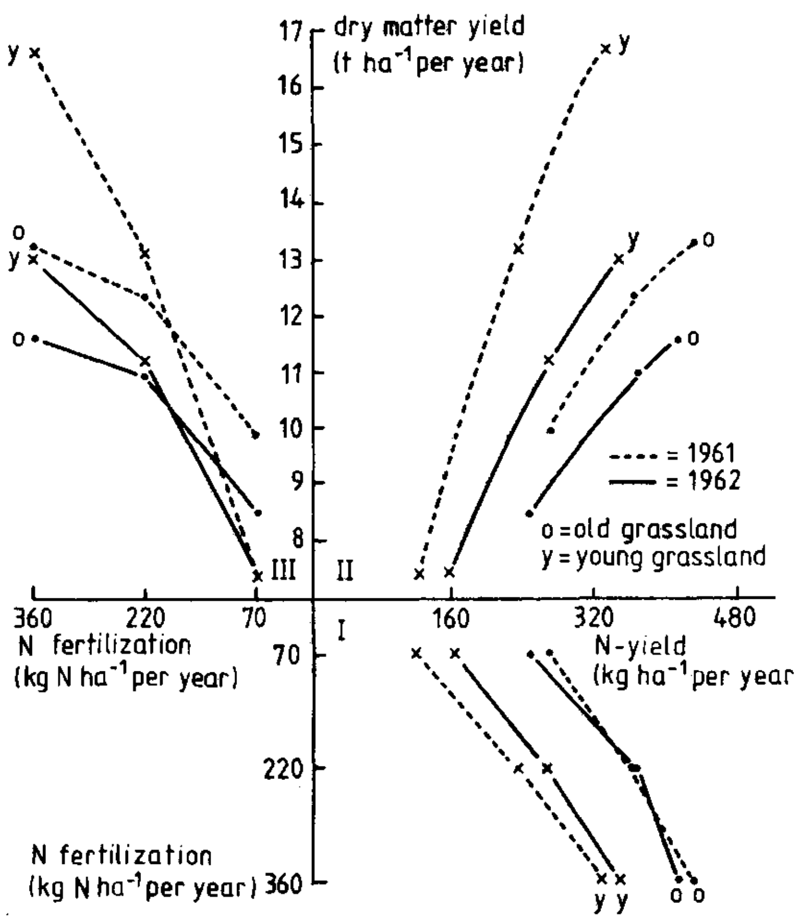
When the period between destruction of the old grass sward and reseeding was lengthened, the yield of the young grass sward was slightly increased in the field experiment (E_{12}), but not in a pot experiment.

3.2 Seeding after arable crops

3.2.1 Results of experimental fields designed for other purposes

a. On an experimental field on heavy river clay soil, where a field of grassland sown after arable crops could be compared with a field of old grassland, the young grassland had a lower N yield, but a higher dry matter yield at the same N yield (Fig. 1). This holds for both the years that the comparison was possible. The two fields are situated near each other.

Fig. 1. Relation between N application and N yield (quadrant I), between N application and dry matter yield (quadrant III) and between N yield and dry matter yield (quadrant II) (Hoogerkamp & Woldring, 1965); O = old grassland and Y = young grassland sown in arable soil (first year).



By combining a lower N yield and a lower N content in the dry matter of the young grassland, the dry matter yield at the lowest N dressing is highest on the old grassland, but at the higher dressings highest on the young grassland.

b. In a crop rotation experiment on the "ir. A.P. Minderhoudhoeve" at Swifterbant the following dry matter yields were harvested (Table 3).

Table 3. Dry matter yields of grassland (t ha^{-1} per year). In 1980 the experimental field was laid down on arable soil (not published data of Sibma; CABO, Wageningen). The grassland was exclusively cut.

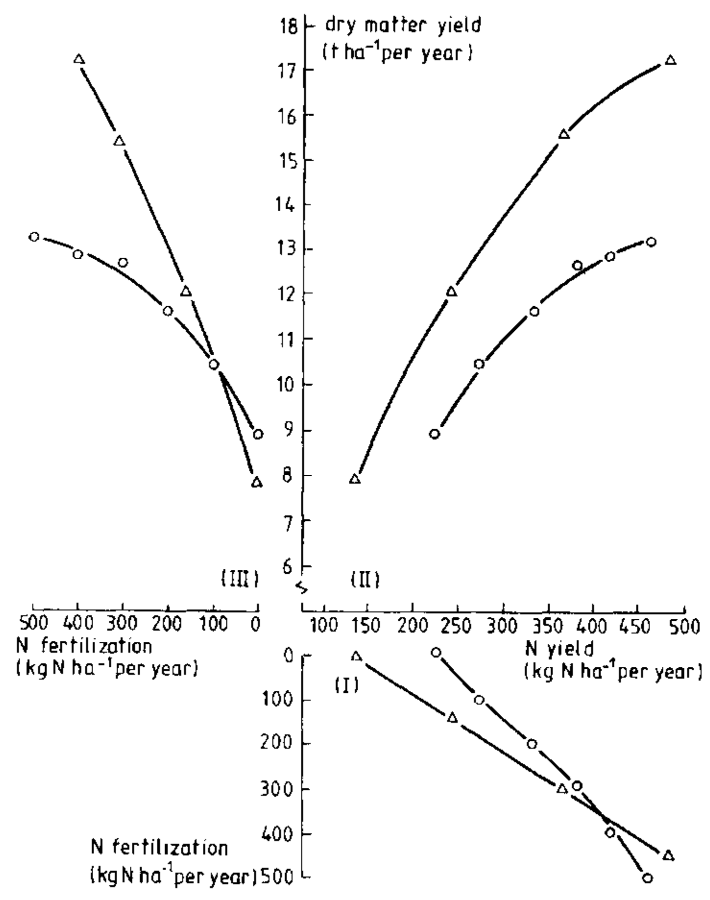
Crop rotation			N fertilizer (kg N ha^{-1} per year)		
1980	1981	1982	400 (1980)	428 (1981)	450 (1982)
grass	grass	grass	19.7	16.2	13.4
w. wheat	grass	grass	-	16.7	13.9
maize	s. wheat	grass	-	-	15.8

One year old grassland always gave a higher dry matter yield than the older grassland (19.7>16.2; 16.2>13.4; 16.7>16.2; 16.7>13.9; 13.9>13.4 and 15.8>13.9).

c. Combination of different results

Van Steenbergen (1977) measured the gross yields of some twenty experimental fields on old grassland at various N levels during 8 to 10 years. On experimental field CABO 314 this was done on a first year grassland sown on arable land in Flevoland. Combination of these yields shows a similar trend as the preceding figure (Fig. 2).

Fig. 2. Relation between N application and N yield (quadrant I), between N yield and dry matter yield (quadrant II) and between N application and dry matter yield (quadrant III).
o----o Van Steenbergen (1977)
W----W CABO 314 (data provided by Sibma; CABO, Wageningen)



Here too a lower N yield and a higher N efficiency of the young grassland at the lowest N dressing resulted in a lower and at the higher N dressings in a higher dry matter yield of the young grassland than of the old.

When the dry matter yields obtained from one-year old grassland liberally fertilized with N and sown in arable soil were compared with those of one-year old resown grassland or old(er) grassland, the same was found; the former yields were distinctly higher than the latter yields (Table 4).

Table 4. Average gross dry matter yields obtained on various experimental fields. A = one-year old grassland on arable soil, B = old(er) grassland or one-year old resown grassland (data after Sibma; CABO, Wageningen).

	A	B
Av. N fertilizer (kg N ha^{-1} per year)	558	592
Av. number of cuts per year	5.4	5.3
Number of experimental fields	6	8
Number of experimental years	11	22
Av. dry matter yields (t ha^{-1} per year)	19.8	16.4

Despite the somewhat lower average N dressing, the average gross dry matter yield of the one-year old grassland sown in arable soil was distinctly the highest; this also applies to most of the separate cases.

d. Comparison of one-year old and two-year old grassland

The high yields attained by Alberda (1968) and Cooper (1969 and pers. comm.) under favourable growing conditions, especially a high N supply, were related to one-year old grassland sown in arable or horticultural soil. In the second year these yields decreased to distinctly lower values (Alberda, pers. comm. and Cooper, 1972; the latter found over 20 t ha^{-1} in the first year and over 13 t ha^{-1} in the second). In reseeding experiments the average yield of the reseeded grassland in the first and in the second year was somewhat lower than that of the old grassland (see 3.1)

3.2.2 Results of rotation experimental fields

a. Experimental fields E_{10} and E_{11}

On both these experimental fields grass was sown after grassland and after one year and two years of growing maize. The establishment of the grass was slow because of drought. In the treatments sown after maize, establishment was distinctly better than after grass; the number of plants in the latter treatment was smaller, the seedlings were smaller and had fewer tillers and the colour was lighter. Further development of the grass sward on the grass treatment was spatially more irregular than on the maize treatments. However, in the course of the year the grass swards on all the treatments became reasonably closed and consisted mainly of Lolium perenne.

Between one and two years maize the differences in establishment and growth were relatively small; the latter treatment was in general somewhat better than the former one.

The dry matter yields showed corresponding differences between the crop rotation treatments (Table 5).

Table 5. Gross dry matter yields (t ha^{-1}) of the experimental fields E_{10} and E_{11} in the year of sowing; A = after two years maize; B = after one year maize and C = after grass.

	N1			N2			N3			N4			Average		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
E_{10}	7.8	6.8	6.0	8.7	8.2	6.0	9.7	8.1	5.7	9.6	8.3	6.8	8.9	7.9	6.1
E_{11}	5.0	6.0	4.2	5.4	6.2	4.7	6.0	5.5	4.4	6.5	6.3	4.5	5.7	6.0	4.5

Despite the presence of a decomposing sod, the grass treatment (C), on both experimental fields yielded less dry matter than the two maize treatments (A and B). On an average this difference decreased in the course of the year. On E_{10} the annual yield of dry matter at all four N levels was significantly higher on A than on B. On E_{11} the dry matter yields at the two highest N levels only were higher on A than those on B; however, these differences were not significant. At the two lowest N levels B even outyielded A.

The N effect varied rather widely; the total N effect

(N_4-N_1) for the annual yields on A was distinctly higher than on C.

In the second year the positive effect of the crop rotation with the arable crop was negligible. The dry matter yields in this year on the grass treatment (C) on an average were somewhat higher than those on the maize treatments (A and B); this positive effect on C occurred, especially at the lowest N dressing (E_{10}) or dressings (E_{11}).

The N yields in both years on both experimental fields showed the same trend as the dry matter yields.

b. Experimental field E_{12}

On E_{12} grass was sown after grass or after a short period (about three months) with other crops (see Table 1).

Establishment of the grass was initially slow because of the current drought and visually seemed somewhat better on A (re-seeding) than on B (summer oilseed rape), C (forage rape) and D (marigolds). At the measurements and countings carried out on 1979-10-25, however, only relatively small differences could be established in plant number, leaf and root lengths and in leaf and root dry weights, which did not even point in the same direction.

With regard to the gross dry matter yield, including a short arable crop period was found to increase the yield for the first three cuts; with marigolds this increase was somewhat greater than with summer oilseed rape and forage rape; this does not hold for the last two cuts (Table 6).

Table 6. Effect of different first crops on the gross yield (dry matter in kg ha^{-1} per year); between brackets the relative yield. Different letters indicate significant differences.

A (reseeding)	B (summer oilseed rape)	C (forage rape)	D (marigolds)
10374 (100) (a)	11233 (108) (b)	11023 (106) (b)	11505 (111) (b)

3.2.3 Results of pot experiments

In the pot experiments 44 two-by-two comparisons were made of grass sown in soil from adjacent grassland and arable fields. In 31 comparisons grass growth the first time after sowing was better in the arable soil than that in the grassland soil. In all the other comparisons the reverse occurred; however, in seven of these instances suggestions were obtained that an adverse effect might be involved of persistent herbicides applied to the arable soil.

These differences in growth of the above-ground parts often came to light in the variables measured: length of plants, fresh grass and dry matter yields per plant and per pot with or without leaf width (Table 7).

Table 7. Leaf stage[1)] and width, length of tillers[2)] and yield[3)] of fresh grass and dry matter of Lolium perenne. 1) and 2) are averages of 5 and 10 of the largest plants per pot, respectively. 1) and 2) were measured 21 and 3) 38 days after sowing, respectively.

	Leaf stage	Leaf width (mm)	Length (cm)	Fresh weight (g pot^{-1})	Dry weight (g pot^{-1})
grassland soil	2-3	1.5	10.3	14.77	1.99
arable soil	3-4	2.0	13.9	17.69	2.98

The better growth on arable soil usually was temporary; probably the greater N-supply by the grassland soil was important in this. The rate at which this better growth disappeared was dependent on the size of the N-dressing. As less N was applied the relatively better growth on the arable crop soil stopped sooner (Table 8).

Table 8. Dry matter yield of Lolium perenne sown in two grassland soils and one arable crop soil (g pot^{-1}).

		N dressing (kg ha^{-1} per year)		
		0	75	150
1st cut (35 days after sowing)	grassland soil	2.74	3.20	2.32
	arable crop soil	3.09	4.47	4.49
2nd cut (54 days after sowing)	grassland soil	2.60	7.48	6.72
	arable crop soil	1.13	7.02	7.92

The advantage of the arable crop soil treatment in the first cut, at ON changed into a disadvantage in the second cut; at 150 N the advantage, though reduced, was maintained also in the second cut.

When the roots reached the rim of the pot this usually also meant the end of the difference.

In the various experiments other symptoms of poor growth occurred besides the differences in the above-ground parts of the plants: for instance, slower germination, damage of the hypocotyledonous internode and stunted growth of the seedlings; moreover, the root system often was smaller (Table 9).

Table 9. Length of the longest primary (Z) and secondary root (K) and number of secondary roots (AK) on 11, 18, 25 and 32 days after sowing.

	Z (mm)				K (mm)				AK			
	11	18	25	32	11	18	25	32	11	18	25	32
arable crop soil	36	40	61	-[1)]	9	42	83	220	2.1	5.3	7.8	-[2)]
grassland soil	13	20	26	-[1)]	6	24	40	78	2.0	3.4	5.2	-[2)]

---

1) Secondary and primary roots could not be separated any more; 2) not counted.

The extent to which root lengths and weights differed varied; origin of the soil, time at which the soil was collected and growing conditions were involved in this aspect. A shorter primary with or without a secondary root system was usually, though not always accompanied by a lighter root system (Table 10).

Table 10. Length of the root system and root weight.

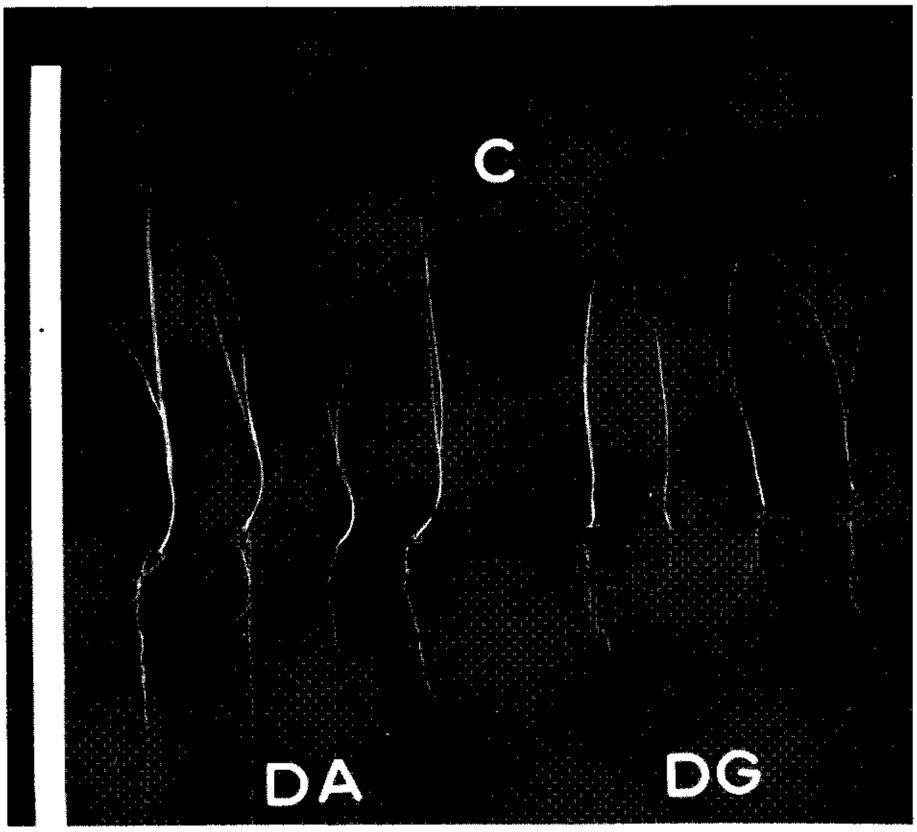
	Root length (mm)				Root weight (dry matter; mg plant^{-1})			
I Number of days after sowing	11	18	25	32	11	18	25	32
arable crop soil (Droevendaal)	36	42	83	220	1.3	2.8	10.0	33.4
grassland soil (Droevendaal)	13	24	40	78	1.4	3.6	6.4	11.0
II Number of days after sowing	21	40			21	40		
arable crop soil (Achterberg)	48	306			3.2	60		
grassland soil (Achterberg)	49	173			4.2	44		
III Number of days after sowing	13	21	27	34	13	21	27	34
arable crop soil	48	74	174	213	9[1)]	21[1)]	138[1)]	267[1)]
grassland soil A	53	69	117	161	14[1)]	20[1)]	66[1)]	156[1)]
grassland soil B	53	85	130	180	18[1)]	26[1)]	86[1)]	187[1)]

1) mg pot^{-1}.

In 25 out of 41 comparisons of grass on arable soil and on grassland soil, a short or lighter root system occurred on grassland soil.

The root systems of the grass growing on the arable crop soil and on the grassland soil differed in many other aspects as well; the latter roots often were browner with or without brown spots, in some places they were more branched ("stubby roots") and thicker and sometimes had thickened root tips, shorter root hairs, emptied cells, local protuberances and shriveled cortex cells. In the roots of the plants growing in grassland soil often more

Plate I



Examples of a more branched root system (C; DG = grassland soil; DA = arable soil) and of thickened root parts of grass sown in grassland soil.

nematodes and fungi were found than in those growing in arable crop soil. The preceding photo page (Plate I) shows some roots from arable and grassland soil.

3.2.4 Farm fields

Both on grassland and grass seed fields and on sports fields often problems occurred at reseeding with the establishment and growth of the young grass plants. These problems were most distinct in periods with extreme weather conditions (specially drought). Sometimes the newly sown grass sward showed rather patchwise slow establishment and growth; sometimes initial germination of the grass was good, but after some time it failed; this usually occurred in the 2 - 3 leaf stage.

These symptoms often corresponded with those observed in the experiments.

The difficulty in estimating farm fields is that extremes can indeed be recognized, but smaller growth retardations are difficult to establish, by lack of comparable treatments.

3.3 Application of nematicides with or without fungicides

In the field and pot experiments, in which the pesticides were applied before (re)seeding, the nematicides and to a less extent the fungicides resulted in a somewhat better establishment and growth of the grass. Table 11 shows an example.

Table 11. Effect of pesticides on the number of seedlings (per 4 m row), the maximum length of the leaves (cm) and the dry weight (g per 15 plants) of the tillers some time after sowing and the absolute dry matter yield (t ha^{-1}) in the first year. Between brackets the relative yields (E_3).
Ne = nematicide; Fu = fungicides; Ne+Fu = nematicide + fungicides and C = control.

	Number of seedlings[1)]	Length[2)]	Dry weight[2)]	Dry matter yield 100[3)]	200[3)]	400[3)]	600[3)]	average[4)]
C	59	11.8	0.91	7.0	9.4	12.8	14.0	10.8[a] (100)
Ne	73	15.1	1.18	8.4	10.9	13.9	14.8	12.0[b] (111)
Fu	68	12.0	0.92	7.9	10.1	14.1	14.2	11.6[b] (107)
Ne + Fu	77	12.9	1.04	8.5	10.4	14.0	15.0	12.0[b] (111)

1)after about 1 month; 2)after about 2 months; 3)N dressing (kg N ha^{-1} per year); 4)the same letter indicates: no significant difference; a different letter a significant difference.

The annual yield of dry matter was significantly increased. Most by application of a nematicide; the combination of a nematicide and fungicides did not give an additional increase. Application of the fungicides only gave a slightly lower increased yield of dry matter.

The rate of fertilizer N had no distinct systematic effect on this; however, the differences tended to be smaller with increasing N dressing.

In the second year (1979) the pesticides applied in the autumn of 1977, still had a slightly increasing effect on the dry matter yields (Table 12).

Table 12. Effect of a nematicide with or without two fungicides on the absolute (kg ha^{-1}) and relative (C = 100) dry matter yields in the second year of production (E_3); (the third cut was lost, because of invading sheep).

	Fertilizer N (kg N ha^{-1} per year)				
	90	180	360	540	average
C	4719 (100)	7135 (100)	10290 (100)	9801 (100)	7986 (100)
Ne	5421 (115)	7514 (105)	10141 (99)	10848 (111)	8470 (106)
Fu	5320 (113)	7347 (103)	9783 (95)	9654 (99)	8026 (101)
Ne+Fu	5245 (111)	6774 (95)	10627 (103)	10811 (110)	8364 (105)

Only the increase of the average yield obtained by application of the nematicide was significant.

The effect of the pesticides on the botanical composition of the grass sward was negligible.

Similar results were obtained on E_4; the yield increases attained in the first year, were however distinctly smaller; the average dry matter yields on treatments C (control), Ne (nematicide,) Fu (fungicide) and Ne+Fu (nematicide + fungicide) successively were 10.6; 11.2; 10.6 and 11.0 t ha^{-1} per year.

In autumn the grassland just reseeded on E_7 was damaged severely (almost all the grass plants were killed) and on E_5 lightly (only slightly thinned out) by larvae of the frit fly (Oscinella frit). The grass on the plots treated with a nematicide was not damaged at all. The dry matter yields, which were only measured on E_5 were distinctly increased by the nematicide in the first cut (averaged 3.9 t ha^{-1} against 3.2 t ha^{-1}). The dry matter yield was hardly further increased by the addition of fungicides to the nematicide.

The dry matter yields on E_5 and E_8 were somewhat increased by the pesticides; those on E_6 and E_{12} however decreased (Table 13).

Table 13. Effect of pesticides on the average gross dry matter yields (t ha^{-1} per year).

	E5	E6	E8	E12
nematicide+fungicide(s)	13.8	6.2	7.1	10.3
nematicide	13.1	5.8		
no treatment	12.3	6.5	5.9	10.4

Only the differences between nematicide + fungicide(s) and no treatment on E_5 and E_8 are significant.

In the pot experiments varying responses were found to the treatment with the various pesticides. In one of these experiments treatment with the nematicide (aldicarb) caused somewhat accelerated germination on the arable soil; however, the slower germination in the grassland soil was not improved by the nematicide. The final number of seedlings was the same and the dry matter yields attained after 35 and 57 days were hardly benefitted by treatment with the nematicide.

In another pot experiment, in which the planted tillers of Lolium perenne in arable crop soil showed better growth than on grassland soil, addition of a mixture of one nematicide (aldicarb) and two fungicides (thiram and captafol) often produced a healthier root system (whiter, straighter and thicker roots and more and longer root hairs). Weight of the root system, however, varied widely in the first cut and was not significantly affected by the pesticides; for the second cut the average effect was negative. The above-ground parts often were more vigorous after disinfecting the soil and two clones out of three showed an increased dry matter yield in the first cut; this yield increase was almost the same for both soils. The yield of the third clone was slightly increased on the grassland soil and decreased on the arable crop soil. The response of the second cut to the pesticides varied widely and was negative for half of the treatments.

A more detailed study of the soil and roots in both the pot and field experiments showed that in treatments with nematicides, the nematode population in the soil had been reduced, the roots were less damaged by nematodes and the number of nematodes in the roots was often smaller, However, these three effects were not always accompanied by better growth of the grass.

3.4 The effect of earthworms

Practical experience

Despite the good growing conditions, a number of problems occur in practice on the intensively managed grasslands without earthworms in O. Flevoland.

- the grass sward, when grazed by cattle and sheep is easily pulled up, especially in summer, late summer and in early spring; the extent to which this takes place depends on the weather conditions (drought promotes pulling up) and the length of the pasture period (grazing the sward down closely also promotes pulling up);
- rapid weed invasion often occurs, especially with chickweed (Stellaria media), annual meadow grass (Poa annua) and to a less extent couch grass (Elymus repens)[1], the latter species is not yet present everywhere in O. Flevoland;
- users report that the yields decrease some years after sowing.

Because of these aspects much grassland has to be reseeded already some years after sowing. Reinders (pers. comm.) of the Advisory Service maintains that in this area almost all the grassland will have been reseeded within six years. On the experimental farms of IVVO and IVO in 1980, 54 and 37% of the grassland sown in the period 1971 through 1974, respectively, was reseeded or sodseeded.

Experimental fields

In the experimental fields where, in the treatments with a low organic matter content induced by changes in the profile (Hoogerkamp,

[1] formely: Elytrigia repens or Agropyron repens

1973a), undoubtedly small earthworm populations were realized, no distinct symptoms of low worm activity were observed for both soil structure and soil morphology.

The earthworms inoculated in the grassland in O. Flevoland, an area without earthworms, in contrast showed a distinct effect on both the soil and grass growth.

a. Soil morphology

The presence of a thatch layer (mat or A0-layer) just above the subsoil (C) is a striking phenomenon for grassland without earthworms in this area (Plate II).

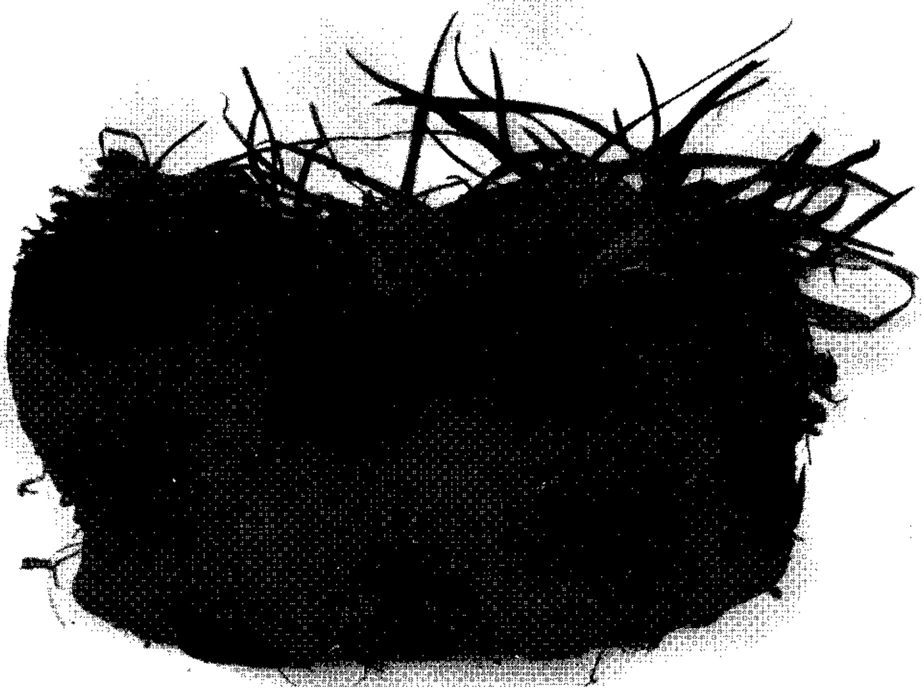
The thatch layer consists mainly of not or incompletely decomposed plant parts. Its maximum depth was about 2½ cm[1)]; in Australia Noble et al. (1970) found a thickness of 2-3 cm and Barley & Kleinig (1964) of 2-4 cm. The weight of the unincorporated organic matter was variable. When measured in 1980 fresh weight varied from 145-263 t ha^{-1} (average 195 t ha^{-1}); the average dry weight was 84 t ha^{-1}. In 1981 an average dry weight was measured of 54 t ha^{-1}. Complete separation of thatch layer and mineral soil was difficult. In Australia Kleinig (1966) found a weight of the thatch layer that varied from 9.0-103.5 t ha^{-1} and Noble et al. (1970) also in Australia found a weight of 72 t ha^{-1} (8 t ha^{-1} on the non earthworm area).

After invasion of the earthworms the thatch layer disappeared gradually. The width of the zone in which earthworms were active, but where the thatch layer had not yet disappeared, averaged about 12 m in 1981. With a lateral spread of earthworms of 9 m $year^{-1}$ (Hoogerkamp et al., 1983), it will take about $1^1/3$ years before the thatch layer has disappeared. The organic matter is mixed through the underlying soil during this process and an A1-layer is formed, which grows thicker as earthworm activity continues. On the experimental field at Elburg the layer was 5-8 cm thick

---

1) on a lawn experimental field in O. Flevoland the maximum depth was about 3½ cm; the concerning sward consisted of Festuca rubra and the earthworm activity was just starting.

Plate II



Build-up of the soil profile of grassland without (top) and with (bottom) earthworms.

after 8-9 years (Hoogerkamp et al., 1983).

b. Organic matter content and amount

The thatch layer is mixed through the soil by earthworm activity, which results in a higher organic matter content of the mineral soil (Table 14).

Table 14. Effect of earthworms on total C and N content of the soil. A = centre of earthworm area; B = periphery of the part of the earthworm area where the thatch layer has disappeared; C = area where the A0-layer has not quite disappeared; D = outside the earthworm area (Swifterbant).

		C%				N%			
		A	B	C	D	A	B	C	D
Field 23.2:	2- 0 cm	-	-	-	26.37	-	-	-	1.91
	0- 2 cm	3.96	4.34	7.41	3.04	0.32	0.37	0.53	0.25
	2- 5 cm	2.48	2.86	3.41	1.63	0.20	0.27	0.28	0.15
	5-10 cm	1.80	1.72	1.78	1.45	0.15	0.16	0.18	0.15
	10-20 cm	1.43	1.41	1.54	1.34	0.13	0.13	0.14	0.13
Field 24.4:	2- 0 cm	-	-	-	21.06	-	-	-	1.66
	0- 2 cm	5.34	5.06	7.81	2.12	0.40	0.38	0.62	0.19
	2- 5 cm	2.93	3.00	2.91	1.60	0.25	0.26	0.25	0.15
	5-10 cm	1.74	1.88	1.65	1.42	0.16	0.16	0.15	0.14
	10-20 cm	1.45	1.42	1.48	1.37	0.13	0.13	0.14	0.13

Since the density of the soil is distinctly affected by earthworm activity (see c), the organic matter content does not say much about the total amount of organic matter and N-total. These amounts for fields 23.2 are mentioned in Table 15.

Table 15. Amounts of C and N-total in the layer 0-20 cm and, if present, in the mat (kg ha^{-1}). For, A, B, C and D see Table 14 (field 23.2, Swifterbant).

	A	B	C	D
C	47384	51200	61140	58152
N-total	4057	4641	5289	5179

Hence earthworm activity resulted in a decrease in the C and N-total amounts. Noble et al. (1970) found the same in mat plus soil layer 0-5 cm. Kleinig (1966) reported a greater organic matter accumulation at the formation of a thatch layer.

The C/N quotient in the mat was higher than that of the organic matter in the soil with earthworms; averaged 13.1 and 12.0, respectively (field 23.2). Kleinig (1966) found the same, but Noble et al. (1970) found a somewhat lower C/N in the mat.

Apart from the wide variation in volume weights and in the contents of C and N-total, a problem for a quantitative approach of these differences is that the density of the soil changes under influence of earthworm activity. The layer 0-20 cm of the area without earthworms should have to be compared with a thicker layer of the grassland with earthworms. Another method might be to calculate the organic matter content above the starting level (e.g. the content in the layer 10-20 cm). The differences are still distinct then, but smaller than in Table 15: 14.8 t organic C and 904 kg N ha^{-1} on the grassland with earthworms against 21.2 t organic C and 1608 kg N ha^{-1} on the grassland without earthworms (field 23.2).

Soil of the latter field was used in an incubation and a pot experiment (see 2). In the first experiment no reliable difference was found in the N supply by the soil. In the pot experiment, however, the soil from the areas without earthworms, especially at low N dressings, gave distinctly better grass growth and a higher dry matter and N-total yield than the soil from the areas with earthworms (Table 16).

Table 16. Dry matter and N-total yield on soil from grassland without (= -w) and with earthworms (= +w)(g m^{-2}).

	N fertilizer level in the pots							
	N0		N1		N2		N3	
	+w	-w	+w	-w	+w	-w	+w	-w
dry matter	356	408	675	765	1310	1312	1577	1588
N-total	5.0	8.1	11.4	13.7	28.4	30.7	46.1	46.5

c. Compactness of the soil

Apart from the thatch layer, the soil of the grassland without earthworms was compacter than that of the grassland with earthworms. This was shown by both the higher bulk densities and the higher penetrometer values (Tables 17 and 18, respectively).

Table 17. Weight of the dry soil (10^3 kg ha^{-1}) (Swifterbant).

	A0-layer	0-2 cm	2-5 cm	5-10 cm	10-20 cm	total
- earthworms	54	282	424	700	1364	2824
+ earthworms	-	221	332	653	1305	2511

Wollny (1890) and Clements (1978) also reported a lower bulk density with earthworms than without earthworms. However, Stockdill (1966) only found small differences in bulk density between the areas with and the areas without earthworms; in the layer 0-4 inches the soil with earthworms had a higher bulk density.

The penetrometer values mainly varied with soil type, moisture content of the soil and age of the grassland; within one field and at the same time values also varied rather widely. However, the values were almost always lower on the areas with earthworms than on the areas without earthworms (Table 18).

Table 18. Effect of earthworms on the penetrometer values (kg cm^{-2}).

		Depth (cm)							
		5	10	15	20	25	30	35	40
Swifterbant (23.2)	with worms	9.5	11.3	11.8	11.3	10.0	11.0	10.2	12.7
" "	without worms	16.5	17.0	14.0	11.7	13.7	13.0	12.3	15.2
" (24.4)	with worms	9.3	11.2	11.0	10.8	11.3	10.2	11.2	11.7
" "	without worms	16.5	17.7	11.7	14.8	14.7	13.8	13.7	14.2

The layer in which evident differences in penetration resistance occurred also varied rather widely; often, however, the layers 0-2.5 cm to 15-35 cm were involved.

A higher shear strength on the grassland without earthworms indicates the same direction (Clements, 1978 and Hoogerkamp et al., 1983).

d. Rooting

When rooting was studied by means of profile holes, roots penetrated deeper of the grassland with earthworms than of the grassland without earthworms; Stockdill & Cossens (1969) came to the same conclusion. However, field sampling did not always confirm this. Sampling problems (a great spatial variation) and the difficulty to separate dead from living roots are involved in these divergent results. Distinct differences in drought sensitivity (e.g. in the dry summer of 1982) were not observed; however, Stockdill (1966) mentioned a reduced drought sensitivity for grassland without earthworms.

e. Botanical composition

The botanical composition of the grass sward can be affected by many factors; both temporal and spatial differences may occur. The effect of earthworms on the botanical composition varied widely and was not easy to separate from other effects.

Generally, when differences occurred between grassland with or without earthworms, this was agriculturally always to the advantage of grassland with earthworms. Table 19 shows a number of examples.

Table 19. Some examples of fields in which distinct differences occurred in the botanical composition of the sward of grassland with (=+) and without (=-) earthworms. A = estimated coverage, B = dry weight percentages.

	(A)		(A)		(B)		(B)		(A)		(A)	
	+	-	+	-	+	-	+	-	+	-	+	-
Lolium perenne	75	45	78	40	70	57	77	47	83	55	74	57
Phleum pratense	4	9	3	8	3	2	3	11	3	10	3	5
Poa pratensis					+		2	0	0	2	1	2
Poa trivialis					10	3		+	3	5	0	+
Poa annua	6	12	5	15	5	10	7	9	5	20	12	14
Elymus repens								2				
Trifolium repens	5	6	5	6	4	3	8	3	5	5	7	1
Taraxacum officinale	1	2	1	1	7	7						
Stellaria media					+	17	+	1	1	1	0[1]	10[1]
Polygonum aviculare								+				
Capsella bursa-pastoris	9	26	8	30	1	1	3	27	0	2		
Bare patches											3	11

[1] total herbs

If there were differences in botanical composition, the percentage of Lolium perenne in the grassland with earthworms was generally higher. A lower percentage of this species was accompanied by a higher percentage of less desirable species, as Poa annua and dycotyledonous weeds. Elymus repens in principle can also profit from the decrease in Lolium perenne, but this species occurred in low percentages in the relevant area. On those fields in which Elymus repens did occur, the percentage in the grassland without earthworms was often higher: when the field at Elburg was sampled on 1979-08-27, 4% of Elymus repens was found in the grassland with earthworms, while this was 15% in the grassland without earthworms. In one of the fields at Swifterbant, where the latter species occurred in patches, the number of patches in grassland without earthworms averaged 5 per 900 m^2, and in grassland with earthworms 1-2 for the same area.

The reasons for these differences in the botanical composition are only partly known. Evidence was found, however, that the formation of bare patches, in which undesirable species can establish is involved. Bare patches are formed, for instance, by scorching by urine, smothering by droppings and the pulling apart of the sod by grazing cattle. In the winter of 1981/1982 Lolium perenne was damaged more severely by frost on the grassland without earthworms than on that with earthworms.

f. Temperature

Thermal infrared images (8-14 µm) made from aeroplanes showed that, especially in spring when grass is not yet growing, the earthworm patches are distinctly visible on both night and day images (Hoogerkamp et al., 1983).

These images indicate that the earthworm patches are warmer by night and cooler by day.

g. Moles and birds

Earthworms are the staple food of moles (Talpa europaea). Until now moles have occurred only in a part of the grassland in O. Flevoland. In the experimental field at Biddinghuizen the moles occurred first on the earthworm patches. Data on the relation between moles and mole damage and the earthworm population are not available. Moles however can do much damage in grassland; in just sown grassland more still than in older grassland.

Various bird species (e.g. lapwings and gulls) often foraged on the worm patches. In a wet period in the summer of 1980, when many earthworms came to the surface this resulted in treading of the sward by these birds. The "damage" caused in this way, however, was no longer visible after a few days.

h. Bearing capacity

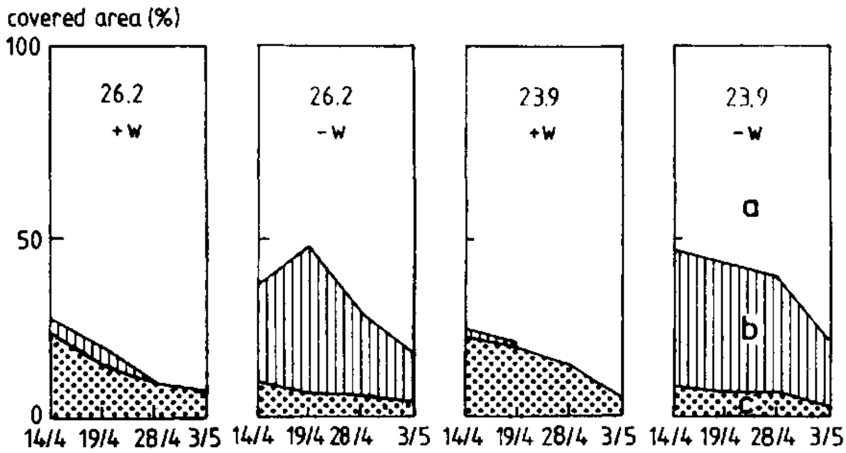
The preceding chapters show that the thatch layer disappears and the penetration resistance decreases by earthworm activity. Both these factors may result in a decrease in the bearing capacity of grassland. A more rapid drainage of the water could have an opposite effect. In wet periods in the summer of 1980 and in the autumn of 1981, most damage by treading at the "Ir. A.P. Minderhoudhoeve" occurred on the grassland with earthworms; in winter and early spring, when sheep are pastured at this farm treading also occurs most on the grassland with earthworms. Until now the effects of treading, at least visibly, were small. Quantitative data are not available.

In wet periods the grassland with earthworms was also rutted most deeply by machines and equipment.

i. Other observations

- In the winter of 1981/'82 the sward was damaged by frost, so that in spring the sward looked poorly with much dead grass and bare patches. On the grassland without earthworms the damage was distinctly more severe than on the grassland with earthworms. In the course of spring the sward recovered gradually; the treatments with earthworms recovered more quickly and at this time the earthworm patches showed up as green oases in the yellow grassland without earthworms. In the coverage measured with the point quadrat method this was evident as well (Fig. 3).

Fig. 3. Percentage of soil covered with green plants (a), with yellow plants (b), or bare soil (c).



The gross yields in spring were distinctly lower on the grassland without earthworms than on the grassland with earthworms (Table 20).

Table 20. Gross dry matter yields obtained in the spring of 1982 (averages of two fields on the "Ir. A.P. Minderhoudhoeve"; kg ha^{-1}).

	14-04	28-04	12-05	24-05/25-05
+ earthworms	66	477	1507	4162
- earthworms	92	258	707	3011
difference	-26	+219	+800	+1151

By application of nitrogen on 19-03 grass growth in both treatments was accelerated; in the periods 14-04 to 28-04 and 28-04 to 12-05 the positive effect of the earthworms was generally greater as more N was applied, in the last period this effect was generally smaller as more N was applied (Table 21).

Table 21. Gross dry matter yield (kg ha^{-1}) obtained in the periods 14-04 - 28-04 (= I), 28-04 - 12-05 (= II) and 12-05 - 26-05[1)] (= III); N0, N1, N2 and N3 are 0, 40, 80 and 120 kg N ha^{-1}, respectively.

	I				II				III			
	N0	N1	N2	N3	N0	N1	N2	N3	N0	N1	N2	N3
Field A + worms	115	270	487	643	493	987	1353	1672	2370	2939	3090	2940
- worms	58	131	183	215	149	344	560	858	1209	2399	2935	2952
difference	57	140	304	428	344	643	793	814	1160	540	155	-12
Field B + worms	290	242	512	728	256	860	1061	1529	1981	2602	2908	2411
- worms	32	99	162	446	203	400	302	774	1606	2014	2588	2774
difference	258	143	350	282	53	460	759	755	375	588	320	-363

[1)] A: 24-05 and B: 28-05

- In the more normal spring of 1981 grass growth on the areas with earthworms also started earlier than on the grassland without earthworms. This was shown by both the green colour of the earthworm patches and by the yields obtained (Table 22).

Table 22. Gross dry matter yields obtained at the "ir. A.P. Minderhoudhoeve" in the spring of 1981 (kg ha^{-1}; mean of four fields).

	+ earthworms	- earthworms	difference
09-04	475	486	-11
27-04	2156	1634	+532
12-05	3678	3070	+608

- Dung patches on the grassland without earthworms remained longer on the surface than those on the grassland with earthworms. Therefore the number of dung patches present at a given time may have differed (Table 23).

Table 23. The number of dung patches on five plots of 10x8 m^2 on 1978-09-28.

	1	2	3	4	5	average
with earthworms	18	12	9	9	16	12.8
without earthworms	32	14	21	15	18	20.0

- In given periods in the year the sward can be damaged by urine scorching so severely that bare patches are formed. The number of these urine scorchings varied with the conditions (especially the weather); in the periods that scorching occurred, the number of scorched patches in the grassland with earthworms always was smaller than that in the grassland without earthworms (Table 24).

Table 24. The number of urine scorched patches per 1000 m^2.

	with earthworms	without earthworms
1976-11-29	8	17
1979-10-09	28	185
1980-07-27	50	70
1980-09-16	25	83

- In distinct periods of the year (especially in early spring, late summer and sometimes in autumn) grazing cattle (especially cows and sheep) pulled up rather many sods, particularly on the grassland without earthworms. For instance, in April 1980 per 100 m^2 18 pulled up sods were found on the grassland with earthworms, whereas 370 on the grassland without earthworms; the relevant fresh weights were 316 and 7090 g, respectively. In drought these tufts often dried out, whereas under moist conditions regrowth could take place.

j. Gross dry matter yields

In 1980 the yields on two fields on the "Ir. A.P. Minderhoudhoeve" were measured for other reasons. Some of these yields were incidentally measured on two earthworm patches. The harvests of the earthworm patches outyielded the average of that of the earthworm-free grassland; however, some of the yields of the grassland without earthworms were equally high. The size of the differences was at most some 0.8 t of dry matter ha^{-1} per year.

In 1981 the yields of four fields were measured on the "Ir. A.P. Minderhoudhoeve" (Table 25).

Table 25. The effect of earthworms on the gross dry matter yield (kg ha^{-1} per year); + = with earthworms and - = without earthworms.

field number									
23.9		24.9		26.2/23.2		24.4		average	
+	-	+	-	+	-	+	-	+	-
16713	15905	15201	14431	17142	14445	15552	14132	16152	14729

On all four fields the gross dry matter yield was highest of the grassland with earthworms. The yields of the first and last cuts differed most (increased average yield about 20%); the increased average yields of the other cuts varied between 3.4-7.0%.

In 1982 the same experiment was repeated on two fields, but now four N fertilizer levels were applied (0, 135, 270 and 405 kg ha^{-1} per year). Again the areas with earthworms outyielded those without earthworms (Table 26).

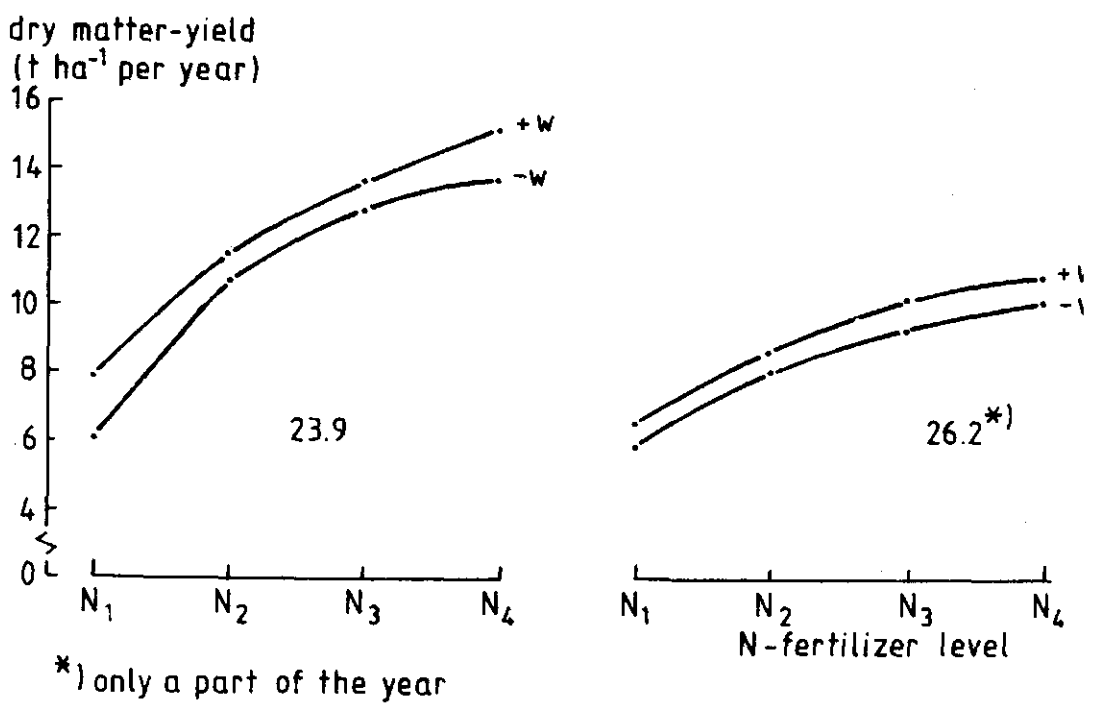
Table 26. The effect of earthworms on cumulative gross dry matter yields (kg ha^{-1} per year).

		Harvest dates					
		28-05	24-06	15-07	18-08	20-09	27-10
Field 23.9:	+ worms	4389	7117	8877	9684	10993	12037
	- worms	3038	5714	7510	8463	9879	10844
	difference	+1351	+1403	+1369	+1221	+1114	+1193
Field 26.2:	+ worms	3935	6463	9056			
	- worms	2984	5347	8365			
	difference	+951	+816	+691			

The differences in yield occurred especially in spring.

N fertilizing had a positive influence on the dry matter yields of both fields; the differences in total dry matter yield between the areas with and without earthworms were not distinctly influenced by the level of N fertilizer (Fig. 4).

Fig. 4. The influence of N fertilizing on the gross dry matter yields (t ha^{-1} per year) of the areas with (= +w) and without earthworms (= -w).



4 DISCUSSION

4.1 Rotation problems

Old grassland soil compared with arable crop soil generally contains a considerable biomass of microflora and fauna (Clements, 1980; Franz, 1950; Klapp, 1971 and Tischler, 1955a). The permanent coverage of the soil with a vegetation, the limited soil tillage, the limited use of pesticides and the great production of organic matter are indicated as the main causes.

A part of the species present may be of a injurious nature to grass growth. Data on the number of harmful organisms in the soil and on dose-effect-relations are hardly available.

Phytophagous organisms can be killed by applying chemicals active against them and by temporarily growing of other crops, which are not host plants to these harmful organisms. In this study special attention was paid to the effect of crop rotation on grass growth. Since rejuvenating grassland may give an increased yield, reseeded grassland was compared with old grassland and with grassland sown after arable crops.

4.2 Design of the experiments

An analysis of the effect of a given crop on a succeeding crop, which is quantitatively useful in practice, is difficult, because the growing conditions for this crop may be affected in many ways and because the extent to which this occurs often depends on many conditons. Factors not causally dependent on the preceding crop, moreover, have to be avoided.

Grassland compared with arable crops as a preceding crop to grassland has both positive and negative aspects for growth of the succeeding grass.

The positive effects are especially based on the amount of organic matter in the soil and the extent of the earthworm population, which both may be greater after grass as a preceding crop than after arable crops as a preceding crop. The negative aspects mainly apply to the stimulation of all kind of harmful organisms (e.g. eelworms, insects and fungi).

In the present study the positive effects of grass as a preceding crop were excluded as much as possible; for organic matter by making the N supply the least possible limiting or by applying various N fertilizer levels. However, a quantitative elimination of the influence of the organic matter is very difficult. The effect of earthworms was excluded as much as possible by using fairly recently tilled soil. When comparing young with older grassland sown in soil with few earthworms (see for instance Table 3) this factor may, however, be important.

Avoiding factors not necessarily dependent on the preceding crop generally could best be realized on crop rotation experimental fields especially designed for this study. Since these kind of studies are time consuming and rather expensive, fields were also compared (pot and field experiments). Although reasonably comparable fields were used for this, i.e. fields situated near each other, the risk is much greater that other factors rather than a difference in preceding crop, are included in the comparison.

Pot experiments may have the disadvantage that harmful organisms that usually occur in patches are insufficiently present in the collected soil.

With regard to the choice of arable crops, there was little experience both with respect to the kind of crop and to the length of the arable crop period, for the effect on the following crop. Because maize is often grown on grassland farms, this crop was frequently used. Possible differences between the arable crops with regard to their value as a preceding crop to grassland were not (systematically) studied.

4.3 Reseeding grassland

When grassland with a good botanical composition is reseeded, grass growth may be improved for several reasons:

- sowing of more productive species and varieties;
- rejuvenating the grass sward;
- aeration, loosening and mixing of the soil (among others decreasing denitrification, stimulating mineralization of organic matter increasing root activity);

- killing injurious organisms;
- bringing nutrients deeper into the soil.

In contrast a part of the growing season is lost to grass growth, because the leaf canopy is reduced for some time; this period may be lengthened considerably, because in the seedling stage the sward is relatively sensitive to adverse weather conditions (especially drought), unfavourable edaphic conditions (e.g. crust formation) and various diseases and pests. Moreover, often young grassland is more sensitive to treading and wheeling.

The results of the present study and those of earlier work (Hoogerkamp, 1974) showed that the gross yield of just reseeded grassland mostly was somewhat lower than that of comparable old grassland. Because only the yield was measured, it is not possible to indicate the reason for these yield differences.

The often mentioned increase in the N supply by the soil by reseeding (stimulating N mineralization) was not demonstrated[1].

Bringing nutrients deeper into the soil seldom was of distinct advantage to total grass yield (Hoogerkamp, 1973a and Klapp, 1971).

The deeper growing root system in young grassland often mentioned seems mainly caused by including arable crops in the rotation (see 4.3).

Cooper (1972) reported that the decreasing yield in the second year after seeding was caused by a decrease in the biological potential of *Lolium perenne*; apparently this decrease did not occur with *Festuca pratensis*. However, in the present study no yield

1) "The initial 'burst' of production in the ploughed-up and reseeded pasture is probably due to the fact that the whole accumulated organic mass is oxidised at one blow" (Voisin, 1960).

increase was found at reseeding, but neither a distinct decrease after the first year. A decrease in yield did frequently occur when grass was sown on arable land (see 4.4).

These reseeding experiments and the preceding ones as well were however carried out on grassland with an active earthworm population. When earthworms are not present a high density of the soil and the presence of an A0-layer may limit the growth of the depth grass. Therefore reseeding theoretically may have a more positive effect on grassland without an active earthworm population than on grassland with an active earthworm population. However, this aspect was only studied in a pot experiment. In this experiment a greater N yield was measured in the grass growing in the soil of grassland without earthworms than in that of grassland with earthworms.

A difficulty in reseeding is the rather great risk of failure. In our research (see 3.1) on four out of twelve experimental fields the resowing was a failure. The percentage of failure mentioned in the literature varies from 6-63 (Davies & Williams and Stapledon & Davies, all cited by Ellison, 1953 Klapp, 1959; Moore, 1954; Sachs, cited by Boeker, 1957; Sonneveld, 1948 and Zürn, cited by Klapp, 1959). The sensitivity of young grass plants to adverse weather and soil conditions and the damage caused by diseases, pests with or without toxic substances may be important in this. The problem of diseases, pests and phytotoxic substances was distinctly worse at reseeding than with sowing on arable soil (see 4.4).

The number of failures can be decreased by improving the reseeding technique and a more correct timing of reseeding.

4.4 Sowing after arable crops versus reseeding

Usually the use of arable crops as a preceding crop to grassland is considered harmful (Arens, 1971 and Voisin, 1960). After an inquiry held in practice Sonneveld (1948) reported on the results of sowing grassland, however: when old arable soil was sown with grass the results were more favourable than when sowing grass on a grassland ploughed up some years before; a distinct cause could not be found. 't Hart (1950), when studying a great number of grassland fields, found under given conditions that a higher organic matter content of the soil often was coupled to a higher gross dry matter yield; "leys" formed an exception, since they produced a good yield with a low organic matter content of the soil. According to 't Hart (1950) this is caused by an after-effect of the arable crop period, which causes better aeration of the soil so that the roots penetrate deeper. Voigtländer et al. (1971) and Behaeghe et al. (1970) also report higher grassland yields after other crops.

Grass-sickness-symptoms are seldom mentioned with grassland, which might theoretically be because in the past such problems did not occur, for instance, because of a much more varied composition of species and so a spatial crop rotation. However, it is also possible that they were not observed, because the yield decrease caused by a decrease in soil fertility by growing arable crops exceeded the positive effect of a decrease in "grass-sickness". Then, these symptoms might not have been observed, because grass after grass could seldom be compared with grass after other crops; such a comparison mostly is necessary to establish differences. But, it is also possible that it was not an important problem in grassland; even if the sward was composed of few species.

Earlier work (Hoogerkamp, 1974) showed on some experimental fields where grass was sown on soil that had not been under grass in the last years, that this grassland attained strikingly high dry matter yields, especially in the first years after sowing and with a liberal N dressing.

In the present study the results showed that grass sown in arable soil mostly gave a distinctly higher yield, especially in the first time after sowing, than reseeded grass or old grassland. However, this frequently occurred only when N dressings were so high that the lower N supply capacity of the arable crop soil was no longer dominant.

Most problems with reseeded grass occurred at a young stage when the root system was still small and the number of harmful organisms per gramme of roots great. In above ground infestations the proportion of growing points/parasites (e.g. larvae of the frit fly) or of leaves/parasites (e.g. larvae of the crane fly) were also unfavourable for the plant in a young stage.

In practice many problems were observed with grass plants in the 2-3 leaf stage, which may have been caused by the grass plants just changing over from the primary to the secondary root system; of wheat it is supposed that this is a rather sensitive stage (Nelson, cited by Williams, 1962).

The size of the differences in growth between the plants on arable soil and those on grassland soil was variable, with regard to the different fields and the different times at which the same soil (field) was used, to differentiation in the growing conditions and to the sown plant species and varieties. For the many factors that may be responsible for poor germination and growth of the grass on grassland soil, the extent to which a number of external factors may be important and growth reductions that may occur on arable soil e.g. by N deficiency or a lower activity of the earthworm population, this is not surprising.

The great yield differences that were established on the experimental fields E10 and E11 occurred in the relatively dry year 1976. The increased yield reported by Behaeghe et al. (1970) in the first year after sowing in arable soil were also obtained in a dry year; however, the yield increases in the following years were measured both in years with a relatively good water supply and under dry conditions. Most difficulties on farm fields also occurred in drought.

The present research showed, however that, also under conditions in which water was not or hardly at a minimum for grass growth, higher yields were obtained after arable crops than with reseeding.

The length of the period that a different preceding crop affects the growth of grass can hardly be established from the present findings. The pot experiments were only partly useful, because the differences in growth mostly disappeared after one or two cuts and the impression was gained that, whenever the roots reached the bottom or sides of the pots, any adverse effects of the soil used, were also at an end.

In the field experiments E10 and E11 the positive effect of the preceding arable crop on the grass disappeared in the second year.

The yield of grassland sown on arable soil often decreased to a more "normal" level in the second year.

In the extremely high yields (>20 t ha^{-1} per year of dry matter) mentioned by some authors (Alberda, 1968 and Cooper, 1969) the "grass sickness" symptoms were probably not important; in these instances the grass was sown in soil which had been under arable or horticultural crops.

The phenomenon often mentioned in the literature that young grassland should have a root system growing deeper and should therefore be less drought sensitive than old grassland (e.g. Jäntti, 1952), might also be related to rotation with other crops. In the present experiments the grass sown in arable crop soil generally had a healthier and deeper root system than reseeded grass. (Klapp, 1971, illustrates the greater rooting depth of young grassland with examples of grassplants sown in arable soil). In addition, the absence of earthworms and with it a greater density of the subsoil and the presence of a mat may be important in theory (see 4.5). Direct drilling of arable crops often causes superficial rooting and sometimes greater drought sensitivity (Leonard, 1973).

The causes of the differences in grass growth when sown in grassland soil and in arable crop soil were studied together with co-operators of the Department of Nematology of the Agricultural University (dr.ir. J.A. Bunt and ing. J. van Bezooijen), the Research Institute for Plant Protection (dr.ir. R.E. Labruyêre) and the Centre for Agrobiological Research (ir. J.W. Heringa and ir. G.C. Ennik) all situated at Wageningen. The results of this part of the research are not discussed in detail.

One of the findings was that a complex of factors may retard germination and first growth of grass; e.g. nematodes, fungi, insects, phytotoxic substances or soil physical restrictions (hydrophoby, anaeroby and loose soil). The literature also mentions: viruses and slugs (Agriolimax spp.) (Breese & Lewis, 1969; Clements & Haggar, 1982; Edwards, 1980 and Plumb, 1978).

Most of the damages were caused in the root system, the above-ground parts were directly damaged only sometimes (larvae of the frit fly and the crane fly and sometimes eelworms). To what extent the above-ground parts are retarded in growth by damage of the root system is dependent on the extent to which the root system is reduced (size and activity of the complex causing damage), but especially on the extent to which the remaining root system becomes growth limiting e.g. to the uptake of water and nutrients and the production of hormonal substances.

In reseeding, which includes a phase when plants have a small root system, the risk of above-ground growth retardation is relatively great: the number of parasites per unit of volume of roots can be great and the size of the root system is often at a minimum for growth.

Growing conditions are also important in this; a limited root system will cause problems especially when water supply is also limited (O'Bannon & Reynolds, 1965 and Jaspers & Kort, 1975).

A quantitative identification of the causes of "grass-sickness" is often difficult, because of the complexity. In the present research suggestions were obtained that the differences in growth between grass grown in grassland soil and in arable crop soil may be caused by a great number of mechanisms: diseases (especially fungi), parasites (especially nematodes and insect larvae), phytotoxic substances, anaerobic conditions, drying of the soil and a too loose soil.

Phytotoxic substances can be formed by living plant roots and during the decomposition of organic matter, especially when this occurs under anaerobic conditions. In the present research phytotoxic substances, for instance, were demonstrated when the rhizomes of couch grass (*Elymus repens*) were anaerobically decomposed. If so and when these substances reach concentrations in the field, which will adversely affect germination of grass seed and growth of grass, was not clear. Most risky probably is when great amounts of organic matter are present, especially if the soil is temporary anaerobic. Heringa (pers. comm.) demonstrated, especially in pot experiments, in reseeded grassland soil all kind of substances which are known to be phytotoxic to grass. The literature also reports the occurrence of such inhibitors (Habeshaw, 1980; Lynch, 1978 and Welbank, 1963).

Loose soil may hamper germination and growth of grass by a limited capillary moisture supply and because rooting may be retarded by compacting of the soil (the secondairy roots formed after compaction of the soil can hardly reach the soil). Grassland soil with its high organic matter content is more difficult to compact than arable crop soil.

Dried up soil : some pot experiments showed that grassland soil once dried up was difficult to moisten again. This may cause retardation in germination and sometimes even a decrease in the germination percentage. This phenomenon was often avoided in the pot experiments by covering the pots after sowing with plastic for some time.

Anaerobic conditions : after destruction of the grass sward a considerable amount of organic matter that is easily decomposed, is present in the soil; much oxygen is needed in decomposing this organic matter, which under certain conditions e.g. the presence of a compacted or a wet topsoil may result in (semi) anaerobic conditions; this may be directly harmful to the grass (oxygen shortage of the roots), but phytotoxic substances may also be formed during the decomposition of organic matter and in the reduction of nitrate to nitrite (semi-toxic to the roots) and of ferri- to ferro-ions.

In various experiments the roots showed a brown discolouration by oxidated iron, which was deposited on the roots. This occurred especially with a liberal moisture supply. If iron is present in the soil in a ferri-compound, this may be transformed to a ferro-compound easily soluble and transportable to the roots. This may occur especially under anaerobic conditions and in the presence of much energy rich organic material; this iron will be deposited on the roots as ferri-oxide (Heringa, pers.comm.).

Pathogebous complex: in the present experiments insect larvae, especially larvae of Oscinella frit and leatherjackets (Tipula spp.), fungi and nematodes seemed to be involved in the poor grass growth in grassland soil.

Nematodes: the patterns of damage (for instance, stubby roots and necrotic spots on the roots) and the number of eelworms in the soil and in the roots indicated that especially root eelworms were involved in the sickness problem under discussion. Now and again stem eelworms seemed to be the causing factor. From the literature we know that grasses can be damaged by eelworms (e.g. van Bezooijen, 1979; Cooke & York, 1980; Cooke et al., 1979; Couch, 1962; Kuiper, 1977; Oostenbrink, 1954, 1957 and 1963 and Vargas & Laughlin, 1972).

However, a distinct relation could not be demonstrated between the number of plant parasitic eelworms and yield decrease.

Application of nematicides often decreased the number of nematodes in soil and roots, improved or even overcame the damage patterns and establishment and growth of the grass often were improved. The average dry matter yield of the first cut of the field experiments was therefore distinctly higher with nematicide application; 15% with nematicides only and 22% with nematicides combined with fungicide(s). However, the annual gross dry matter yields only were increased to a limited extent (Table 25).

Table 25. Effect of nematicides on the dry matter yield (kg ha^{-1} per year). See table 3 for exact N dressings.

	N1 (ca 100)	N2 (200-300)	N3 (ca 400)	N4 (ca 600)	average
E 5			1263	340	802
E 6		-533	-953		-743
E 4	486	67	793	1190	633
E 3	1351	1510	1142	778	1196
average	919	348	561	769	472
E 8[1)]	287	2025			1156
E12[1)]			-121		-121

[1)] nematicide + fungicide(s)

In the pot experiments in which nematicides were used, rather varying results were obtained, which were corroborated by others (Ennik, pers. comm.).

The increased yields obtained in the field experiments (average about 5% , corresponding to about 500 kg dry matter ha^{-1} per year) were lower than some reported in the literature. On 6 reseeded grasslands Oostenbrink (1954) found a yield increase in the first cut of 45 to 114% (about 10.000 kg fresh grass per ha). On 61 fields Eissa (1971) obtained an average increase in yield of 32% (average of various nematicides and broad-spectrum fumigants); on another 33 experimental fields the average yield increase was 16% (various pesticides). Ennik & Baan Hofman (1977) after application of a nematicide to established grassland obtained an average yield increase of about 1 t dry matter ha^{-1} per year. On reseeded grassland Spaull et al. (1982) obtained considerable yield increases by aldicarb; application in August gave a yield increase of 69 % and 91% during the rest of the year and, if repeated in spring yield increases of 4.6% and 10.3% during the rest of that year; the aldicarb amounts were 5 and 10 kg a.i., respectively and the data are averages of three ryegrass species. However, Henderson & Clements (1974) and Clements (1978), working with an experimental nematicide did not obtain an increase in the dry matter yield. Woldring (1972), when desinfecting the soil with DD against *Trichodorus teres*, obtained an average increase of the dry matter yield of 12.5 % (1030 kg ha^{-1} per year).

In our experiments the nematicide was applied to reseeded grassland. To what extent crop rotation and nematicides have the same effect with regard to killing the nematodes and limiting grass growth, is not known. On the crop rotation experimental field (E10) applying a nematicide to the rather poorly growing grass, which was sown after grass, gave a yield increase of 22.6%; the grass sown after maize, which grew distinctly better, also produced a higher dry matter yield after application of a nematicide (grass after two years of maize 13.3% and grass after one year of maize 16.0%). The increases in the absolute yields were closer together, 1193 (grass after grass), 1017 (grass after two years of maize) and 1096 kg dry matter ha^{-1} (grass after one year of maize)[1].

Fungi: colouring the roots with cotton blue in lactophenol and isolation showed that, especially the roots from grassland soil contained many species of fungi; many of these are known to be pathogenous. Disinfection with nematicides with or without fungicides sometimes considerably reduced the number of fungi in the roots. The damage to the roots caused by nematodes seem to be entries for the fungi, to entre the roots more easily (Labruyère, 1979).

On the experimental fields the fungicides applied only gave a small increase in the gross dry matter yield: fungicide(s) compared with untreated, 3.6% (comparable increase by nematicides, 8.6%) and fungicide(s) combined with nematicides compared with nematicides only, 2.2% (comparable increase by nematicides 4.7%[2]). Moreover, there was a wide variation (Table 27).

---

1) This experiment was done in cooperation with ir. G.C. Ennik and T. Baan Hofman; the pesticides were applied after mowing the first cut.

2) The yield increase by nematicides combined with fungicides averaged over all the experimental fields was 6.7%.

Table 27. Effect of fungicide(s) on the gross dry matter yield.
(A) = fungicide(s) compared with untreated
(B) = fungicide(s) + nematicide compared with nematicide

	N1 (ca 100)	N2 (200-300)	N3 (ca 400)	N4 (ca 600)	average
E3 (A)	929	751	1302	195	795
E4 (A)	76	-349	-13	202	-21
E3 (B)	184	-517	-33	187	-29
E4 (B)	642	-252	-236	-947	-198
E5 (B)			519	867	693
E6 (B)		221	577		399

On the crop rotation experimental field E10 application of one nematicide and two fungicides gave an increase in the dry matter yield of about 30.6% on the treatment grass after grass (a nematicide only: 22.6%). On both the arable crop treatments the addition of fungicides to the nematicide, in comparison with the addition of a nematicide only, even gave a small yield reduction (2.2% on the treatment two years maize and 7.3% on the treatment one year maize)[1].

Broom et al. (cit. by Wilkins et al., 1981), Clements et al. (1982a), Ennik & Baan Hofman (1977) and Eissa (1971) also attained no or only slight yield increases by the application of fungicides, apart from exceptions.

Insects: despite numerous insects occurring in old grassland (see for instance Clements, 1980 and Franz, 1950) visible damage occurs relatively seldom.

However, from the literature and from practice we know that insects, for instance larvae of the frit fly (Oscinella frit), leatherjackets (Tipula spp.), larvae of chafers (Melolontha, Phyllopertha) and wireworms (Agriotes spp.) may cause damage

[1] This experiment was done in cooperation with ir. G.C. Ennik and T. Baan Hofman (CABO, Wageningen).

(e.g. Clements, 1980; Dwarshuis, 1975 and Klapp, 1971).

Establishing swards are more susceptible than established swards. On two of our experimental fields serious infestation of the larvae of the frit fly (Oscinella frit) occurred in the young sward. On the experimental field E7 establishment on the control was a complete failure, whereas in the treatment with the nematicide (aldicarb) not a sign of damage was found. On the experimental field E5 the young sward without the nematicide was slightly damaged by the larvae of the frit fly and yielded somewhat lower in the first cut. In a pot experiment the young grass plants were completely consumed by leatherjackets.

In these experiments the damage was distinctly related to the small size of the plants; the larvae of the frit fly destroyed almost all the growing points, necessary for growth and the larvae of the crane fly had litle trouble in consuming the small amount of biomass of the grass. The same number of parasites on an old grass sward would have caused much less damage.

Clements (1980), Clements et al. (1982a) and Henderson & Clements (1977), with a view to their experiments in the UK, suggest that insects normally cause considerable damage in establishing and established grasslands. Clements et al. (1982a) established an increased number of seedlings at about one-third of the fields supplied of pesticides (nematicide and insecticide). Henderson & Clements (1976) on young grassland attained a dry matter yield increase up to 5% in the first year and up to 17% in the second year by using dimethoate. By using phorate on young grassland sown with various varieties of Lolium perenne the increase in dry matter yield over a period of four years was 3.85 t ha^{-1} (= 12.2%). Henderson & Clements (1977) on 14 fields attained on increase in the annual yield of 0-32% (average: 11%) and Clements (1978) obtained on grassland to which insecticides (aldrin and phorate) were regularly applied, hardly an increase in dry matter yield in the first year after sowing, but in the next seven years dry matter yield increases of 3-40% (average: 15.5%). However, Clements et al. (1982b) on relatively low productive upland grassland obtained after application of insecticides (aldrin and phorate) a yield increase on only a small part of the experiments.

Interpreting the results of experiments in which pesticides are applied to grassland is difficult, because different factors may cause improvement in grass growth; in addition to killing a particularly harmful species or group of species, different kinds of growth stimulating effects may occur: killing other injurous organisms, retardation of nitrification, increased mineralisation, better growth of clover, killing of weeds, together with or without stimulating some physiological processes in the plant. Opposite these positive effects some adverse effects are possible, e.g. phytotoxicity to the grass, rapid recolonization of parasites and pathogens and killing benificial organisms (Cook et al., 1979; Eissa, 1971; Ennik & Baan Hofman, 1977; Hijink, 1969, and Yeates et al., 1976).

4.5 Effect of earthworms

The effect of earthworms may be important in grassland because generally many earthworms are present and the anthropogenous tillage is mostly limited.

Earthworms may affect the growth of grass in many ways (3.4; Edwards & Lofty, 1977; Guild, 1955; Hoogerkamp et al., 1983; Stockdill, 1959 and Stockdill & Cossens, 1969):

a) Incorporation in and mixing through the soil, fragmentation, mineralization and humification of organic matter of vegetable and animal origin. Preventing the formation of an AO-layer, decreasing the accumulation of organic matter, improving the quality of the organic matter and distributing of it through the profile.
b) Formation of holes and soil aggregates. Aeration, water retaining capacity and infiltration capacity of the soil can be improved in this way.
c) Vertical distribution of agro-chemicals applied to the soil

surface, such as fertilizers and pesticides.

Now and again the production of growth substances is mentioned (Graff & Makeschin, 1980 and Nielson, 1965).

In contrast to these effects, which often increase soil fertility, earthworms may sometimes have an adverse effect on grassland; e.g. by stimulating mole activity and increasing both the risk of treading in wet periods and leaching of nutrients (e.g. calcium).

The influence of earthworms on the agricultural value of grassland may therefore be very complex, the more so, since many of the mentioned factors can influence this value in many ways. For instance, an A0-layer may cause: a reduction in evaporation; less damage by treading; less damage by moles; retention of water, which can evaporate rapidly later on; a lower organic matter content of the mineral soil; reduction of the rooting depth; greater nitrogen losses; production of growth retardants; nitrogen immobilization; more severe damage in extreme weather conditions (drought, heat, cold); promoting disease and pest problems and problems with sod seeding (3.4; Beard, 1973; Canode & Law, 1979; Clements, 1978; Edwards, 1980; Habeshaw, 1980; Kirkwood, 1964; Kleinig, 1966; Ledeboer & Skogley, 1967; Skirde, 1974 and 1980 and Stockdill, 1982).

The extent to which these effects occur may be influenced by the earthworm population (size, age structure, species composition, activity, etc.), the length of the period in which the earthworms were active and by all kind of other factors, like soil type, the activity of other organisms with similar influence, weather conditions and age, use, fertilizer status and botanical composition of the grassland.

The extent to which earthworm activity affects the yield of grassland is, in view of the many effects that earthworms may have on grass growth, variable. In trying to gain a better understanding of the changes in yield affected by earthworms, the following methods are applied:

a) determining a correlation between the biomass of earthworms and grass yield;

b) pot experiments with treatments with and without earthworms;

c) killing of earthworms locally in fields populated with earthworms;

d) local inoculation of earthworms in fields without earthworms, but where the ecological conditions are favourable to this animal species.

ad a. Some authors established a positive correlation between grass yield and number or biomass of earthworms; in New Zealand Sears (1950) found a dry matter yield of 1000 kg per 112 kg earthworms and Waters (1955) 1000 kg ha^{-1} per 170 kg and in Australia Barley (1959) found an annual dry matter yield of 1000 kg ha^{-1} per 80 kg earthworms. Henderson & Clements (1979), however, did not find a relationship between number or weight of earthworms and gross dry matter yield. Moreover, a correlation need not necessarily be based on a causative relation between the two factors; it might be possible that factors stimulating grass growth do the same for earthworms. A causative relation can also be based on an effect of grass growth on earthworms, for instance, via the supply of food.

ad b. Many workers have studied the relationship between earthworms and grass growth in container experiments. The results were most variable; usually, however, earthworms had an increasing effect on grass yield. Nielson (1953) obtained dry matter yield increases varying from 30-120%, Waters (cit. by Stockdill, 1959) of 77% (Lolium perenne) and 113% (the Lolium perenne component in a Lolium perenne/Trifolium repens-mixture) and Hopp & Slater (1948) by adding live or dead earthworms found an increase in the air-dry herbage yield of 350% (when giving also NPK fertilizer this increase was 226%). Van Rhee (1965) found in cage cultures, an increased dry matter yield of 400%.

In these experiments however, only a part of the growing factors that might be influenced by earthworms are considered, since they usually are continued for a period, which is too short to study the effect of compaction of the soil and of the forming of a mat. This also applies to (other) effects caused by grazing cattle, such as scorching of the sward by urine, smothering of the grass by droppings and pulling up tufts of grass. Another argument is that the relatively liberal supply of earthworms in these kind of experiments, via the nutrients supplied in this way, may in itself cause a better grass growth; information on this variant can be obtained by application of the same amount of dead earthworms (see the results of Hopp & Slater, 1948 and 1949).

ad c. and d. Field experiments, in which grassland with earthworms is compared with grassland without earthworms are important, in view of the limitations of the former approaches.

In experiments in which earthworms are killed with pesticides, often other organisms are also killed; when these organisms are harmful to grass growth (for instance, some insect larvae and eelworm species), grass growth may be stimulated; a positive effect is also possible, when in the mineralization of the organisms killed, nutrients are released for grass growth. These might be the causes of the yield increases (up to 40%) obtained by Clements (1978), who applied insecticides to grassland.

Moreover, the favourable effects of the earthworms in these kind of experiments may continue for some time after the earthworms have been killed.

Introduction of earthworms into grassland without these organisms is only effective, if the ecological conditions are favourable to earthworms and food supplies are not limited. Experiments in which yields are measured are only limited. Doeksen (pers. comm.) introduced earthworms in Zeeland after flooding with sea-water and he established improved grass growth; however, yields were not measured here. Van Rhee (1969) in O. Flevoland, where just after reclaiming earthworms did not occur, carried out inoculations of earthworms in young grassland exclusively cut; dry matter yields were not distinctly increased (Table 28).

Table 28. Dry matter yield of grassland (kg ha^{-1}) with and without earthworms in the Netherlands (Van Rhee, 1969).

	+ earthworms		-earthworms
	Allolobophora caliginosa	A.chlorotica	
1965	6550	6720	6450
1966	11540	11830	11590
1967	11570	11840	12090
average	9887	10130	10043

In New Zealand, where earthworms are not naturally present that may increase the agricultural value of grassland and where European species are introduced, similar experiments were carried out. The increased yields obtained in this way were considerable (Table 29).

Table 29. Dry matter yield of grassland with and without earthworms in New Zealand (kg ha^{-1} per year or per ½ year).

	Period	+earthworms	-earthworms	increase abs.	increase %
Stockdill (1966):	½ year (1954)	10472[1)]	18079[1)]	7607[1)]	73
Stockdill (1982):	1 year (1965/'66)	12100	9400	2700	29
	1 year (1966/'67)	8490	7800	690	9
	1 year (1965/'66)[2)]	11180	9400	1780	19
	1 year (1966/'67)[2)]	9630	7800	1830	23

[1)] green material; [2)]just entering.

Stockdill & Cossens (1969) mentioned an average annual yield increase of about 2250 kg dry matter per ha (± 20-30%). Crump & Stockdill (1969) calculated that earthworm introduction for this grassland is a profitable investment. Noble et al. (1970) found in N.S. Wales (Australia) a higher dry matter yield on grassland with earthworms than on grassland without earthworms (2995 and 2732 kg dry matter ha^{-1}, respectively; this difference, however, was not significant).

The present experiments in O. Flevoland carried out on grassland of some 8-10 years old and intensively used gave an average increased gross dry matter yield of about 10% (upwards 1 t ha^{-1} per year) on the areas with earthworms. Because of the great temporal and spatial variability of the yields and the many factors that can be affected by earthworms more experiments are necessary, in which conditions (stress and non stress) are studied under which the favourable effect of earthworms occurs. Other unknown aspects are: dose/effect and duration activity/effect and the possibility of realizing the yield increasing effect (partly) by other measures (e.g. fertilizing).

Earthworms may not only affect the gross yield, but also the value of the dry matter yields for animal production; e.g. by changes in the botanical composition.

To what extent the results found in O. Flevoland can be transferred to soils in the "old land", is not known. Young "undeveloped" soils are involved which may differ in many repects from the older soils: seed bank in the soil, species composition of the sward, activity of the earthworm population (possibly fewer diseases and pests) and activity other organisms, which may have the same effect on (a part of) the growing factors for grass. In the present study when Lolium perenne failed (e.g. by frost or by urine scorching) the bare patches were overgrown by species, which had many viable seeds in the soil (Poa annua, Stellaria media, Capsella bursa-pastoris, Taraxacum officinale, etc.). However, these species are relatively easily suppressed by Lolium perenne, with or without herbicides. When species like Elymus repens are involved, the adverse effects on the net yield of grassland may be greater.

Experiments on the "old land" mostly are difficult, because earthworms are present and killing or removing these earthworms in the control fields will be difficult and may result in side effects.

The limitation in the present study was that there only was one earthworm spot per field, which moreover was situated usually in the middle of the field and which was rather large, because of the lateral spread of the earthworms (about 9 m per year; Hoogerkamp et al., 1983). The areas that were compared in the study (grassland without earthworms and grassland where earthworms had been active for some years) were therefore not optimally situated for the experimental technique. Another drawback was that grazing animals could use the earthworm areas differently from the non earthworm areas.

5 SUMMARY

5.1 Reseeding grassland

Reseeding grassland with a good botanical composition theoretically may result in a rise in productivity, e.g. by introducing more productive varieties, killing injurious organisms, bringing nutrients deeper into the soil and by aeration, loosening and mixing of soil. However, both the present and earlier research (Hoogerkamp, 1974) did not confirm this; on an average the gross N- and dry matter yields were even somewhat decreased.

In reseeding a period, the establishment phase, occurs in which the sward is sensitive to adverse weather and soil conditions (e.g. drought and crust formation, respectively) and to diseases and pests. This can result in yield decreases and even in complete failure of the reseeding.

5.2 Crop rotation

Permanent grassland is in a rather unique situation in agriculture, because it remains in place year after year and may nevertheless give high yields. Yet problems with "grass sickness" may occur also in grassland. However, the effect of a rotation with other crops (e.g. arable crops) on the grassland following may be complex.

Organic matter content of the soil and size of the earthworm population (and of other growth stimulating organisms) may be reduced by growing arable crops. A decrease in organic matter content had a yield decreasing effect on grassland with a low percentage of clover (Hoogerkamp, 1973a); on grassland that is mainly dependent on clover as a nitrogen source the effect may be smaller. A small earthworm population also had adverse effects on gross yield, especially on long duration grassland. If no or few earthworms are present, growing arable crops after grassland may cause decomposition of the thatch layer and may loosen the soil, which may possibly stimulate grass growth in the first time after seeding (see 3.4).

Growing arable crops may also decrease the "disease and pest" potential of the soil. In this, grassland dependent on leguminous species as a nitrogen source should be distinguished from grassland where this is not so. In the former instance, which was not studied in the present experiments, the clover component may be stimulated by the growing of arable crops to such an extent that the yield of grassland is temporarily increased. A decrease in the organic matter content and a reduction in diseases and pests are involved. In grasslands in which clovers are not important soil "sickness" also may have an effect. However, reduction of these diseases and pests by growing arable crops only have a positive effect on productivity, if the disadvantages of growing arable crops, especially the decrease in the organic matter content and reduction in the earthworm population are eliminated. This is not easy to realize, and certainly not in a quantitative way. The best way to do this is to use grassland just sown, in which an earthworm population is not (yet) important and to compensate the main adverse effect of a lower organic matter content, a lower nutrient supply by the soil, by fertilizing; especially the N dressing is important.

Moreover carrying out a study on crop rotation effects is time consuming and expensive. In this research only a limited number of crop rotation experiments was set out (three) and in addition an indirect approach was chosen:

1) pot experiments in which soil was used of comparable grassland and arable crop fields;
2) comparing dry matter yields of old grassland with a good botanical composition with those of reseeded young grassland;
3) comparing dry matter yields of grassland sown after arable crops with that of reseeded grassland.

All these approaches showed that grass sown after arable crops mostly grows distinctly better in the first time and outyields reseeded grassland. The extent of these differences varied widely.

Few experiments were directed at studying the length of the period of the positive effect; however, the findings mostly indicate a short period: about one year.

Deeper rooting with or without a reduced drought sensitivity of young grassland, which are frequently mentioned in the literature and in practice, could be attributed to this effect; grass sown in arable crop soil frequently had a deeper root system than reseeded grass. However, reseeding grassland with a relatively small earthworm population by which the thatch layer disappears and the mineral soil is loosened may also cause deeper rooting.

5.3 Earthworms

In old grassland generally a relatively large earthworm population occurs; a normal biomass, according to the literature, is some 2000 to 2500 kg ha^{-1}; however, ecological conditions have to be favourable to earthworms. In old arable crop soil, the earthworm population is much smaller. So, if arable soil is sown with grass, under favourable conditions to earthworms, the population will increase.

In a new polder in the Netherlands the effect of earthworms on grassland could be studied, because earthworms were not present when this soil was first cultivated and natural distribution of earthworms only takes place slowly. Earthworms were introduced in small spots in grassland. This gave the opportunity to compare in these pastures plots with and without earthworms.

Earthworms may have an important positive effect on the chemical and physical soil fertility. The absence of an active earthworm population, among others, led to the formation of a thatch layer and, in comparison to grassland with earthworms, a higher volume weight, a reduced infiltration capacity of water, a reduced oxygen diffusion rate and a lower water retaining capacity.

Although, the growing conditions (soil type, drainage, use of grassland) were generally favourable to grass growth, the areas with earthworms usually gave a distinctly higher gross yield. Moreover the botanical composition of the sward on soil with earthworms was now and again better than on soil without earthworms. In contrast, however, earthworms may reduce the bearing capacity and might increase the damage by moles.

6 REFERENCES

Alhgren, H.L. (1952). Comparisons of the productivity of permanent and rotation pasture on plowable land.
Proc. of the sixth Int. Grassland Congr. I; Pennsylvania State College, August 17-23, 1952: 356-362.

Alberda, Th. (1968). Dry matter production and light interception of crop surfaces. IV. Maximum herbage production as compared with predicted values.
Neth. J. Agric. Sci. 16: 142-153.

Arens, R. (1971). Neuanlage von Dauergrünland.
In: E. Klapp; Wiesen und Weiden (4th Ed.).
Verlag Paul Parey, Berlin and Hamburg: 326-369.

Barley, K.P. (1959). The influence of earthworms on soil fertility.
I. Earthworm populations found in agricultural land near Adelaide.
Austr. J. Agr. Res. 10: 171-178.

Barley, K.P. & C.R. Kleinig (1964). The occupation of newly irrigated lands by earthworms.
Aust. J. Sci. 26: 290-291.

Beard, J.B. (1973). Turfgrass: science and culture.
Prentice - Hall Inc. Englewood Cliffs, N.J.

Behaeghe, T., M. Slaats & J. Traets (1970). Interim-verslag over blijvende bemestingsproeven op grasland.
Meded. 1970-I van het Nationaal Centrum voor Grasland- en Groenvoederonderzoek, 2e sektie. Rijksuniversiteit, Gent-Fakulteit van de Landbouwwetenschappen.

Boeker, P. (1957). Dauergrünland und ley farming in englischer und deutscher Sicht.
Das Grünland 6: 57-60.

Bezooijen, J. van (1979). Nematodes in grasses.
Med. Fac. Landbouww. Rijksuniv. Gent 44/1: 339-349.

Breese, E.L. & E.J. Lewis (1969). Grasses - species and hybrids.
In: Grass and forage breeding. Occ. Symp. no. 5.; Brit. Grassl. Soc: 15-20.

Canode, C.L. & A.G. Law (1979). Thatch and tiller size as influenced by residue management in Kentucky Bluegrass seed production. Agron. J. 71: 289-291.

Clements, R.O. (1978). The benefits and some long-term consequences of controlling invertebrates in a perennial ryegrass sward. Scientific Proc., Royal Dublin Soc., Series A, Vol. 6: 335-341.

Clements, R.O. (1980). Grassland pests- an unseen enemy. Outlook on agriculture 10: 219-223.

Clements, R.O., N. French, C.T. Guile, W.H. Golightly, S. Lewis & M.J. Savage (1982a). The effect of pesticides on establishment of grass swards in England and Wales. Ann. appl. Biol. 101: 305-313.

Clements, R.O. & R.J. Haggar (1982). Impact and control of pests, weeds and diseases on sward establishment and herbage production. Proc. 9th Gen. Meeting Eur. Grassld. Fed.; "Effect grassland farming" (Ed. A.J. Corall): 69-75.

Clements, R.O., I.F. Henderson & B.R. Bentley (1982b). The effects of pesticide application on upland permanent pasture. Grass and Forage Science 37: 123-128.

Cook, R. & P.A. York (1980). Nematodes and herbage improvement. Welsh Plant Breeding Station, Aberystwyth. Annual Rep. 1979: 177-207. Aberystwyth, 1980.

Cook, R., P.A. York , P.J. Blackman & B.H. Chew (1979). Effect of M. naasi on yield of ryegrass. Welsh Plant Breeding Station, Aberystwyth. Annual Rep. for 1978: 102. Aberystwyth, 1979.

Cooper, J.P. (1969). Potential forage production. In: Grass and forage breeding. Eds. Ll. Phillips and R. Hughes. Occ. Symp. no. 5, Brit. Grassland. Soc.: 5-13.

Cooper, J.P. (1972). Biological potential of simulated swards. Rep. of the Welsh Plant Breeding Station for 1971: 7-8.

Couch, H.B. (1962). Diseases of turfgrasses. Reinhold Publ. Corp., New York and Chapman & Hall, London.

Crump, D.K. & S.M.J. Stockdill (1969). Earthworms - a profitable investment. N.Z.J. Agric. 119 (2): 84-85.

Doeksen, J. (1969). Regenwormen, hun gedrag en betekenis.
Natuurk. Voordrachten Nieuwe reeks 47: 1-8.

Dunger, W. (1964). Tiere im Boden.
Kosmos-Verlag, Stuttgart.

Dwarshuis, E. (1975). Ziekten en plagen in grasvelden.
In: Grasveldkunde. Eds. M. Hoogerkamp and J.W. Minderhoud. PUDOC, Wageningen: 127-149.

Edwards, C.A. & J.R. Lofty (1977). Biology of Earthworms.
2nd ed.; Chapman and Hall, London.

Edwards, R.V. (1980). Slot-seeding-development to commercial introduction.
Proc. 1980 Brit. Crop. Prot. Conf. - Weeds: 637-643.

Eissa, M.F.M. (1971). The effect of partial soil sterilization on plant parasitic nematodes and plant growth.
Meded. Landbouwhogeschool Wageningen; Nederland. 71-14.

Ellison, W. (1953). Marginal land in Britain.
Geoffrey Bles Ltd London.

Ennik, G.C. & T. Baan Hofman (1977). Response of pasture grass to thionazin and other pesticides.
Agric. Res. Reports 867; PUDOC, Wageningen.

Franz, H. (1950). Bodenzoologie als Grundlage der Bodenpflege.
Akademie-Verlag Berlin.

Garstang, J.R. (1978). The transition of a ley to permanent grass over the 10 years following reseeding.
Changes in sward composition and productivity. Occ. Symp. no. 10. Brit. Grassld. Soc. Eds A.H. Charles and R.J. Haggar: 31-39.

Graff, O. & F. Makeschin (1980). Beeinflussung des Ertrags von Weidelgras (Lolium multiflorum) durch Ausscheidungen von Regenwürmern dreier verschiedener Arten.
Pedobiologia 20: 176-180.

Guild, W.J. McL. (1955). Earthworms and soil structure.
in: Soil Zoology; Ed. D.K.McE. Kevan. Butterworths Sci. Publ., London: 83-98.

Habeshaw, D. (1980). Indigenous growth and germination inhibitors and their role in grass survival and pasture management.
Grass and Forage Sci. 35: 69-70.

Hart, M.L. 't. (1950). Organische stof en grasland.
Landb.k. Tijdschr. 62: 532-542.

Henderson, I.F. & R.O. Clements (1974). The effect of pesticides on the yield and botanical composition of a newly - sown ryegrass ley and of an old mixed pasture.
J. Br. Grassld. Soc. 29: 185-190.

Henderson, I.F. & R. O. Clements (1976). The effect of a short-persistence systemic insecticide on the yield of perennial ryegrass.
J. Br. Grassld. Soc. 31: 15-17.

Henderson, I.F. & R.O. Clements (1977). Grass growth in different parts of England in relation to invertebrate numbers and pesticide treatment.
J. Br. Grassld. Soc. 32: 89-98.

Henderson, I.F. & R.O. Clements (1979). Differential susceptibility to pest damage in agricultural grasses.
J. agric. Sci., Camb. 73: 465-472.

Hijink, M.J. (1969). Werking en nevenwerkingen van grondontsmettingsmiddelen.
Landb.k. Tijdschr. 81: 87-92.

Hoogerkamp, M. (1973a). Accumulation of organic matter under grassland and its effects on grassland and on arable crops.
Agric. Res. Rep. 806; PUDOC, Wageningen.

Hoogerkamp, M. (1974). Ley, periodically reseeded grassland or permanent grassland.
Agric. Res. Rep. 812; PUDOC, Wageningen.

Hoogerkamp, M., H. Rogaar & H.J.P. Eijsackers (1983). Effect of earthworms on grassland on recently reclaimed polder soils in the Netherlands.
In: Earthworm ecology; from Darwin to vermiculture (Ed. J.E. Satchell); Chapman and Hall, London.

Hoogerkamp, M. & J.J. Woldring (1965). Ontwatering van rivierklei.
Meded. no. 116, PAW, Wageningen.

Hopp, H. & C.S. Slater (1948). Influence of earthworms on soil productivity.
Soil Sci. 66: 421-428.

Hopp, H. & C.S. Slater (1949). The effect of earthworms on the productivity of agricultural soil.
J. of Agric. Res. 78: 325-339.

Jäntti, A. (1952). Comparisons of the productivity of permanent and rotation pasture on plowable land.
Proc. of the 6th Int. Grassl. Congress I; Pennsylvania State College, August 17-23, 1952: 363-370.

Jaspers, C.P. & J. Kort (1975). Herstellingsvermogen van haver bij aantasting door het graancystenaaltje.
Gewasbescherming 6(1): 1-4.

Kirkwood, R.C. (1964). A study of some factors causing mat formation of reseeded hill pasture swards.
J. Br. Grassld. Soc. 19: 387-395.

Klapp, E. (1954). Wiesen und Weiden.
2th Ed.; Paul Parey, Berlin and Hamburg.

Klapp, E. (1959). Wege zur Verbesserung des Grünlandes nach 24jährigen Erfahrungen des Versuchsgutes Rengen.
Forschung und Beratung, Reihe B. Wissenschaftliche Berichte der Landwirtschaftlichen Fakultät der Universität Bonn, Heft 2.

Klapp, E. (1971). Wiesen und Weiden.
4th Ed.; Paul Parey, Berlin und Hamburg.

Kleinig, C.R. (1966). Mats of unincorporated organic matter under irrigated pastures.
Aust. J. Agric. Res. 17: 327-333.

Kuiper, K. (1977). Introductie en vestiging van planteparasitaire aaltjes in nieuwe polders, in het bijzonder van *Trichodorus teres*.
Thesis Agricultural University Wageningen; H. Veenman & Zonen B.V., Wageningen.

Labruyère, R.E. (1979). Resowing problems of old pastures.
In: Soil-Borne Plant Pathogens. Eds. B. Schippers & W. Gams. Acad. Press. London, New York and San Francisco: 313-326.

Ledeboer, F.B. & C.R. Skogley (1967). Investigations into the nature of thatch and methods for its decomposition.
Agron. J. 59: 320-323.

Leonard, W.F. (1973). New approaches to increasing fodder production. 1. Direct drilling of chou moellier in New Zealand. Outlook on Agriculture 7(4): 168-170.

Lynch, J.M. (1978). Production and phytotoxicity of acetic acid in anaerobic soils containing plant residues. Soil Biol. Biochem. 10: 131-135.

Moore, H.I. (1954). Presidential address. J. Br. Grassld. Soc. 9: 1-6.

Nielson, R.L. (1951). Effect of soil minerals on earthworms. N. Z. J. Agric. 83: 433-435.

Nielson, R.L. (1953). Recent research work; earthworms. N. Z. J. of Agric. 86: 374.

Nielson, R.L. (1965). Presence of plant growth substances in earthworms demonstrated by paper chromatography and the Went Pea test. Nature 208: 1113-1114.

Noble, J.C., W.T. Gordon & C.R. Kleinig (1970). The influence of earthworms on the development of mats of organic matter under irrigated pastures in Southern Australia. XI Int. Grassland Congress; Queensland, Australia, 13-23 April 1970: 465-468.

O'Bannon, J.H. & H.W. Reynolds (1965). Waterconsumption and growth of root-knot-nematode-infected and uninfected cotton plants. Soil Sci. 99: 251-255.

Oostenbrink, M. (1954). Over de betekenis van vrijlevende wortelaaltjes in land- en tuinbouw. Versl. en Meded. Pl.ziektenk. Dienst Wageningen 124: 196-233.

Oostenbrink, M. (1957). Nematoden in verband met de vruchtbaarheid van de grond. Openbare Les uitgesproken bij de openlijke aanvaarding van het lectoraat in de nematologie aan de Landbouwhogeschool te Wageningen op 28 maart 1957. H. Veenman & Zonen, Wageningen

Oostenbrink, M. (1961). Populations of plant parasitic nematodes in meadows. Int. Nem. Symp. VI Gent: 77.

Oostenbrink, M. (1963). Onderzoek aaltjesschade grasland.
Tuinbouwk. Onderz. 1963: 31.

Plumb, R.T. (1978). Invertebrates as vectors of grass viruses.
Sci. Proc., Royal Dublin Soc., Series A, vol. 6: 343-350.

Rhee, J.A. van (1965). Earthworm activity and plant growth in artificial cultures.
Plant and Soil XXII, no. 1: 45-48.

Rhee, J.A. van (1969). Development of earthworm populations in polder soils.
Pedobiologia 9: 133-140.

Sampson, K. & J.H. Western (1954). Diseases of British Grasses and Herbage Legumes.
Univ. Press Cambridge

Satchell, J.E. & K. Martin (1981). A bibliography of earthworm research.
Institute of Terrestrial Ecology; Merlewood Res. Station, Grange-over-Sands, Cumbria, U.K..

Sears, P.D. (1950). Soil fertility and pasture growth.
J. Br. Grassld. Soc. 5: 267-280.

Skirde, W. (1974). Ergebnisse zur Narbenfilzanhäufung (thatch) bei Rasenflächen.
Rasen 5: 105-109.

Skirde, W. (1980). Regenwurmaktivität im Boden nach Ausbau darüber liegender Rasentragschichten.
Z.f. Vegetationstechnik 3: 100-104.

Sonneveld, A. (1948). Overzicht betreffende een enquête door de Rijkslandbouwvoorlichtingsdienst over de inzaai van grasland in 1947.
Stencil CILO, Wageningen.

Spaull, A.M., R.O. Clements & P.G. Mewton (1982). The effect of root-ectoparasitic nematodes on grass establishment and productivity.
Proc. 9th Gen. Meeting of the Eur. Grassl. Fed. "Efficient Grassland Farming" (Ed. A.J. Corrall); Reading: 310-311.

Steenbergen, T. van (1977). Invloed van grondsoort en jaar op het effect van stikstofbemesting op de graslandopbrengst.
Stikstof no. 85: 9-15.

Stockdill, S.M.J. (1959). Earthworms improve pasture growth. N.Z.J. Agric. 98: 227-233.

Stockdill, S.M.J. (1966). The effect of earthworms on pastures. Proc. of the New Zealand Ecological Soc. 13: 68-75.

Stockdill, S.M.J. (1982). Effects of introduced earthworms on the productivity of New Zealand pastures. Pedobiologia 24: 29-35.

Stockdill, S.M.J. & G.G. Cossens (1969). Earthworms a must for maximum production. N.Z.J. Agric. 119: 61-67.

Tischler, W. (1955a). Synökologie der Landtiere. Gustav Fischer Verlag Stuttgart.

Tischler, W. (1955b). Effect of agricultural practice on the soil fauna. In: Soil Zoology; Ed. D.K. McE. Kevan, Butterworths Sci. Publ. London: 215-230.

Turgeon, A.J. (1982). Turfgrass pest management. Proc. of the 4th Int. Turfgrass Res. Conf., Univ. of Guelph, Canada, July 19-23, 1981: 351-368.

Vargas, J.M. & C.W. Laughlin (1972). The role of Tylenchorhynchus dubius in the development of Fusarium blight of Merion Kentucky Bluegrass. Phytopathology 62: 1311-1314.

Voigtländer, G., F. Mädel & F.J. Blaha (1971). Entwicklung und Leistung von Grünlandansaaten im Vergleich zu Dauerbeständen in 6 Nutzungsjahren. Z. Acker- u. Pflanzenbau 134: 93-112.

Voisin, A. (1960). Better grassland sward. Crosby Lockwood and Son Ltd., London.

Vries, D.M. de (1949). Survey of methods of botanical analysis of grassland. Proc. 5th Int. Grassl. Congr.; Noordwijk: 143-148.

Waters, R.A.S. (1955). Numbers and weights of earthworms under a highly productive pasture. N. Z. J. of Sci. and Techn. Section A, 36: 516-525.

Welbank, P.J. (1963). Toxin production during decay of Agropyron repens (Couch grass) and other species.
Weed Res. 3: 205-214.

Wilkins, R.J., J. Morrison & P.F. Chapman (1981). Potential production from grasses and legumes.
In: Jollans, J.L. (Ed.). Grassland in the British Economy. CAS Paper 10. Reading: Centre for Agricultural Strategy: 390-413.

Williams, R.D. (1962). On the physiological significance of seminal roots in perennial grasses.
Annals of Botany, n.s. 26: 129-136.

Woldring, J.J. (1972). Het effect van maatregelen tegen het aaltje trichodorus teres in grasland.
Rapport Proefstation voor de Rundveehouderij no. 9.

Wollny, E. (1890). Untersuchungen über die Beeinflussung der Fruchtbarkeit der Ackerkrume durch die Thätigkeit der Regenwürmer.
Forschungen auf dem Gebiete der Agrikultur-physik 13: 381-395.

Yeates, G.W., W.B. Healy & J.P. Widdowson (1976). Effect of a soil fumigant on the establishment and growth of a grazed pasture on a yellow-brown loam.
N.Z. J. Agric. Res. 19: 397-403.