Changes in productivity of grassland with ageing

Promotor: ir. M.L. 't Hart, oud-hoogleraar in de leer van de landbouwplantenteelt en het grasland.

M. Hoogerkamp

Changes in productivity of grassland with ageing

Proefschrift

ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C. C. Oosterlee,
hoogleraar in de veeteeltwetenschap,
in het openbaar te verdedigen
op vrijdag 6 april 1984
des namiddags te vier uur in de aula
van de Landbouwhogeschool te Wageningen.

Contents

page

STELLINGEN

1

De produktiviteit van grasland kan door stijging van het organische-stofgehalte van de grond toenemen.

Dit proefschrift.

2

Het stikstofrendement van aan grasland toegediende meststoffen wordt niet verlaagd door organische-stofophoping in de grond.

Huntjens, J.L.M. Immobilization and mineralization of nitrogen in pasture soil.
Agric. Res. Rep. 781; PUDOC, Wageningen, 1972.

3

Vruchtwisseling en pesticiden vormen weinig geëigende middelen ter vermindering van bodemmoeheid bij het hedendaagse Nederlandse grasland.

4

Alhoewel Charles Darwin reeds meer dan 100 jaar geleden de gunstige invloed van regenwormen op de bodem wereldkundig maakte en er sindsdien veel onderzoek hieromtrent is verricht zijn nog steeds geen generaliseerbare kwantitatieve gegevens beschikbaar omtrent de invloed van regenwormen op de produktiviteit van grasland.

Darwin, C. The Formation of Vegetable Mould through the Action of Worms.
Faber and Faber, Londen, Fourth impr. (1966).
Dit proefschrift.

5

De huidige grote activiteit op het gebied van de herzaai van grasland is onvoldoende onderbouwd met resultaten van kosten/baten analyses.

6

Door de intensivering van het graslandgebruik, het beschikbaar komen van effectieve en relatief goedkope onkruidbestrijdingstechnieken en de herwaardering van de wilde flora en fauna zijn veel distelverordeningen niet meer actueel

7

Bij het onderhoud van openbaar groen is een vermindering van het gebruik van herbiciden mogelijk; geheel afzien van deze middelen leidt echter tot hogere kosten of tot een beperking van de verscheidenheid van groenelementen.

8

De grote belangstelling voor het kweken van wormen berust niet op een grote actuele of potentiële vraag naar de hierbij voortgebrachte hoofd- en nevenprodukten.

Höbaus, P. Het commercieel kweken van regenwormen en het onderzoek daarnaar.
NRLO, Den Haag. 1983.

9

Bij alternatieve akkerbouw waarbij geen herbiciden worden toegepast, is inschakeling van meerjarige kunstweiden in de vruchtwisseling gewenst om een sterke uitbreiding van overblijvende onkruiden te voorkomen.

Commissie Onderzoek Biologische Landbouwmethoden - Alternatieve landbouwmethoden. Inventarisatie, evaluatie en aanbevelingen voor onderzoek. Eindrapport - oktober 1976. PUDOC, Wageningen. 1977.

10

Het door erkende gewetensbezwaarden militaire dienst laten verrichten van bij hun opleiding passende arbeid is onrechtvaardig tegenover andere werkzoekenden met eenzelfde opleiding.

11

Fietsen verzuurt hooguit de fietser zelf.

Proefschrift van M. Hoogerkamp.
Changes in productivity of grassland with ageing.
Wageningen, 6 april 1984.

Abstract

Hoogerkamp, M. (1984). Changes in productivity of grassland with ageing. Doctoral thesis, Wageningen VIII + 78 p., 11 tables, 7 figs., 128 refs., Eng. and Dutch summaries.

The productivity of grassland may change greatly with ageing. Frequently, a productive ley period, occurring in the first time after (re)seeding, is followed by a period in which productivity decreases. Under conditions favourable to grassland this may be temporary. A production level finally can be attained almost equalling that of young reseeded grassland, but mostly not that of liberally fertilized grassland sown in arable crop soil.

Especially changes in organic matter content in the soil, activity of the earthworm population, the occurrence of "soil sickness" and an insufficient longevity of the sown species can be involved.

Grassland with a high clover percentage in the sward may react differently to these changes than grassland with a low clover content. In the present research usually no clovers were sown.

A decrease in the organic matter content of the soil had a negative effect on productivity; this negative influence was evident almost from sowing onwards, decreased gradually and asymptotically with ageing and could be compensated for the most part by N fertilizing.

Sowing grass in an arable crop soil, with a liberal N dressing resulted in more productive grassland than reseeding. This difference in productivity was only temporary.

A low earthworm population caused mat formation, an unfavourable physical condition and a lower gross yield.

Disappearance of the sown grass species and varieties may result in a decreasing productivity.

Preface

To all those, who have helped in any way to realize this thesis, I wish to express my thanks. Special thanks are due to:

Professor ir. M.L. 't Hart for his stimulating interest, his constructive criticisms both in the research phase and during the writing of this thesis and also for the facilities he offered me to do part of the research on fields used by the Department of Field Crops and Grassland Science of the Agricultural University Wageningen.

Mr. A. Hoogerbrugge and Mr. G. Besselink for their considerable contribution in the experiments.

Ir. G.C. Ennik for his critical comments on the manuscript, Mrs. A.H. van Rossem for translating it in English, Mrs. E.A. Sinnecker for doing all the typing and Mr. G.C. Beekhof for drawing the figures.

Woord vooraf

Aan diegene die, op welke manier dan ook, hebben meegewerkt aan de totstandkoming van dit proefschrift, wil ik graag mijn dank betuigen. In het bijzonder wil ik hierbij noemen:

Professor ir. M.L. 't Hart voor zijn stimulerende en opbouwend kritische inbreng, zowel tijdens de onderzoeksfase als tijdens het schrijven van dit proefschrift en voor de gelegenheid die hij mij bood om een deel van het onderzoek uit te voeren op de terreinen in gebruik bij de Vakgroep Landbouwplantenteelt en Graslandkunde van de Landbouwhogeschool te Wageningen.

De heren A. Hoogerbrugge en G. Besselink voor hun belangrijke bijdrage bij de uitvoering van de proeven.

Ir. G.C. Ennik voor het plaatsen van kanttekeningen bij het manuscript, mevr. A.H. van Rossem voor de vertaling ervan in het Engels, mevr. E.A. Sinnecker voor het vele typewerkwerk en dhr. G.C. Beekhof voor het tekenen van de figuren.

Levensloop

De auteur werd op 11 augustus 1936 geboren te Veendam. Na het behalen van het diploma HBS-B aan het Winkler Prinslyceum te Veendam en het vervullen van de militaire dienstplicht, studeerde hij aan de Landbouwhogeschool te Wageningen. Het ingenieursdiploma werd behaald op 25 september 1961 en het ingenieursexamen omvatte de volgende vakken: de landbouwplantenteelt, de leer van het grasland, de fytopathologie en de regionale bodemkunde.

Op 1 april 1961 trad hij in dienst van het toenmalige Proefstation voor de Akker- en Weidebouw (PAW) te Wageningen, werd op 1 mei 1969 aangesteld bij het voormalig Instituut voor Biologisch en Scheikundig Onderzoek van Landbouwgewassen (IBS) te Wageningen en is sinds januari 1976 werkzaam bij het Centrum voor Agrobiologisch Onderzoek (CABO), dat is gevormd door fusie van het IBS en het Centrum voor Plantenfysiologisch Onderzoek (CPO). Het in deze periode uitgevoerde onderzoek had vooral betrekking op de aanleg en het onderhoud van grasland en grasvelden.

De auteur is momenteel hoofd van de afdeling Onkruidkunde van het CABO.

1 Introduction

The formation of permanent grassland of a good agricultural quality often may be accompanied by many problems. The old saying "to break a pasture makes a man, to make a pasture breaks a man" speaks volumes. Especially the continuation of a high productivity is difficult. The first time after sowing productivity of the grassland usually is relatively good, but after some time often a yield decrease occurs; the grassland deteriorates.

Some consider this deterioration permanent; the productive ley changes over to less productive old grassland. Others consider this deterioration temporary; the productive ley changes over to productive old grassland via a temporary poor period; hence names like "years of depression", "hungry years" ("hunger years"), "sukkelperiode" (Dutch) and "Hungerjahre" (German).

The literature includes many articles devoted to this subject, for instance: Ahlgren, 1952; Arens, 1971; Bates, 1948; Davies, 1960; Elema, 1920; 't Hart, 1950; Klapp, 1954 and Voisin, 1960.

The beginning, duration and intensity of the "years of depression" vary considerably. Formerly the period on heavy soils lasted longer and was more serious than that on sand or peat soils; seeding after a period of arable crops often emphasized the "years of depression" and on mown grassland the "years of depression" were more serious than on grazed grassland.

The deterioration usually started 1 to 4 years after sowing and might last for some 15 to 20 years.

The symptoms of the "years of depression" may include, besides poor grass growth, a yellow colour of the grass, distinct faeces and urine patches (colour and growth), disappearance of the sown plant species (giving bare patches, mosses or deterioration of the botanical composition), accumulation of not or slightly decomposed plant parts at the soil surface and a compacted soil.

Quantitative data on the yield trend are hardly available and if so, age dependent yield decrease cannot always be separated from other changes in the yield, for instance, those caused by weather conditions.

The yield depressions in the "years of depression" may be considerable. Klapp (1954), for instance, calculated from a number of data the following relative yields: 100.0; 73.0; 68.4; 58.6 and 44.3 in 1-5 years after sowing, respectively. 't Hart (1947) in comparing fields on sandy soil, found a yield decrease of about 26% on 5-9 year old fields compared with old grassland.

Sown grassland may deteriorate by many climatic, edaphic and biotic factors. Some of these factors are directly age-dependent and can cause the characteristic "years of depression". Many causes of the "years of depression" are mentioned. The most important are: starvation of nutrients (especially N), adverse physical condition of the soil, absence of a beneficial microflora and fauna in the soil, accumulation of undecomposed or partially decomposed organic matter (mat formation) and a low persistence of the sown species. Experimental work to find the effect of these factors on the "years of depression" has hardly been done. Assumptions on causative relationships are often based on theoretical considerations, on observed changes showing parallelism with the trend in the productivity and on the effect of certain measures on the length and severity of the depression.

The solutions found to avoid this period differed widely. In Great Britain attempts were made to prevent deterioration of sown grassland by breeding grass and clover varieties which yielded higher and lived longer; moreover, farmers mostly were advised to plough up the grassland after a few years and if possible, to include it in a ley-arable rotation. In Germany, however, farmers mostly were advised to improve inferior grassland by management measures, and to avoid ploughing up as much as possible to prevent the "years of depression". In the Netherlands some advocated the ley-arable system and most others permanent grassland; resowing being an important aspect of grassland improvement.

Our study was especially directed at a better understanding of the causes of the "years of depression" and at the development of measures and means to prevent it. With regard to this, we can distinguish two main developments:

1. Detection of soil factors, which cause the poor grass growth in the "years of depression" and of the measures to control these causes or

prevent them; with regard to the latter measures special attention was paid to N fertilizing and the activity of earthworms;

2. Looking for varieties of productive grasses and clovers which are persistent under the prevailing conditions, so that after sowing, a good grass sward is maintained.

In Great Britain breeding of grass and clover varieties for perennial use already started in the twenties of this age, and the value of these new varieties was clearly shown in various studies and in practice (Jenkin, 1930 and 1949 and Stapledon, 1939). For the Netherlands the work of Van Daalen in the thirties and that of Sonneveld in the forties should be mentioned (Van Daalen, 1935, 1937 and 1943 and Sonneveld, 1948b and 1950). The term pasture type was generally accepted in this period as a synonym for a grass variety with which the qualitative decrease in the grass sward could be prevented. However, these varieties gave less positive results with regard to the decreasing dry matter yield. Our research was therefore concentrated on soil fertility factors, affecting growth and productivity of the sown grasses. However, a distinct interaction was shown between age-dependent edaphic causes of the "years of depression" and the persistence of the grasses sown. Low persistence may enhance the results of adverse edaphic conditions, whereas the reverse, a decrease in the persistence caused by adverse conditions, is also possible. Disappearance of the sown species may cause an open grass sward, which in its turn makes the soil more liable to harmful effects on the structure (rainfall, sunshine, trampling, etc.).

Age-dependent edaphic factors causing growth retardations during the "years of depression" are:

a. a low organic matter content and an organic matter accumulation;
b. the formation of a thatch layer (AO-layer);
c. a too low activity of the edaphon;
d. a poor structure of the soil.

These factors may interact; for instance, a low organic matter content may cause a poorer soil structure and less activity of the edaphon.

In our research the effect of a low organic matter content of the soil was studied and the possibilities to decrease the adverse effects of this on grass growth by nitrogen application. In addition attention was paid to a number of aspects of microbial and animal activity in the soil; especially crop rotation diseases and pests ("grass sickness") and earthworm activity. The often stated cause of the "years of depression", a poor structure of the soil, is not studied intensively; moreover, the influence of the structure cannot always be distinguished from those of organic matter and earthworms. With regard to the persistence of the grasses the mentioned pioneer work was continued to a limited extent.

The following aspects will be discussed:

a. the effect of the organic matter content of the soil and N fertilizer application on the botanical composition and productivity of the sward;
b. the effect of the sown variety on the quality of the grass sward and on the yield;
c. the effect of soil structure on productivity of grassland;
d. the effect of mat formation;
e. the effect of a preceding arable crop on establishment and early development of the sown grass and the yield of young grassland;
f. the effect of animal activity in the soil, especially that of earthworms, on grassland.

This paper is a sequel to three preceding ones: Hoogerkamp, 1973a, 1974 and 1984, and relates the changing productivity with ageing, with data already published and with some new results. A description of the experimental fields from which these latter results originate is given in the Appendix (11).

2 Organic matter content of the soil

Mineral arable crop soil generally has a distinctly lower organic matter amount than old grassland soil (Hoogerkamp, 1973a). On a river clay soil this difference for the layer 0-20 cm was 229-113 = 116 t ha^{-1} (Hoogerkamp & Minderhoud, 1966). 't Hart (1950) found on clay soils a difference of 120 and on sandy soils of 60 to 70 t ha^{-1}. Grassland sown on mineral arable soil accordingly has a lower organic matter content than comparable old grassland soil; however, because of an accumulation of organic matter after the arable land is laid down to grass this difference is gradually bridged. A relatively low organic matter content of the soil in which grassland is reseeded can be obtained in other ways as well; by deep ploughing, for instance, this content can be decreased in that part of the soil that is important for productivity.

There is little difference of opinion on the effect of organic matter accumulation under grassland on the growth of arable crops sown after ploughing up the grassland; fertility accumulated during the grassland period generally increases the yields of the relevant crops (Hoogerkamp, 1973a). However, opinions differ considerably on the influence of the organic matter accumulation on the productivity of the grassland itself (Hoogerkamp, 1973a). Davies (1960) noted: "It has often been said that permanent grass builds up fertility - the evidence rather, and more correctly, suggests that old grass swards lock up fertility, particularly in respect of organic residues". Davies considered this accumulated organic matter as a "locked-up capital bearing no current interest", that could only be well used, if the grassland was changed into arable land. In contrast is the experience that the accumulated organic matter may also be of importance to the grassland itself. Practical experience, for instance, showed that the "years of depression" occurred especially on soils with a low organic matter content and was more serious as the preceding period of arable cropping was longer, but was decreased by the application of organic manure and by the excrements of grazing cattle. At first this favourable effect was attributed to improvement of the soil structure and stimulation of the biological activity in the soil, but later evidence was found that especially a more liberal supply of inorganic nutrients was involved, and particularly of nitrogen (Arens, 1971; Elema, 1920; 't Hart 1950 and Klapp, 1954).

In comparing the gross yields of old grassland fields with differing organic matter contents of the soil often little relation is found between the two variables, because the equilibrium level of organic matter and the productivity of grassland are not always affected in the same way by the prevailing conditions.

In our study, in which on the same experimental field different organic matter contents of the soil were applied by changes in the soil profile or by cultivating arable crops, it was shown that this content indeed had a distinct effect on the gross dry matter and N-total yield. A decrease in the organic matter content of the soil gave a yield decrease and an increase in this content enhanced the yield; moreover, on grassland with an organic matter content below equilibrium level both organic matter content and productivity increased with ageing of the grassland. The effects of a decreased and an increased organic matter content of the soil generally diminish with the ageing of grassland (Hoogerkamp, 1973a and Fig. 1).

Sometimes, grassland recently sown in an arable crop soil did indeed give a lower N yield than did comparable old or reseeded grassland, but only a lower dry matter yield with a low N supply (e.g. Fig. 6, quadrant III and II; see for more information 6.2).

With a low organic matter content and a low N application symptoms of the "years of depression" often occurred: poor grass growth, a yellow colour of the grass, an undesirable botanical composition and distinctly better growth and greener grass on the faeces and urine patches.

The yield decreases achieved by reducing the organic matter content of the soil are dependent on many factors, such as the extent to which the organic matter content is reduced and nitrogen supply. The yield decreases can be substantial; on the experimental field ALG 97 (E5-Appendix) the maximum reduction in gross N-total yield was 23% in a period of 13 years (Table 1).

Fig. 1. Relative annual yields of N-total (treatment 2 = 100). Treatment 2 is old grassland (content of organic matter near the equilibrium level); 1 = increased and 3 = decreased content of organic matter. The N fertilizing was mostly 180 kg N ha^{-1} per year (ALG 97 = E5-Appendix = E8- Hoogerkamp, 1973a).

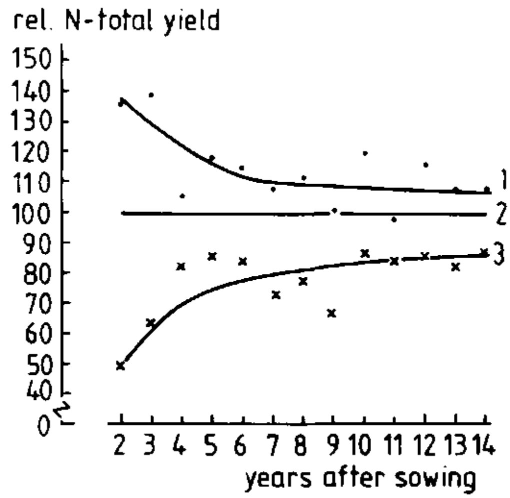


Table 1. Effect of N fertilizer and organic matter content of the soil on the average relative gross N-total yields; between brackets the average absolute yield (kg N ha^{-1} per year). 0N, 1N and 2N mostly were 0, 180 and 360 kg N ha^{-1} per year, respectively (E5-Appendix; duration of the experimental period was 13 years).

	0N	1N	2N
A. High organic matter content	128	113	108
B. Old grassland	100 (233)	100 (349)	100 (413)
C. Low organic matter content	79	77	87

A useful quantification for practice cannot be made with the available data.

The differences in organic matter content of the soil made at the time of (re)seeding, may affect grass growth for a long time (Fig. 1, Table 2 and Hoogerkamp, 1973a).

Table 2. N-total yields (g pot^{-1}) in a glasshouse experiment (E5b) in 1979, in which Lolium perenne was sown in Mitscherlich pots filled with soil from the layers 0-10 and 10-20 cm of the experimental field E5; lay-out of the experimental field in 1965 (see Appendix).

	soil from the layer	
	0-10 cm	10-20 cm
soil with a high organic matter content	1.74	0.15
old grassland soil	1.64	0.14
soil with a low organic matter content	1.07	0.07

Increase in the organic matter content of the soil by, for instance, increasing the moisture retaining capacity and the cation exchange capacity and improving the soil structure may increase soil fertility and with it grass growth. Changes in the organic matter content of the soil may however also have an effect on the net mineralization of N and with it on the N supply by the soil. As the organic matter content of the soil was higher, the organic matter accumulation was lower and the N supply by the soil higher. Sowing grassland in a mineral old arable soil means that the N amount in the young grassland is small and the N accumulation with ageing of the grassland great. The difference in N amount between old grassland soil and arable crop soil, mentioned at the beginning of this section was 9600 - 5800 = 3800 kg N ha^{-1} (Hoogerkamp & Minderhoud, 1966); normally the N amount is about 5% of the weight of organic matter.

On the experimental fields, situated on good moisture retaining soils with a liberal supply of P and K, the differences in the gross dry matter yields were found to be almost completely caused by a difference in the N supply by the soil; indications were: colour of the grass, crude protein and nitrate content in the grass, clover percentage in the sward, effect of N dressing on grass growth and relation between yields of dry matter and nitrogen (Hoogerkamp, 1973a). The gross yields were enhanced by application of mineral N and within the range of the diminishing returns the differences between the treatments with different organic matter contents could be decreased (Table 1 and Hoogerkamp, 1973a).

The results do not demonstrate, whether differences in yield would disappear with optimum N application, because these treatments were not available.

An organic matter content below the equilibrium level of old grassland and therefore a relatively low N supply by the soil may have such a negative effect on productivity i.e. the N demand of this grassland, at least if the sward is poor in legumes, because usually N supply is the most important growth limiting factor. A high grass production requires much N; indicative: 12 t dry matter, a normal annual yield per ha, contains about 350 kg N. Moreover the N inputs by precipitation and by free-living N fixers are relatively low and recycling of N is poor, even under grazing conditions.

However, the occurrence of Trifolium repens may have the same yield leveling effect as N fertilizing, because a higher organic matter content of the soil results in a decrease in this species (Table 1: despite the lower N dressing the dry matter yield on treatment C-0N was higher than on treatment C-1N; this is because Trifolium repens is present). Therefore, the effect of a low organic matter content of the soil with regard to the N supply by the soil, on productivity of grassland rich in legumes may be much smaller than on that of grassland poor in legumes. On the experimental fields, this species was not sown and occurred (probably a natural strain) at a relatively low frequency.

Without legumes in the sward, N recovery in the grass yield usually remained the same or was decreased with increasing total N supply (soil plus fertilizers). N recovery neither decreased with increasing N accumulation, which contradicts the supposition (e.g. Harmsen & Van Schreven, 1955; Huntjens, 1972 and Woldendorp, 1963) that the low fertilizer N recovery in the shoots, about 50-60%, is partly caused by N immobilization in the soil.

Though to a much lower extent, it also applies to phosphate that accumulation of organic matter is accompanied by the immobilization of P. The N:P ratio in organic matter is often about 10:1. In the present study this was ignored; P application was adjusted so far as possible to grass growth not limited by P.

The accumulation of organic matter, which seems to start soon after establishment of the grass, has no distinct lag phase, shows an asymptotic trend and may continue for many years (Hoogerkamp, 1973a). On E5-Appendix in the treatment with a low organic matter content the accumulation still continued after 14 years, while on the "old grassland", at least 20 years older, a small rise occurred also.

Richardson (1938) found an accumulation period for grassland in England of more than 100 years (0-20 cm). 't Hart (1950) estimated the period in which the top (0-5 cm) of an arable soil could be changed into grassland soil, for sandy soil at 10-25 years and for clay soil at 10-15 years. Russell (1960) and Richardson (1938) found a half-life (= time needed to come half-way to the equilibrium content) of about 24 (layer: 0-5 cm) and 25 years (layer: 0-20 cm), respectively.

Quantification of the N accumulation rate is difficult, because of the problems occurring in the detailed analysis of the N amount in the soil (Hoogerkamp, 1973a), the asymptotic trend in the annual N accumulation and the differences in various environments and soils. For two experimental fields the annual accumulated amounts were calculated: about 130 kg ha^{-1} over a period of 11 years for the experimental field E5-Appendix on clay soil and 72-98 kg ha^{-1} over a period of 7 years for the experimental field E5- Hoogerkamp, 1973a on sandy soil (Hoogerkamp, 1980 and 1973a, respectively). These amounts are in the range of 30-190 kg N ha^{-1}, which is often mentioned in the literature (Barrow, 1969; Clement & Williams, 1967; 't Hart, 1950[1]; Huntjens, 1972; Richardson, 1938; Russell, 1960; Vetter, 1966; Walker et al., 1959 and Whitehead, 1970).

The differences in yield caused by differences in organic matter content of the soil, for the most part could be bridged over by a higher N dressing. This seems to be mostly a short term effect. The size of the mineral N application did not have a clear and consistent effect on the rate of accumulation of organic matter and N-total in the soil (Table 3 and Hoogerkamp, 1973a).

[1] N content of the organic matter is supposed to be 5%.

Table 3. Influence of N dressing on N-total and organic matter content of the soil (E5-Appendix; young grassland with a low organic matter content of the soil). 0N, 1N and 2N mostly were 0, 180 and 360 kg N ha^{-1} per year, respectively.

			0N	1N	2N
1. N-total content	(%; 0- 5 cm)	1967	0.11	0.13	0.11
		1972	0.19	0.21	0.22
		1978	0.26	0.31	0.27
	change in 1967-1978		0.15	0.18	0.16
2. N-total content	(%; 5-40 cm)	1978	0.07	0.08	0.07
3. N-total content	(%; 0-10 cm)	1979	0.21	0.19	0.21
	(%; 10-20 cm)	1979	0.04[1)]	0.10	0.12
	(%; 10-20 cm)	1980	0.07	0.08	0.06
4. Organic matter content					
	(%; 0-10 cm)	1979	6.1	5.9	6.1
	(%; 10-20 cm)	1979	3.4	3.1	3.1
	(%; 10-20 cm)	1980	2.8	3.2	2.8

[1)] Undoubtedly this is an incorrect value (see also 3-1980 and 4-1979).

However, because of difficulties in analysing the organic matter and N-total content of the soil exact values for these parameters cannot be obtained and so, neither an accurate estimation of the influence of the N dressing on N-total and organic matter content of the soil.

Another method is to study the growth of grass with the same N dressing. For the experimental field E5-Appendix this is done in two ways: a pot experiment in which soil is taken from the experimental field (E5b) and a field experiment in which the former N levels were replaced by one N level (E5a). The results of these experiments are recorded in Table 4.

Table 4. N-total and dry matter yields of grass from a field (E5a) and a pot experiment (E5b); young grassland with a low organic matter content (E5). The former N levels mostly were 0(=0N), 180 (=1N) and 360 (=2N) kg N ha^{-1} per year (see Appendix).

		0N	1N	2N
1) Dry matter yield E5b:	0-10 cm	36.1	37.5	44.0
(g pot^{-1})	10-20 cm	5.8	6.8	6.3
2) N-total yield E5b:	0-10 cm	0.95	1.07	1.42
(g pot^{-1})	10-20 cm	0.06	0.07	0.07
3) Dry matter yield E5a (t ha^{-1})		7.3	6.9	6.5
4) N-total yield E5a (kg ha^{-1})		208	186	176

The differences were relatively small and not in accordance with each other. In the pot experiment the highest former N level gave the highest yield and in the field experiment this was at the lowest former N level. In a similar field experiment (E1- Hoogerkamp, 1973a) the dry matter yields were about the same for all the former N levels (0, 110, 220 and 330 kg N ha^{-1} per year), the lowest one excepted; here the yield was somewhat higher.

The higher yield in the field experiments at the lowest former N application may be caused by a higher percentage *Trifolium repens*, which developed in the preceding years (On E5 the average dry weight percentages of *Trifolium repens* over the total experimental period were: 24, 5 and 0 on the treatments 0N, 1N and 2N respectively). The increasing N yield in the pot experiment at increasing former N application may be caused by a higher mineral N content of the soil, which was often established in this research and also in research of others (e.g. Prins, 1983).

No evidence was found that the equilibrium levels of organic matter and N-total were affected by N fertilizing.

The mineralization of organic matter can be stimulated by soil tillage (Rippel-Baldes, 1952; Rovira & Greacen, 1957 and Woldendorp, 1963). Reseeding is therefore supposed to increase productivity of grassland (e.g. Klapp, 1954 and Voisin, 1960). However, in our experiments the accumulated N under grassland could not be mobilized by soil tillage for grass growth, at least not when reseeding is performed just after sward destruction. On almost all the experimental fields, on which grassland with a good botanical composition was resown, the gross dry matter and N-total yields were somewhat lower on the reseeded grassland than on the old grassland. During the first year after reseeding the dry matter and N-total yields of the young grassland were 8.5 t ha^{-1} and 261 kg ha^{-1}, respectively, while the old grassland in the same period yielded 9.1 t dry matter per ha and 280 kg N-total per ha (averages of 8 experimental fields; for more details see Hoogerkamp, 1984). Earlier work usually gave the same results (Hoogerkamp, 1974).

This negative effect of reseeding good grassland was increased when the organic matter was brought deeper into the profile (Hoogerkamp, 1973a).

The amount of accumulated N can be reduced by the cultivation of arable crops, but this may have a negative effect on the succeeding grassland (Hoogerkamp, 1973a and 1984).

Under special conditions the accumulation of organic matter can occur on or near the soil surface (A0-layer). Such a mat formation is generally considered unfavourable. The organic matter accumulation and with it the immobilization of nutrients (especially nitrogen) is (probably) greater than with the formation of an A1-layer (Hoogerkamp, 1984 and Kleinig, 1966). Moreover, the mat itself and the lower organic matter content of the mineral soil may have a negative effect on grass growth. However, the bearing capacity of the sward may be enlarged by an A0-layer (see 6.3).

Comparable data on the gross and net yield of grassland with an A0 and an A1 accumulation type are however hardly available. Moreover, other factors that may affect the yield often differ as well; the A0 type of accumulation often is accompanied by one or more adverse growing conditions for grass: shortage of nutrients, low pH, excess or shortage of water, etc..

In a pot experiment a part of the immobilized N in the A0-layer could be mobilized for grass growth (Table 5).

Table 5. Relative N-total yields of a pot experiment in which Lolium perenne was sown in Mitscherlich pots filled with soil collected from grassland with an A0-layer and from grassland with an A1-layer; grassland without and with earthworms, respectively (Hoogerkamp, 1984).

	N dressing			
	N0	N1	N2	N3
A1-layer	100	228	568	920
A0-layer	162	274	614	930

3 Sown species and varieties

In sowing grassland, which is maintained for a long time without reseeding, the aim is to obtain by choice of seed mixture, as soon as possible a sward corresponding to that of good old grassland. Seed mixtures were composed to this purpose which reflected the latter sward. Corrections were applied by decreasing the amount of seed of aggressive species and by increasing the amount of seed of less competitive species. Moreover, species that were not desired or did not thrive were not included in the mixture. In general the mixtures gradually became simpler (fewer species) and Lolium perenne secured a more dominating position.

To prevent a temporary or permanent deterioration of the botanical composition, it is important that (a) species dominating in the initial phase (is) are persistent or can be replaced quickly by other good species. However, maintaining of the most productive species, especially Lolium perenne, was considered almost impossible in the past (e.g. Barenbrug, 1908; Elema, 1924; Schneider, 1927 and Voisin, 1960). The sown species disappeared after some time from the sward, after which a "natural" sward was formed; (mostly) by less desirable species, e.g. by Poa spp. on the good soils and on the poorer soils especially by Agrostis spp. and fine leaved Festuca spp. The unstable young sward transformed into a more stable one, which was adapted to local conditions. On soils which contained few viable seeds and vegetative reproductive organs of grasses (for instance, many previous arable crop soils) the replacement of the disappeared species occurred sometimes very slowly.

Deterioration of the botanical composition is mentioned by many authors as an important cause of the "years of depression" in grassland (Davies, 1952; Falke, 1920; 't Hart, 1950; Jenkin, 1949; Klapp, 1959; Sonneveld, 1951 and Thomas, 1969).

Deterioration of the botanical composition may be caused by:

- the use of short living species which do not (sufficiently) reproduce naturally (for instance: Lolium multiflorum);
- the use of short living ecotypes of perennial species;
- adverse ecological conditions for the sown species;

-low competitive ability of the sown species.

If short living species are used in such amounts that they dominate in the sward, so that after they disappear there is a risk that the perennial species sown cannot replace them (at short notice), the natural ability of the soil to form a sward is important.

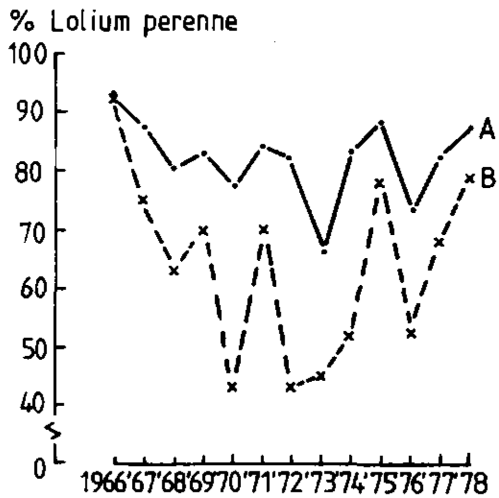
Because of the dominance of Lolium perenne in the sowing of long duration grassland at present (see for instance Fig. 5), the performance of this species is specially important.

To keep Lolium perenne in the sward often used to be impossible; Barenbrug (1908) therefore advised not to use this species for sowing permanent grassland. Various other authors also report bad experience with this species (e.g. Arens, 1963; Baur, 1940 and Klapp, 1943 and 1959).

Selecting Lolium perenne from old pastures, for example by Stapledon and Jenkin in Great Britain and Van Daalen and Sonneveld in the Netherlands, succeeded in varieties that persisted much better than those on the market at that time ("commercial varieties"). In experiments of Van Daalen (1935, 1937 and 1943) the "commercial varieties", mostly hay strains, gave early shooting plants that disappeared relatively soon for the greater part from the sward; the improved varieties consisted of leafy and prostrate plants that remained longer in the sward. Creating better ecotypes was continued successfully.

Results of this improvement for the botanical composition are shown by the results of the experimental field ALG 119 (E1-Appendix) (Fig. 2).

Fig. 2. Trend in the dry weight percentages of Lolium perenne; averages of the two highest N-levels (E1-Appendix). Sown in spring 1966. A = a new variety and B = an old variety of Lolium perenne.



The old variety used here, however, was already much better than the "commercial varieties" used in the earlier past. Results of experiments in which the modern varieties are compared with the "classical" varieties are not available.

The ability of improved varieties to remain longer in the sward may be based on various characteristics: persistence, winter hardiness, drought resistance, disease and pest resistance and competitive and recovery ability. Of these characteristics persistence is perhaps the most important.

Persistence usually means the ability of a species to remain present sufficiently viable in monocultures, at least when this is not distinctly based on winter hardiness, or drought, disease and pest resistance. Persistence is an empiric quality, the origin of which is only partly known. Separation of the other properties is, however, not always possible, and certainly not in practice. Between the varieties of Lolium perenne there are great differences in persistence. These differences often increase, as the growing conditions are more adverse; the order in persistence often shows correspondence under different conditions (though not always) (Camlin & Stewart, 1976; Ennik et al., 1980 and Scheijgrond & Vos, 1960).

With respect to winter hardiness Lolium perenne also shows intervarietal differences (Arens, 1963; Baker & David, 1963 and Copeman, 1964). Winter hardiness was found to be better in the selected varieties than in the "commercial" seed from the past (Sonneveld, 1948a). Despite the attempts at further improvement, winter hardiness is still relatively weak in Lolium perenne. With respect to this, problems did occur in some years on the experimental fields (1961/'62; 1962/'63; 1978/'79 and 1981/'82).

A distinctly direct relationship between winter damage of Lolium perenne and the age of grassland was not observed in our study; the damage by frost was however limited. Baker & David (1963) suggested on the contrary that the risk of failure by frost increased with the ageing of the ley. In the earthworm study, grassland without earthworms had been more damaged in the winter of 1981/'82, than grassland with earthworms (Hoogerkamp, 1984).

Lolium perenne occurs naturally in maritime areas and especially on the rich and heavy soils and on the moisture retaining fertile sandy soils. The species is susceptible to nutrient deficiency (nitrogen, phosphate and potassium), moisture excess and drought, and specially when competing with less susceptible species. Under grazing conditions the species usually grows better than under cutting for winter feeding (especially haying). Since a more liberal N supply in the past often was achieved by Trifolium repens, these two species often accompanied each other. Because of increased dressing, especially of N, and the following increased frequency of harvesting, the influence of the other ecological factors has decreased (Arens, 1963 and Klapp, 1965).

Because of the rapid germination and early growth of Lolium perenne the effect of ecological conditions is relatively limited in young grassland and grows more important with ageing (Arens, 1963).

Adverse ecological factors partly are and partly are not age-dependent; for instance, a too high water table and adverse weather conditions (drought, frost) belong in the latter category. However, the not age-dependent factors can cause more damage in distinct age classes; for instance, the sward may be rather susceptible to stress especially in the "years of depression".

Of the age-dependent adverse ecological conditions for Lolium perenne, N shortage, caused by a combination of accumulation of organic matter, low N application and a low clover content can induce a deterioration of the botanical composition. In theory P deficiency, which may be unfavourable to Lolium perenne, may also occur with organic matter accumulation (see 2). Low earthworm activity may also bring about a deterioration of the botanical composition (Hoogerkamp, 1984 and Voisin, 1960). The first time after (re)seeding, when the influence of anthropogenous soil tillage is still present, this effect is much less distinct than in the succeeding period when an AO-layer has been formed and the soil structure is deteriorating. In fields where the ecological conditions for earthworms are favourable and a start population is present, this situation may be ended when a grassland population is formed.

For Trifolium repens rotation with other crops is important to prevent "clover sickness" (see 6.2). Though it was not demonstrated in our research, it may be assumed that crop rotation diseases and pests are also important in keeping Lolium perenne in the sward. When Lolium perenne is sown on a soil free of "grass sickness", it grows well, but when in the course of time "disease and pest stress" grows, the risk is greater that the species fails or is suppressed by other species. The importance of diseases and pests may decrease again at a later stage by the "decline effect" (see 6.2).

A rather striking phenomenon occurred in fields in which Elymus repens (formely: Elytrigia repens or Agropyron repens) had been controlled. In the third and fourth year after sowing explosive development of this species occurred rather frequently (Table 6 and Hoogerkamp, 1975).

Table 6. Dry weight percentage of Elymus repens in ageing grassland. N1 = average 212 kg N ha^{-1} per year and N2 = average 379 kg N ha^{-1} per year. A, B, and C times of the first cut; averaged 1-2; 4.4-5.0 and 7.3-7.7 t dry matter ha^{-1}, respectively (E6-Appendix). Sowing took place in spring 1976.

	No Ely planted						Ely planted					
	N1			N2			N1			N2		
	A	B	C	A	B	C	A	B	C	A	B	C
1977	10	4	2	2	6	6	4	3	7	3	13	9
1978	1	2	3	4	2	8	6	8	8	7	6	12
1979	3	7	18	15	14	25	35	36	40	44	40	60

This increase in Elymus repens may be caused by both a decreasing competitive ability in Lolium perenne and by an increasing competitive ability in Elymus repens; for instance, by the build-up of the rhizome system. The results of CABO 1783 (E6-Appendix), in which a higher initial level caused more explosive development indicate this. In the past, when grassland was less fertilized, Elymus repens was much less important, than at present (Hoogerkamp, 1975).

An important aspect of maintaining a good botanical composition is the ability of Lolium perenne to recover from a set-back (Fig. 2; 1979). Recovery is possible either by germination of seeds or by spreading of the remaining individuals because they are better adapted to local conditions or because ecological conditions for Lolium perenne have improved. Lolium perenne is at a disadvantage in this respect, because mostly only a small number of viable seeds of this species occurs in the soil (Van Altena & Minderhoud, 1972 and Davies, 1952). Furthermore, the species hardly forms stolons and rhizomes; recovery therefore has to come mainly from tillering and this only occurs to a limited extent. In tillering and recovery the pasture types were superior to the hayfield types of the early "commercial" seed (Sonneveld, 1948a and 1950 and 't Hart, pers. comm.). Genetic variation of the Lolium perenne sown, may be important in this recovery.

If in addition to genotypes that cannot withstand the prevailing growing conditions, genotypes are sown that can, recovery may start from these. In the experimental field ALG 119 (E1-Appendix) the persistent variety of Lolium perenne was still present fifteen years after sowing; by then the less persistent variety probably had been replaced by another ecotype (Elgersma & Scholte, 1982). Increasing the "genetic variation" of varieties or using blends may result in a higher frequency of Lolium perenne. (Relatively) unfavourable growing conditions for Lolium perenne and the presence of species difficult to suppress by Lolium perenne will retard this recovery.

Although a good botanical composition of the sward may be important and much attention is paid to this in the breeding of grasses, the number of quantitative data on the effect of the botanical composition on thè gross dry matter yield, the yield of metabolizable energy, the utilized output and the yield of animal products is only limited. Moreover, the available results vary widely, depending on the following factors:

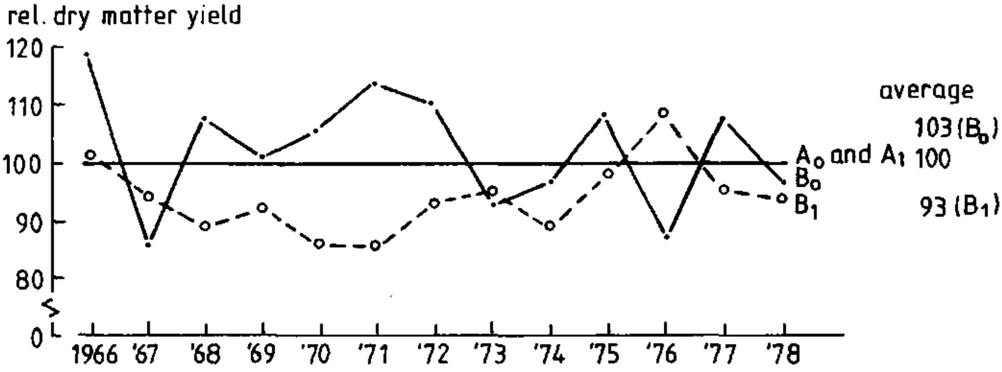
- The rate at which the disappearing species is (are) replaced by other species. This is dependent on the rate and pattern of disappearance and on the possibilities of other species to occupy the open spaces. Open places that cannot be rapidly filled in may cause serious yield decreases. This may occur, for instance, in fields with few seeds or vegetative reproductive organs in the soil (e.g. arable crop fields) and in fields where many plants of the sown species disappear rapidly. An open grass sward may also cause a deterioration of soil structure and damage by treading.
- The species and ecotypes that replace the original species and varieties. Both the agricultural value and the possibility that the substituting species, with or without control measures, are replaced by desired species vary widely. Species as Poa annua and P. trivialis are suppressed more easily by Lolium perenne than Elymus repens. Dicotyledonous species (Stellaria media, Capsella bursa-pastoris, etc.) can be easily controlled selectively. Since chemical composition, palatability and digestibility may vary widely, the gross dry matter yield is a poor standard for the agricultural value of grassland; yields of digestible energy or rather still animal production are better parameters.

- Possibly, a certain threshold value has to be passed before effects on the yield are manifested. Aldrich & Camlin (1978) gained the impression that, when the percentage of *Lolium perenne* did not drop below 70-75%, a yield decrease did not occur.
- Differences in agricultural value between species and ecotypes, those of *Lolium perenne* too, may be affected by growing conditions and use. Cooper (1969), for instance, at low N applications found few differences in the dry matter yields between some varieties of *Lolium perenne*, whereas he found great differences at high N applications.

The effects that the disappearance of the sown species may have, vary therefore considerably. The available data also show this.

On the experimental field ALG 119 (E1-Appendix), where more and less persistent varieties were sown, the differences in gross dry matter yield were only small. At the two highest N levels the treatments sown with the persistent varieties yielded somewhat higher; on the ON treatment, where *Trifolium repens* occurred to a liberal extent, the dry matter yield of the treatment sown with less persistent varieties was, however, somewhat higher than of the treatment with the more persistent varieties (Fig. 3).

Fig. 3. Relative dry matter yields. A = 100 (new varieties) and B = old varieties. 0 = without fertilizer N; 1 = average yields of the treatments dressed with mostly 180 and 360 kg N ha^{-1} per year (El-Appendix).



On the same experimental field, even the average dry matter yield of the treatment not reseeded only was somewhat lower than that of the sown treatments (Table 8).

Green & Corrall (1965) in comparing bred and "commercial" varieties of Lolium perenne, mainly under grazing conditions, found in the former varieties less ingression of non-sown species, but also a smaller spread of Trifolium repens; on an average the total gross dry matter yields were almost the same. Camlin & Stewart (1978) found on cut grassland low correlation coefficients between persistence and the total dry matter yield of Lolium perenne in the fourth year. Ennik (1980) on the other hand, found in an experiment on grassland heavily fertilized with nitrogen, exclusively cut (causing a rapid decrease in Lolium perenne) and sown in arable crop soil in a newly reclaimed polder soil (few seeds and vegetative reproduction organs), already in the second year rather wide differences in total dry matter production; for the most persistent varieties of Lolium perenne the relative dry matter yield was 100, for a somewhat less persistent variety 83 and for the least persistent 69. Scheijgrond et al. (1955), using Lolium perenne varieties with a divergent persistence, did not find a difference in average dry matter yields.

Other workers also found mostly small differences when comparing persistent with less persistent varieties (Table 7).

Table 7. Relative dry matter yields at sowing <u>Lolium perenne</u> varieties with diverging persistence. P1, P2, P3 and P4 is the order of decreasing persistence; y = year; wt = pasture type; ht = hay type.

		moist sandy soil[1]		dry sandy soil[1]	
		1°y	2°y	1°y	2°y
Van Dijk (cited by Ennik, 1980)	P1	100	100	100	100
(cutting experimental field)	P2	95	94	96	91
	P3	88	96	93	87
	P4	65	84	94	68

		average of the first 4 y.
Anonymus (1971)		
(grazing experimental field)	P1 (ht)	100
	P1 (wt)	96
	P2 (ht)	89

		clay soil			sandy soil	
Anonymus (1978)		1°y	2°y	3°y	1°y	2°y
(grazing experimental field)	P1[2]	100	100	100	100	100
	P2	120	119	99	105	89

		sandy soil		
Visscher (1981)		1°y	2°y	3°y
(grazing experimental field)	P1 (wt)[3]	100	100	100
	P2 (wt)[4]	94	95	92
	P1 (ht)[5]	100	100	100
	P2 (ht)[6]	96	87	95

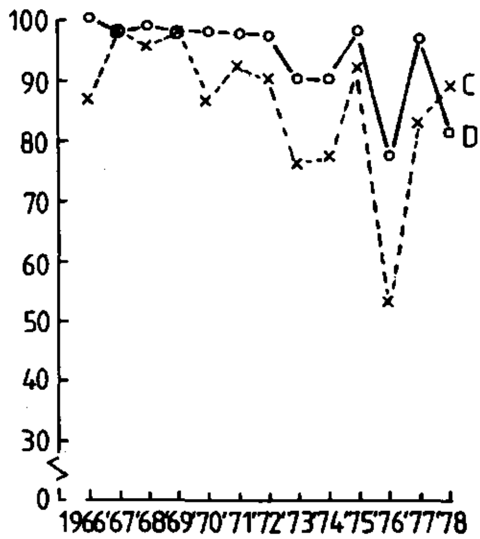
1) green material; 2), 3), 4), 5) and 6) average of 2, 13, 11, 15 and 9 varieties, respectively; 3), 4), 5) and 6) average coverage in the second and third year was 66-80%, 50-65%, 66-80% and 50-65%, respectively.

Because of the replacement of the sown species by non-sown species the differences in gross yield under grazing conditions mostly were limited. However, the age of the experimental grassland was restricted. In some cutting experiments greater differences were obtained; Lolium perenne is here less persistent than under grazing. A complication in these experiments is that the persistence and the yield potential cannot be separated.

Results of experiments in which animal production of grassland sown with persistent and less persistent varieties were compared are hardly available. Prendergast & Brady (1955) did not find differences in live weight gain between bred and "commercial" strains. Scheijgrond et al. (1955) using Lolium perenne varieties with divergent persistence, found an average higher yield of starch equivalent and more heifer grazing days on the grassland sown with the least persistent varieties; this was probably so because Trifolium repens was stimulated by the decline in Lolium perenne (this did not occur on the areas where the dry matter yields were estimated and which were protected by cages). Indeed in various studies a positive correlation was found between the animal output, or comparable data (e.g. the metabolizable energy output) and the proportion of preferred species (especially Lolium perenne) in the sward, but this correlation often was indirect (Collins & Murphy, 1978; Dibb & Haggar, 1978 and Peel, 1978).

By improving the persistence, winter hardiness (and perhaps resistance against drought, diseases and pests) and the ecological conditions for Lolium perenne, especially soil fertility, drainage, use and sometimes water supply, a grass sward mainly consisting of this species can be maintained for a long time (unlimited ?). Fig. 2 and Fig. 4 show examples.

Fig. 4. Dry weight percentages of good grasses (mainly Lolium perenne and Phleum pratense, Poa pratensis and Festuca pratensis); C = soil with a high and D = soil with a low organic matter content (E5-Appendix). N dressing usually 360 kg N ha^{-1} per year.



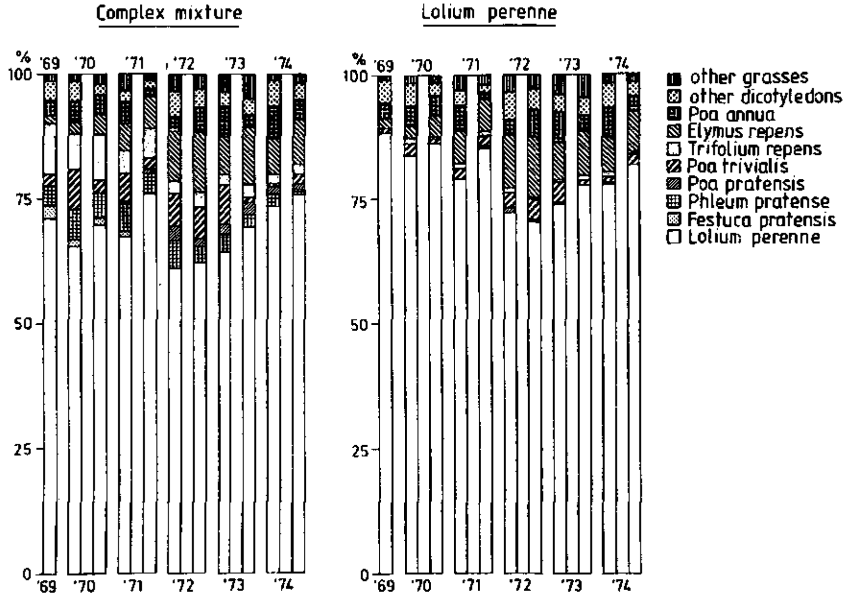
Other studies also showed this (e.g. Andries & Van Slijcken, 1965; Garwood & Tyson, 1978; Hoogerkamp, 1973b and Zürn, 1971).

Deterioration of the botanical composition of (young) grassland, despite the mentioned improvements, is still an important phenomenon, also in modern grassland management; especially on sandy soil this often is a problem (De Gooijer, 1973; Hoogerkamp, 1973b; Idle, 1975 and others). To what extent this is also caused by the occurrence of the "years of depression" cannot be established from these results, because comparable data of old grassland are not available. In comparison with the situation in the past, much has been improved. The varieties of Lolium perenne used have been much improved and the organic matter accumulation causing immobilization of nutrients is usually compensated by fertilizing. Soil-borne diseases and pests and sometimes, low earthworm activity may still cause problems . Further improvement of the persistence of Lolium perenne is probable (Ennik, 1980).

A modern risk to the botanical composition is the mismanagement, evoked by the sharp rize in N fertilizing of the grassland: because of a more rapid grass growth the risk of too heavy silage or hay cuts has increased. In addition erroneous application of slurry and the increased risk of scorching of the sward by urine may be negative side-effects of this rize. Other factors, which may be responsible for the present day deterioration are a field period of the hay that is too long, poor management of grassland and mechanisation of field work. The rapid increase in Elymus repens, for instance, is difficult in this respect (Andries & Carlier, 1976; De Gooijer, 1975 and Hoogerkamp, 1975).

A solution for the problems occurring generally in monocultures, for instance, in those of Lolium perenne, might be species rich grassland. Apart from the effect this would have on the yield (e.g. Van den Bergh, 1968), under the present conditions it is difficult to realize these mixed swards. In experiments in which sowing exclusively Lolium perenne was compared with the sowing of mixtures, in which other species (Phleum pratense, Festuca pratensis, Poa pratensis, P. trivialis and Trifolium repens) were included, it was shown that these latter species could only establish to a limited extent and were seldom successful in occupying open places caused by the failure of Lolium perenne (Hoogerkamp, unpublished data and Fig. 5).

Fig. 5. Average botanical composition (estimated percentage of ground cover) on a number of grasslands sown with a complex mixture or with Lolium perenne only (IBS series 1969 = E4-Appendix).



Three years after sowing the percentage of non-sown species was about 20-25; this percentage hardly differed on the Lolium perenne treatments and on the treatments sown with the complex mixture.

On two experimental fields (E2 and E3-Appendix) the ingression of non-sown species was even greater on the treatments sown with a complex mixture than on those sown with Lolium perenne only. However, the findings mentioned in the literature differ sometimes (e.g. Behaeghe & Slaats, 1968; Andries & Carlier, 1976 and Chestnutt, 1974).

"Selbstberasung" (making grassland without seeding or planting): in the German grassland literature an intensive discussion occurred, especially at the time when persistence of the varieties was low, about making a sward by natural vegetation; in this way species and ecotypes would establish that were better adjusted to local conditions. Especially in those fields, which had not been under arable crops for a long time, this method was applied in certain areas (Arens, 1963; Epple, 1962 and Klapp, 1954).

On the experimental field ALG 119 (E1-Appendix) this system was applied in a field on river clay soil, which after being at least 20 years under grass, was grown for one year with a cereal crop. Compared with the sown treatments the non-sown treatment was occupied less rapidly with a sward, the percentage of good grasses remained distinctly lower for a long time and the gross dry matter yield was somewhat lower (Table 8).

Table 8. Dry weight percentage of good grasses (Lolium perenne, Festuca pratensis, Phleum pratense, Poa pratensis and P. trivialis) on the sown (A) and non-sown grassland (C) and the relative dry matter yields (I) of the non-sown treatment (the yield of the sown grassland was set at 100). (E1-Appendix; usually 360 kg N ha^{-1} per year).

	1966	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76	'77	'78
C	-	41	46	27	24	37	38	53	53	63	64	67	95
A	97	98	99	98	95	93	97	75	93	95	81	91	85
I	31	86	86	79	79	85	96	95	85	99	91	94	87

Although conditions were relatively favourable (short arable period and good ecological conditions) the results were not promising. These results agree with those of other experiments (e.g. Baur, cit. by Klapp, 1954). For a good result a large seed bank is necessary of viable seeds of good grassland species. Since the number of viable Lolium perenne seeds in the soil is usually too small for a Lolium perenne dominant sward, this is not a useful method under our circumstances.

An aspect of the deterioration of the botanical composition which was excluded in our study, but which may be important with respect to the "years of depression", is the decrease in the percentage of Trifolium spp; sometimes the short living T. pratense, but especially the perennial T. repens.

In sowing under conditions of low N supply, Trifolium repens can establish if the other growing conditions are favourable (mineral supply, pH, weather conditions, management etc.). Especially sowing in arable land may often be successful (Ennik, 1982 and Scheijgrond et al., 1958a).

The sown *Trifolium repens* mostly is not truly persistent, but the persistence, has been distinctly improved in the last decennia (Davies, 1960 and Scheijgrond et al., 1958b). Moreover, the species is relatively sensitive to crop rotation diseases and pests and to many adverse climatic and edaphic conditions and the percentage of *Trifolium repens* often decreases with an increasing organic matter content in the soil.

Trifolium repens therefore is liable to disappear partly or completely from the sward, which may have an adverse effect on the yield, especially if this grassland is dependent on this species for its nitrogen supply.

Various authors considered the decrease in clover percentage as an important cause of the "years of depression" (Elema, 1920; Guyer, 1964 and Steen, 1966).

4 Physical condition of the soil

Many authors considered the "years of depression" to be caused especially by too heavy compacting of the soil (e.g. Elema, 1920; 't Hart, 1950; Klapp, 1943 and 1954; Klitsch, 1932/'33 and Voisin, 1960). By soil tillage before (re)seeding the soil is loosened and because soil tillage is omitted afterwards compaction occurs; especially on heavy soils with a low organic matter content the effect of this compaction was considered to be negative. Old grassland, however, usually has a relatively high pore volume (Hoogerkamp, 1973b and Klapp, 1954); a high organic matter content, a high activity of the soil fauna and a closed sward may be important in this. The build-up of a good physical condition may take a long time. Low (1950) found the process of restoring crumb structure often takes much more than 25 years.

Too much compacting may have all kind of adverse effects on plant growth (also on the growth of grasses): e.g. O_2-shortage, CO_2-excess, water excess, a low water holding capacity and mechanical hampering of root growth (Russell & Mac Donald, 1949). Some weed species (Juncus spp; Carex spp etc.) can come foreward on compacted soils, whereas also mosses, in an open sward, have a chance to develop.

Quantitative data about the relation between these parameters of the physical state of the soil and the productivity of the grassland and the botanical composition of the sward are hardly available and a causal relation between a poor physical condition of the soil and the "years of depression", in which the latter situation is caused by the former, however, has never been demonstrated.

In our studies a relation between the compactness of the soil and the yield of grassland could not be demonstrated (Hoogerkamp, 1973b) and neither did reseeding result in a yield increase (Hoogerkamp, 1974 and 1984). Other studies showed, moreover, that grasses are relatively little susceptible to poor aeration of the soil (Heinonen, 1953 and Van Wijk, 1980).

Later research in which the activity of earthworms was studied indicated distinctly that without earthworms considerable compacting of the soil may occur. To what extent this causes a lower yield, cannot be established from the results, because there are more differences between the earthworm and non-earthworm areas. However, in the present research the total differences in gross yield were limited; the literature mentions greater differences (Hoogerkamp, 1984).

A great effect as mentioned in the older literature does not seem likely. More research in which soils are included with an agriculturally poor physical status is necessary for a better understanding.

Perhaps compacting of the soil was more extreme in the past, because the species sown partly disappeared from the sward in the "years of depression", so that an open sward occurred; a permanent soil cover reduces such a deterioration ('t Hart, 1950; Heinonen, 1953; Russell & Mac Donald, 1949 and Schneider, 1927).

5 Mat formation

Some time after seeding grassland the development of a mat, a layer of not or partially decomposed organic matter, on or near the surface of the soil is possible. Mat formation frequently occurred in old grassland; an exception was formed by the best quality pastures (Davies, 1960 and Orr, 1928). Bates (1948) established a start of this mat formation in the second year and the permanent grassland situation was attained in five or six years. Mat formation did not only occur when mat forming species (Agrostis spp. - A.stolonifera and A.canina -, fine leaved Festuca spp - Festuca rubra and F. ovina -, etc.) were present, but according to Bates (1948) also in swards with Lolium perenne. However, in our experiments mat formation in swards with Lolium perenne as the dominating species, only took place in the absence of earthworms (see 6.3).

Mat formation is generally considered unfavourable for grassland. 't Hart (1950) mentions this type of accumulation of organic matter as a symptom of the "years of depression". Bates (1948) concluded that mat formation together with the simultaneous increase in the number of tillers (overcrowding) was the main reason for the deterioration occurring some years after sowing. However, a mat may have a positive influence on the bearing capacity of the grassland.

Causes of mat formation mentioned in the literature are:

a) acidity of the soil; this may result in a restriction of the earthworms and of distinct types of microorganisms. Liming reduces the weights of the mats, probably by stimulating the microbial activity and, in the long run also earthworm activity (Kirkwood, 1964 and Troughton, 1962);
b) N-shortage; N fertilizing might stimulate the biological activity and remove a present mat (Davies, 1960). However, Troughton (1962) did not find a decrease in mat weight by fertilizing with a combination of N, P and K, but he did with a combination of Ca, N, P and K. Orr (1928) suggested Trifolium repens as one of the remedies against mat formation;
c) Absence of digging and mixing animal species, especially earthworms (see: 6.3 and Hoogerkamp, 1984);

Furthermore an excess of moisture and extreme drought may also result in an accumulation of roots (Kmoch, 1952).

These factors can cause a deterioration of the grassland; sometimes, especially c and perhaps to some extent b, this deterioration can have a temporary character (the "years of depression").

In the present research no mat formation was observed on the experimental fields on the "old land", not even on the treatments low in N (soil N and fertilizer N). In O. Flevoland, however, the absence of earthworms resulted in mat formation, even if mat forming grass species did not occur. When earthworms were introduced the mat was removed (see 6.3.).

6 Soil microflora and soil fauna

6.1 Introduction

Old grassland compared with arable soil contains large populations of soil organisms (bacteria, fungi, nematodes, earthworms, arthropods, mammals, etc.); after sowing grassland in arable soil these populations usually increase until the variable equilibrium level of old grassland has been attained (e.g. Arens, 1971; Franz, 1950; Tischler, 1955b and Voisin, 1960).

The permanent soil cover with a vegetation, the limited soil tillage, the low pesticide application and the considerable amount of organic matter supplied to the soil by dying roots and leaves and by faeces and organic manure can be mentioned as causes.

Quantitative findings on the total biomass and its composition are few. Most of these are on earthworms (see 6.3).

A part of the organisms present in grassland soil is (facultatively) phytophagous or parasitic (for instance, various fungi, nematodes and insect larvae), but another part may have a positive effect on soil fertility: mineralization and humification of organic matter, mixing and loosening the soil, etc.. We do not exactly know the influence of these organisms on productivity of grassland and persistence of the sown species.

A difficulty in studying the positive and negative effects of the edaphon is that partial elimination, for instance by application of pesticides or by crop rotation, is only possible to a limited extent. Moreover, estimating the yield of grassland is relatively difficult and comparison of grassland in which organisms with a positive or negative activity are present or not is possible only seldom.

In our research some aspects of this problem were studied and the findings are related to the "years of depression". The aspects studied were the effect of earthworms and the occurrence of diseases and pests when grass is sown after grass and after arable crops.

6.2 Diseases and pests (especially "grass sickness")

Grass is usually grown in the same field for many years and sometimes even permanently. Yet, both in the literature and in practice diseases and pests related to the age of grassland or preceding crop ("grass sickness" or "grass sick" soil) are hardly mentioned. It is even said that these kinds of problems do not or hardly occur in grassland. Several (theoretical) arguments in favour of the latter opinion can be advanced, for instance:

- because of the species diversity in grassland a better protection can be obtained, for instance, by "crop rotation" within the field than in monocultures;
- in sowing grassland indigenous grass species are used that are adjusted to the prevailing diseases and pests by natural selection; moreover, in ageing grassland another selection may occur in favour of the most resistant plants;
- in breeding grasses an important selection criterion is persistence, which may include resistance against diseases and pests;
- in general the sward shows a great recovery potential for all kind of damages, e.g. because of excess of plants, numerous growing points and an extensive root system.

However, grassland plants can be damaged by all kinds of organisms (Couch, 1962; Dwarshuis, 1975; Sampson & Western, 1954 and others). These organisms may be air-borne, soil-borne and seed-borne and especially the soil-borne organisms can be influenced by crop rotation.

Perhaps, investigators have paid little attention to this aspect and practice did not observe it, also because, estimating yields of grassland is difficult.

It is also possible that this problem did not occur in the past, but does at present, because, for instance:

- species diversity of the sward has decreased considerably in the last decennia;
- other growth limiting factors have been eliminated (e.g. N supply; see

2); the adverse effects of diseases and pests have been distinctly revealed.

The damage caused by these organisms may be age-dependent in two ways:

a. by number and activity of the relevant organisms;
b. because of the sensitivity of the grass sward; for instance, establishing plants are often relatively sensitive, because the proportion biomass/harmful organisms is unfavourable and the recovery potential - e.g., the number of growing points per unit of surface - is low.

With regard to the age-dependent characteristics of the diseases and pests, in our study special attention was paid to the "ley period". The effect of the preceding crop (arable crops or grassland) was studied on the establishment and first growth of the grass and to a limited extent the effect of pesticides in this period. The following comparisons were made:

1) old grassland with a good botanical composition with reseeded grassland (field experiments);
2) young grass(land) sown in arable soil and reseeded grass(land) (pot and field experiments);
3) grassland of various ages sown in arable and in grassland soil (field experiments);
4) influence of nematicides and fungicides on the growth of young grass(land) (pot and field experiments).

Some of the experimental fields were specially designed for these purposes and some for other purposes. A complication in studying rotation problems is to separate the positive effects of the preceding crop(s) from the negative effects. This is especially important if grassland is compared with arable crops as a preceding crop to grassland; the positive effects of the accumulated fertility under grassland have to be separated from the negative effect of "grass sickness".

In the reseeding experiments the gross dry matter yields in the first year, mostly were somewhat lower of young grassland than those of old grassland; in the second year hardly any differences in gross yields occurred anymore (2 and Hoogerkamp, 1974 and 1984). The young reseeded sward showed relatively much damage from diseases and pests and possibly also from toxic substances; in extreme instances this resulted in a complete failure of resowing.

In the pot experiments 31 out of 44 two-by-two comparisons showed that grass growth in arable soils the first time after sowing was better than that of grass grown in grassland soils; the grass was well supplied with nutrients and water. In most of the experimental fields the gross dry matter yields were highest on the grassland sown in arable soils, if these were supplied with liberal N dressings (Table 9, Fig. 6 and Hoogerkamp, 1974 and 1984).

Table 9. Average gross dry matter yields (t ha^{-1} per year) on various experimental fields.

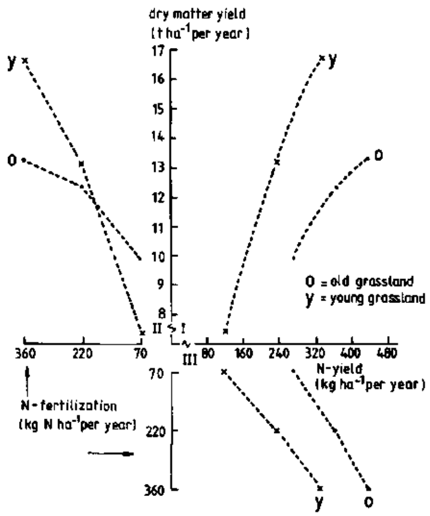
1) A = one-year old grassland sown in arable crop soil with an average N dressing of 558 kg N ha^{-1} per year and B = old(er) grassland or one-year old resown grassland with an average N dressing of 592 kg N ha^{-1} per year; averages of a number of experimental fields (data of Sibma; CABO, Wageningen);

2) A = grassland after a preceding crop of one or two years maize and B = grassland after a preceding crop of grass (first year).

(for more information see: Hoogerkamp, 1984)

	A	B
1)	19.8	16.4
2)	8.4	6.2

Fig. 6. Relation between N application and N yield (quadrant III), between N application and dry matter yield (quadrant II) and between N yield and dry matter yield (quadrant I) (Hoogerkamp & Woldring, 1965). O = old grassland and Y = young grassland sown in arable crop soil.



The N yield of the young grassland (Fig. 6) was lower than that of the old grassland; this is because of the lower organic matter content and the consequently lower N supply of the arable soil. However, the dry matter yield at the same N yield of the young grassland was higher than that of the old grassland. By combining the lower N yield and the lower N content in the dry matter of young grassland, the dry matter yield at the lowest N dressing was highest on old grassland, but at the highest N dressings highest on young grassland.

In the second and sometimes (also) during the following years the gross dry matter yield of the grassland sown in the arable soil decreased to about the level of resown grassland (Hoogerkamp, 1974 and 1984). Experiments of Behaeghe et al. (1970) and Cooper (1969, 1972 and pers. comm.) showed the same tendency. Resown grassland did not show this fall in production (Hoogerkamp, 1974 and 1984).

In comparing the plants of the grassland soil with those of the arable crop soil suggestions were obtained that pathogens and parasites (nematodes, insect larvae and fungi) were important causes of the observed differences in yield. Whether these organisms are indeed (fully) responsible for these differences observed was not conclusively shown in this study. The correlations between number of organisms and grass growth were only low and with mixed populations the effects of the individual species are difficult to separate. However, in these experiments the same injuries were observed as those occurring at the inoculation of many of these organisms. Furthermore, these injuries could be reduced or prevented by applying pesticides working against these organisms. On the experimental fields the increases in gross dry matter yields were limited, however (Table 10).

Table 10. Average increase in dry matter yield (kg ha^{-1}) by applying nematicides (nem.), fungicides (fun.) and nematicides + fungicides (n. + f.) and the dry matter yield (t ha^{-1}) of the control; first year after application (see for more information Hoogerkamp, 1984).

	E3[1)]	E4[1)]	E5[1)]	E6[1)]	E7[1)]	E8[1)]	E12[1)]	average
nem.	1196	633	802	-743				472
fun.	795	-						387
n. + f.	1167	435	1495	-344	+[2)]	1156	-121	631[3)]
control	10.8	10.6	12.3	6.5	-[2)]	5.9	10.4	9.4[3)]

[1)] Hoogerkamp, 1984; [2)] resowing not succesful without pesticides;
[3)] without E7.

Besides soil-borne diseases and pests also seed-borne and air-borne diseases and pests may be involved.

The yield increases obtained were smaller than some reported in the literature; even on established swards (Clements, 1978; Eissa, 1971; Ennik, 1972; Ennik & Baan Hofman, 1977 and Spaull et al., 1983).

Nematicides and insecticides usually were most effective in improvement of establishment and increasing productivity of grassland (Hoogerkamp, 1984).

Respected the small number of experimental fields conclusions about the part of soil-borne diseases and pests in the differences in productivity between reseeded grassland and grassland sown in arable crop soil are not possible. Heringa (pers. comm.) suggests that phytotoxic substances could be involved. Other possibilities may be: a loose soil and hydrophobic and anaerobic conditions (Hoogerkamp, 1984).

The deeper rooting of young grassland, which is reported on in the literature rather often, might especially occur in grassland recently sown in arable crop soil. In pot experiments rooting in the arable crop soil was found to be deeper than that in grassland soil (Hoogerkamp, 1984).

In grassland, which is dependent on *Trifolium repens* as its (main) nitrogen source crop rotation diseases and pests, which damage this species may be an additional difficulty in the problem under treatment. Clovers generally are relatively sensitive to crop rotation diseases and pests ("clover sickness"), and so is *Trifolium repens*. When sown in arable crop soil the species will often grow better than when sown in grassland soil (Ennik, 1982; Mann, 1938; Russell, 1961 and Scheijgrond et al., 1958a and b).

Whether the yield decrease occurring one or some years after sowing ("years of depression") is also caused by increasing activity of pathogens and parasites and whether in the recovery afterwards the reverse process takes place ("decline") has not been studied in our research. In view of the events in many other crops cultivated in monoculture year after year (Kupers, 1981 and Maenhout, 1981), this is not out of the question. Morever, it is also possible that in ageing grassland, which is not resown, selection occurs in favour of the most resistant plants. The deterioration during the first part of the "years of depression" and the recovery at the end of this period, in theory, also may be influenced by the vigour of the grass, which may be poor during the "years of depression" and good during the permanent grassland phase. Finally the accumulation of organic matter can have a sickness reducing effect (Kupers, 1981 and Russell, 1961); Gilbert (cited by Mann, 1938) found no "clover sickness" in a garden soil which had a high organic matter content and Mann (1938) found that prevention was also possible by large amounts of farmyard manure.

6.3 Earthworms (*Lumbricidae*)

Old grassland compared with arable crop soil often contains many earthworms; numbers of 200–900 per m^2 and biomasses of 1000-2500 kg ha^{-1} are reported regularly for old grassland, whereas for arable crop soil a number of 30-150 per m^2 and a biomass of 100-500 kg ha^{-1} are usual (e.g. Dreidax, 1931; Edwards, 1983; Edwards & Lofty, 1977; Hoogerkamp, 1984; Russell, 1961 and Tischler, 1955 a and b).

Grassland sown in arable crop soil generally has a relatively small earthworm population in the first years. However, this will only be temporarily if an earthworm population can develop, for instance, because of the presence of an initial population and favourable ecological conditions. The reproductive capacity of earthworms is great; for instance, Van Rhee (1969) found an increase from 4664, introduced in the period 1964-06 - 1967-04, to 336700 in 1967-10 and to 384740 in 1968-04 and Eijsackers (in: Hoogerkamp et al., 1983) from almost 3000 in 1971 to about 2.3 million in 1979[1]. Findings on the rate of development of an "arable soil population" to a "grassland soil population" are hardly available. With an unchecked increase of $Nt = N0.e^{rT}$ (N0 = the number present at time 0, Nt = the number after T months, e = the root of natural logarithm and r = the intrinsic rate of natural increase), as in the said experiments of Van Rhee and Eijsackers and r-values for *Allolobophora caliginosa* of 0.1445 and 0.022 (Van Rhee) and 0.07 (Eijsackers), the growth from 50 m^{-2} (an arable soil population) to 500 m^{-2} (a grassland soil population) only takes 1.3 (r-value : 0.1445), 8.7 (r-value : 0.022) and 2.7 years (r-value: 0.07). However, these reproductive rates are calculated from the results of inoculation experiments in new polder soils.

---

1) This means that inoculation of 10.000 earthworms per ha (1 m^{-2}) is of little importance, when a normal arable population (30-150 m^{-2}) is present.

Much research has been done on the effect of earthworms on soil fertility (see among others Satchell & Martin, 1981); the burrowing, mixing and digesting activities of the earthworms often bring about better growing conditions for the crop: aeration, drainage, mineralization, etc.. However, few quantitative findings are known about the importance of these improvements for grass growth under practical conditions. In pot experiments often considerable yield increases were measured and in correlative approaches in the field distinctly positive relations were established (Hoogerkamp, 1984). In field experiments in O. Flevoland (Hoogerkamp, 1984) and in Australia (Noble et al., 1970) and to a greater extent in New Zealand (Stockdill, 1959 and 1982) distinct suggestions were obtained that earthworms may promote grass growth (Table 11).

Table 11. Dry matter yields from grassland with and without earthworms (kg ha^{-1} per year).

	period	+earth-worms	-earth-worms	increase abs.	%
Hoogerkamp (1984)	2 x 1 year	14094	12789	1305	10
	½ year	9056	8365	691	8
Noble et al. (1970)	not mentioned	2995	2732	263	10
Van Rhee (1969)	3 x 1 year[1)]	10009[2)]	10043	-34	0
Stockdill (1959)	½ year	18079[3)]	10471[3)]	7607[3)]	73
Stockdill (1982)	2 x 1 year	10295	8600	1695	20
	2 x 1 year[4)]	10405	8600	1805	21

[1)] first year 2 cuts; [2)] 9881 for Allolobophora caliginosa plots and 10130 for A.chlorotia plots; [3)]green material; [4)] soil recently invaded with earthworms.

Stockdill & Cossens (1969) report an average increase in the annual dry matter yield of 20 to 30% or about 2250 kg ha^{-1}.

Quantification of the earthworm effect is, however, hardly possible from these experiments, because of the experimental technique applied, in which earthworm effect and side effect cannot be separated. However, a good experimental design, in which these effects can be separated is difficult to realize, because of the relatively high rate of lateral spread of the earthworms (up to 8 to 10 m year^{-1}), the number of years required to study the interaction (development population, AO-layer formation, compaction of the soil, etc.) and the limited availability of grassland fields without earthworms, but with favourable ecological conditions for these animals. The mentioned increases in gross yields, may be considered only as an indication of the yield increases possible under the prevailing conditions. Many more findings are required for a better quantitative understanding of the dose/effect relation and of the co-operation between earthworms and other soil organisms.

Findings on the effect of earthworms on the net yield and animal yield are not available and these are necessary, because they may be influenced in another way than the gross yield; this because, for instance, botanical composition of the sward and bearing capacity of the grassland can be changed by the activity of earthworms (Hoogerkamp, 1984).

In the literature a relation is assumed between the "years of depression" and the absence of earthworms (Bates, 1948 and Voisin, 1960); however, experimental findings that indicate a causal relationship are hardly presented. A number of symptoms of the "years of depression" which also occur with limited earthworm activity, are indeed regularly reported; e.g. the formation of an AO-layer and compacting of the soil (Bates, 1948; Elema, 1920; Klapp, 1954; Müller, 1951; Schneider, 1927 and others). The finding of Elema (1920) that moles (Talpa europaea) are seldom observed in grassland during the "years of depression" and that the end of this period is introduced by the coming of moles, might indicate such a relationship. In our studies, in which the "years of depression" was induced by attenuation of the profile and the symptoms disappeared almost completely by liberal mineral N dressings, no indication was obtained that earthworms should be active in causing this depression. However, in these experiments limited plot sizes, the quick rate of lateral spread of the earthworms and a nearby earthworm rich grassland, theoretically allowed for ingression of earthworms into the young grassland within one year. Therefore we may not conclude from these findings that earthworms are unimportant in the "years of depression".

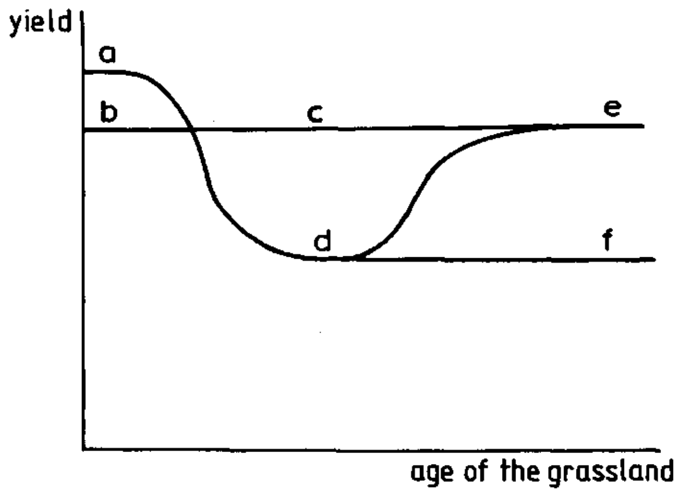
The study of grassland with and without earthworms in O. Flevoland showed however, that without an active earthworm population symptoms may occur similar to those in the "years of depression"; even when the grassland is fertilized intensively and when persistent Lolium perenne varieties are used in sowing. These symptoms are: formation of an AO-layer, compacting of the soil, temporary or permanent deterioration of the botanical composition of the sward and a lower yield (Hoogerkamp, 1984).

Practical experience in this area indicates that the absence of earthworms causes few or no problems in the first few years after sowing. Findings of Van Rhee (1969), which do not show changes in the yield after inoculation of earthworms in young grassland in a new polder soil, might indicate the same (Table 11). This also corresponds with the assumption that counteracting the formation of an AO-layer and of compacting of the soil are the primary causes of the positive effects of earthworms; neither process occurs in the first time after seeding including intensive soil tillage.

7 Integration of the various factors

Productivity of (re)seeded grassland, when ageing, may change greatly under influence of various factors. These factors are age-dependent, or not. Especially the occurrence of the former factors may induce a characteristic trend in the production: the "ley period" (Fig. 7; a>b), the "years of depression" (Fig. 7; d<c) and the "permanent grassland period" (Fig. 7; e>f).

Fig. 7. Various trends (schematically) in productivity of grassland, when ageing.



Some possibilities of changes in productivity with ageing are:

ade The yield of the young grassland is relatively high, after which it decreases ("years of depression") and after some years increases again to the level of good old grassland, which is lower than that of the ley.

bde Young grassland yields about as much as good old grassland, but a temporary decrease occurs during the transition period ("years of depression").

bce Similar to bde, but without the "years of depression".

adf Similar to ade, but no complete recovery to the level of good old grassland.

The "ley period": in the first time after sowing grassland production may be higher than that of old grassland (Fig. 7; a>e).

Replacing of old grassland by crop rotation, including short duration leys and arable crops, increased the grassland production in many countries. The success of this system is dependent on good growth of clovers. A classic example of the successful application of this method is the ley-farming system that was developed in Denmark in the 19th century and in which clover percentages of 20-50 occurred in leys of two years. Here nitrogen fixation allowed a much higher yield level than that of old grassland where the clover percentage is seldom higher than 10. The ley farming system in Great Britain is a second example and an important part of the agricultural improvement in N. America was possible by the use of grass-clover mixtures. Good growth of high producing ecotypes of Trifolium repens generally needs a crop rotation with arable crops; N supply by the soil is limited then and problems with "clover sickness" are fewer. In the Netherlands ley farming never was a success, primarily because many of the soils are suitable for permanent grassland and much less suitable for arable crops; on such soils clovers are uncertain and average yields low. The good arable soils are used as much as possible for the culture of marketable crops; only a small area is used for the culture of clovers or lucerne. In the last decennia the importance of clover both in arable farming and in grassland farming has changed in favour of N fertilizers, because these enabled higher and more certain yields and financial results were usually better.

Liberally dressed young grassland without legumes can give a higher yield than old grassland by using productive but short-living species such as Lolium multiflorum.

Reseeding grassland which has an agriculturally poor botanical composition may cause increased gross and net yields. Reseeding grassland which has a good botanical composition in theory might also show an increased productivity for all kind of reasons; however, in our study (see 2) this was not observed. Suggestions were obtained that reseeding of grassland without an active earthworm population may result in a higher yield, because the physical condition of the soil is positively influenced and the

A0-layer is eliminated; more detailed research is required on this subject (see 2).

Sowing grassland on arable crop soil mostly gave a higher gross yield than reseeding grassland, provided the disadvantages of a low organic matter content inherent to arable crop soil is corrected, especially by supplying a liberal N dressing. Diseases and pests probably play an important role in this (see 6.2). How long this higher yield can be maintained was not studied; we found indications that it was often especially the first year.

The frequently mentioned low drought sensitivity of young grassland, which, for that matter, was only observed to a limited extent in the present study, may be caused by various factors (Hoogerkamp, 1974 and 1984):

a. a better supply of nutrients by the subsoil;
b. a better root growth because of the anthropogenous soil tillage at (re)sowing; this situation may be especially important in soils with no or a few earthworms;
c. less damage to the root system by diseases, pests or toxic substances.

Since these factors mainly occur in grassland sown in arable crop soil and to a less extent in reseeded grassland, probably the said experience is mainly based on young grassland sown in arable crop soil. The effects of deep rooting can be decreased by the lower organic matter content together with the low moisture retaining capacity of the former arable crop soil. The sward of old grassland, moreover, often contains species as *Poa trivialis* and *Agrostis spp.*, which have a superficial root system.

Productivity of the grassland in the "ley period" may, however, be disappointing. This may occur, for instance, when the low N supply by the soil, caused by low organic matter content of the (arable) soil, is not sufficiently compensated by other sources of N supply (*Trifolium repens* and fertilizer N) (see 2). The accumulation of organic matter in the soil and hence the N immobilization seems to start just after establishment of the grass and not, as is supposed by Hébert (1966) and Voisin (1960), some years later. If there is no alternative N supply, the yield of the young grassland is low almost from the beginning and tends upwards with ageing of the grassland (Fig. 1). In addition adverse weather conditions, the occurrence of diseases and pests and excessive growth of weeds may have an adverse effect on productivity, because in a very young stage grasses are relatively sensitive to these factors. Experience shows that a number of soil-borne diseases and pests occur especially in reseeded grassland. Other factors that may cause low productivity of young grassland are, for instance, mis-applied sowing techniques, poaching of the sward (young swards are relatively susceptible) and adverse edaphic growing conditions (low P or K status, etc.).

The "years of depression": in this period productivity of grassland may be relatively low (Fig. 7; d<c). Various causes can be mentioned.

A major cause may be a low organic matter content in the soil, for instance, when grassland is sown in mineral old arable crop soil. Especially the low N supply by the soil is an important aspect (the denomination "hungry years" is right here). In addition other factors, such as a low P supply of the grass and a low moisture retaining capacity and a bad structure of the soil may play a part in theory. In the present study, in which various organic matter contents of the soil were applied, the low N supply by the soil was a dominating factor, which could be compensated by increased fertilizer N; however, in these experiments good moisture retaining soils were involved and the P supply was not limiting grass growth (2). Because of the distinctly higher fertilizer application in the last decennia, especially of nitrogen, in practice this aspect of the "years of depression" has been much reduced or even eliminated.

In theory *Trifolium repens* also might compensate a low N supply by the soil. In the present Dutch grassland, however, this species is generally not important; because of the high N dressing. Moreover, it is uncertain to what extent this species can persist in the "years of depression". Insufficient persistence, clover sickness and unfavourable ecological conditions, mainly not directly age-dependent, may result in a decrease in the clover percentage. In the past the disappearance of clover is often mentioned as one of the causes of the "years of depression".

During the "years of depression" a retardation of the increase in N supply by the soil with ageing of grassland, sown in soil with an organic matter content below the equilibrium level of old grassland, may occur either by a delay in the rate of the net mineralization of the organic matter or by a decrease in the supply of organic matter to the soil caused by a decrease in productivity of grassland. Such a retardation of the net mineralization because of the absence of an active earthworm population suggested itself in this study.

The sowing of grass species that can not be maintained in the sward may lead to the "years of depression". The disappearance of the sown species may be caused by using relatively short-living species (for instance Lolium multiflorum), using little persistent, competitive and winter hardy varieties of perennial species, with or without adverse ecological conditions. Lolium perenne may often dominate in the young sward, because it mostly is included to a liberal extent in the current mixtures and because of its rapid rate of establishment. In the first time after sowing the ecological conditions for this species only play a relatively minor part. After some time, however, the ecological conditions grow increasingly important and if they are adverse for the relevant species, it may disappear from the sward. The ecological factors involved may be age-dependent (e.g. N-shortage) and not directly age-dependent (e.g. moisture excess). The "commercial" varieties often used in the past, were hay types of grasses reproduced on arable land; they usually disappeared from the sward soon. By improving the persistence and the winter hardiness this situation was much improved, so that at present Lolium perenne can persist as a dominant species for many years (unlimited?) (see 3); this is supported by an improvement of the ecological conditions for the relevant species. However, because of all kind of frequently or infrequently occurring stress factors (misuse, drought, etc.) keeping Lolium perenne in the sward is still difficult in many fields, especially on sandy soils. Further improvement of ecological conditions and persistence, also under the adverse effects of modern grassland use, is desirable and seems possible.

The consequences of the disappearance of the sown species from the sward on the agricultural quality of grassland, are dependent on the extent and the rate at which this occurs, the ability of the remaining plants to occupy the open places in the sward and the ingression and quality of the non-sown grass species. The species included in the mixtures besides Lolium perenne, generally contributed only slightly to the filling up of open places.

To what extent active suppression of the sown species by the non-sown species takes place, besides a passive replacement, is not known; in modern grassland Elymus repens might suppress the sown species.

In soil remaining under grass for many years without soil tillage, compacting may occur under influence of various processes (treading, rutting, gravity, etc.). Moreover, organic matter (leaves, faeces, etc.) can accumulate at the soil surface, forming an A0-layer. Apparently, an active earthworm population may reduce both these phenomena or even eliminate them, but other soil organisms may also be involved. However, such an earthworm population is not always present. This may be caused by conditions which are independent of the age of grassland (low pH, drought, etc.), but age-dependent causes are also possible; if for instance, grassland is sown on arable land, the earthworm population may be so small that soil compaction and mat formation may occur after some time, when the anthropogenous soil tillage applied before sowing is no longer sufficiently effective.

Under favourable conditions for grassland, the gross dry matter yield of grassland without earthworms on an average was about 10% (ample 1 t ha^{-1} per year) lower than that of grassland with earthworms. In experiments in New Zealand, where much grassland occurs without benefical earthworms, generally much wider differences (average 20-30%; about 2.2 t ha^{-1} per year) were found.

When a small earthworm population is present at the time of sowing grassland, which is usually so on arable crop soil, this population will gradually increase under favourable ecological conditions. However, earthworms may be absent for instance, when sowing on recently reclaimed polder soils. If and how rapidly an "old grassland population", is formed, depends especially on the size of the initial population and on the reproduction rate of the earthworms. Because of the high potential reproductive rate of earthworms, the time needed to bridge this difference can be short, for instance, compared with the organic matter accumulation. If we use the equation $Nt = N0.e^{rT}$ and r-values 0.022, 0.07 and 0.1445, an arable population of 50 m^{-2} has reached a grassland population of 500 m^{-2} in 8.7, 2.7 and 1.3 years, respectively (see 6.3).

When earthworms are not present, the import (passive or active) from elsewhere may be of importance.

Whether other organisms occur, which increase in number or biomass with the ageing grassland and have a positive effect on grass growth, was not investigated in our study. In the literature the absence of a good bacterial flora is repeatedly mentioned; the bacterial flora of arable soil would have to be changed first into a bacterial flora of grassland (Elema, 1920). Klapp (1954) in relation to this mentioned "Kleinleben" activity, which causes mineralization and humification of organic matter and stimulating favourable soil conditions.

Whether modern grassland management affects the size and the effect of earthworms is uncertain. Theoretically, it is possible that a higher production of organic matter, e.g. as faeces, and a denser sward stimulates the growth of the earthworm population; it is also possible that the effect of the earthworms on grass growth is less , e.g. because a denser grass sward may protect the soil better against structural deterioration by weather conditions and treading. It is also possible that heavy N application, dressings with slurry and copper containing manure and intensive treading and rutting have a negative effect on growth of earthworm population, or in the latter case, increase the effect of the earthworm population, because more compacting of the soil by treading would have to be compensated by the loosening activity of earthworms.

To what extent diseases, pests and phytotoxic substances are important in the "years of depression", is only partly known. Legumes usually respond positively to a rotation with other crops. The occurrence of "clover sickness" in ageing grassland, besides an increase in N supply by the soil, might be important in the decrease often observed in the coverage of clover during the "years of depression", especially when it is sown in arable crop soil. In grasses a similar soil "sickness" might occur. In our study it was observed that grassland after arable crops mostly yielded distinctly more than reseeded grassland of the same age, that reseeded grassland did not yield more than old grassland with about the same botanical composition and that the first said differences often have disappeared by the second year after sowing. Diseases, pests and phytotoxic substances may be important in this, other factors however, as the decreasing quality of the sward of grassland heavily fertilized with nitrogen (Prins, 1983) or a low earthworm activity may also be responsible. In theory "grass sickness" might develop, bringing down the yields even below those of old grassland.

Sowing little persistent varieties of Lolium perenne in soils with a low population of viable seeds and vegetative reproductive organs of grassland plants (some arable crop soils) may bring about an open sward; such an open sward, especially on heavier soil, may increase the susceptibility of the soil to structural deterioration and without an active earthworm population recovery from such an adverse situation may be retarded. N starvation may result in a reduction in the good grass species, which are replaced by species with a lower productivity. Excessive N dressing, absence of earthworms or the use of Lolium perenne varieties with low persistence may have the same effect.

In the "years of depression" the susceptibility to adverse weather conditions, for instance, severe winters and drought in the growing season, may be greater. The winter hardiness of the grassland with earthworms in O. Flevoland was found to be greater than that of the grassland without earthworms (Hoogerkamp, 1984).

The activity of the different factors causing the "years of depression" need not start and stop at the same time. For instance the accumulation of the organic matter may continue for a very long time (may be more than 100 years on the heavy soils; see 2), whereas the formation of an earthworm population normal for old grassland, when an inital population is present, seems to be much more rapid (see 6.3).

The "permanent grassland period": the age-dependent effects impeding grass growth during the "years of depression" may have stopped in this phase; production may be at a relatively high level (Fig. 7; e). The organic matter content of the soil approaches or is at the equilibrium level of old grassland and therefore the N supply by the soil is greater than in the preceding periods. The earthworms and possible other soil organisms with the same effect on the soil have increased to such an extent that they can realize a good soil structure and moreover, can prevent mat formation. The sward consists by this time of locally adjusted species and ecotypes; provided that the remaining growing conditions are favourable, these are species most desired in agriculture (especially Lolium perenne). Theoretically, it is also possible that "grass sickness" problems in this phase are reduced e.g. by the occurrence of hyper parasites, the natural selection of less sensitive plants, the buffer effect of the organic matter with or without better growing conditions for the grass ("decline-effect"). However, the production level during this phase is below the potential production level during the ley phase (Fig. 7; a>e). A higher disease and pest stress may be an important cause; pesticides may give a rise in production (6.2).

However, old grassland is not always agriculturally good grassland. Much old grassland has a poor botanical composition and a low productivity (Fig. 7; f), because one or more growing conditions are adverse. These causes can be of a pedological, climatological and management nature; for example lack of nutrients, low pH, drought, water excess and under or overgrazing (Davies, 1949; 't Hart, 1950 and Klapp, 1954). Davies (1960) even regarded the conversion of the instable "ley phase" into the more stable "old grassland phase", with for Britain usually a domination of Agrostis spp. and/or fine leaved Festuca spp., as a normal ecological succession; in this grassland clovers were sparse and mat forming normal. Permanent grassland with mainly Lolium perenne and Trifolium repens was only possible on the naturally fertile soils with a good water management and a good grassland management; in this grassland there was hardly any disposition to mat formation, and biological activity in the soil and productivity of the sward were high.

When the adverse growing conditions are improved, the area of grassland with a good botanical composition is much enlarged and productivity much increased (e.g. Green cited by Williams, 1980 and Idle, 1975). Especially the increase in N fertilizer is important in this, because in spite of the relatively high organic matter content, the N supply by the soil is too low and legumes mostly are of relatively little importance; in many cases over and above that improvement of the drainage and the water supply also are important; contrary to the old grassland mentioned Trifolium repens is sparse here.

Some concluding remarks:

A general useful quantification of the length and severity of the changes in productivity with ageing of the grassland (Fig. 7), is hardly possible with the results mentioned; because of the number of variables that may or may not interact, the rather limited number of findings and the possible influence of not age-dependent factors.

This research was performed under conditions prevailing in practice at that time. A proceeding "intensification" of grassland management e.g. higher N dressings, increasing mechanisation of field activities and application of more organic manure (especially slurry), may stimulate, directly or indirectly, the deterioration of (young) grassland.

Alternating grassland with arable crops, ley-arable farming, may be of advantage to the arable crops, because they can profit from the relatively great soil fertility that has been built up in the grassland period; especially the N supply by the soil is important (Hoogerkamp, 1973a). Other advantages of alternating arable crops with grassland for the arable crops may be: decrease in the rotationial disease and pest problems in the relevant arable crops and suppression of some arable crop weeds. Advantages to grassland of including an arable crop period may be that "grass sickness" is reduced for a time and that legumes may also be stimulated by the reduction in disease and pest stress and by a decrease in the N supply by the soil. Moreover, an arable crop period is sometimes included to better kill the old grass sward (for example Elymus repens) or to improve the soil by leveling, deep ploughing etc. However, the growing of arable crops brings about mineralization of organic matter and a reduction in the earthworm population, which may have an adverse effect on productivity of the succeeding grassland. In the question whether ley-arable farming is preferable to separate growing of grassland and arable crops, a great number of additional aspects should be considered: suitability of the fields for both arable crops and grassland in connection with soil type, situation, drainage etc., and, if relevant, the financial and social consequences of changing the farm type over from arable crop farming or grassland farming to ley-arable farming. When this consideration is in favour of the ley-arable system, the weighing of the benefits and losses of combination or separation in arable crops and grassland is set in. The initial cost of this system should also be considered, for instance, cost of sowing the grassland, fencing costs, cost of supplying drinking water etc..

8 Summary

The productivity of ageing grassland may change greatly. A characteristic trend is that a productive ley period, occurring in the time just after (re)seeding, is followed by a period in which productivity is distinctly decreased. Under conditions favourable to old grassland this decrease has a temporary character (the "years of depression"); finally a production level can be attained almost equalling that of young reseeded grassland, but mostly not that of liberally fertilized grassland sown in arable crop soil.

This trend in production is caused by an age-dependent change in a number of production factors; especially, the organic matter content in the soil, activity of the earthworm population and the occurrence of "soil sickness". Besides, the insufficient longevity of the sown species can be involved.

This trend in productivity can be enhanced, but it can also be decreased, if with ageing of grassland other production factors also change. A separation of the influence of both categories of factors can be obtained by comparing the yields of old grassland with those of young grassland during a number of years.

Grassland that is mainly dependent on clover for its N supply, for various reasons may react differently to changes in the production factors than grassland that is mainly supplied with fertilizer N.

Sowing grassland in an arable crop soil, normally is the best starting point to obtain a sward with a high percentage of *Trifolium spp.*; because of the low N supply by the soil and the absence of "clover sickness". However, because clover is sensitive to all sorts of adverse edaphic, climatic and management factors, including a rising N supply and increasing "clover sickness" with ageing of the grassland, frequently the clover content decreased some years after sowing. Sometimes, the use of the short living *Trifolium pratense* contributed to this decrease. A drop in clover content in grassland without other important N sources resulted in a decrease in productivity ("years of depression").

Because in the present Dutch grassland clover is not important for

the N supply, in our experiments usually no clovers were sown.

In grassland with a low percentage of clover a decrease in the organic matter content of the soil, wich was realised either by exchange of soil layers or by growing arable crops on grassland soil, affected productivity negatively. By applying fertilizer N this effect could be compensated for the most part. Clovers may have a same effect.

This lower productivity caused by a decreased organic matter content of the soil was evident almost from sowing onwards and roughly showed an asymptotic decrease with ageing of the grassland. It may last some decades or even longer to reach the equilibrium level of old grassland.

The relatively low yields during the "years of depression" may indeed have been partly caused by a decreased organic matter content of the soil, but this cannot be the cause of the yield depression often occurring at the change-over from "ley period" to "years of depression".

The use of arable crops as a preceding crop to grassland compared with reseeding of grassland, resulted not only in a lower N supply of the soil but often also in less "grass sickness". Grassland with a low clover percentage sown after arable crops with a low N application therefore often had a lower gross yield than reseeded and old grassland, whereas with a liberal N dressing the reverse was often found.

In crop rotations with arable crops and grassland (ley farming) both arable crops and grassland may benefit from a decrease in "soil sickness". Furthermore soil fertility accumulated during the grassland period favours the arable crops, especially via a greater N supply by the soil, whereas the mineralization of the organic matter during the arable crop period, also mostly via a lower N supply by the soil, has an adverse effect on productivity of the grassland; at least when the sward is poor in legumes. To what extent the nitrogen saved during the arable crop period corresponds to the extra N supplied in the grassland period could not be inferred from the available results. By applying grassland with a high clover percentage the higher fertilizer N requirement in the grassland period can be decreased or prevented.

Reseeding old grassland with a good botanical composition on an average resulted in a somewhat lower gross yield. The results of a pot experiment indicated that reseeding of grassland with an AO-layer may give a yield increase.

As possible causes of a lower yield in the "years of depression" compared with that in the "ley period", can be mentioned: absence of a sufficiently active earthworm population, the disappearance of the sown grasses from the sward and an increase in "grass sickness".

An insufficiently active earthworm population brought about an unfavourable physical condition of the soil and the formation of a thatch layer (AO-layer). In the first time after sowing this low activity is not significant, because of the antropogenous soil tillage shortly before sowing, but these effects are more distinct with ageing.

Disappearance of the sown grass species and varieties from the sward was caused by sowing varieties of the perennial species that were insufficient persistent, winter hardy or competitive and because the ecological conditions for the sown species were or became unfavourable. If open places occur, because of this disappearance, the productivity of the grassland may decrease. If the disappearing sown species and varieties are replaced by other species and ecotypes the productivity of the grassland will depend on that of the relevant plant species and ecotypes.

A possible increase in productivity of the grassland at the end of the "years of depression" may be caused by a further increase in the organic matter content of the soil, formation of an active earthworm population, recovery of the botanical composition of the sward and perhaps a decrease in "grass sickness".

The problems of the "years of depression" can be solved to some extent, especially by increasing the N dressing and by improvement of the sown grass varieties, especially those of Lolium perenne, which is often dominant.

However, over-dosage of fertilizer N, incorrect management of the grassland (cutting too deep, mowing of too heavy cuts and a too long field period in haying), incorrect application of organic manure, especially slurry, may constitute a new hazard for the botanical composition and productivity of ageing grassland.

9 Samenvatting

De produktiviteit van grasland kan met het ouder worden sterk veranderen. Een karakteristiek beeld is dat het grasland gedurende de eerste tijd na de (her)inzaai (relatief) produktief is en dat na één of enkele jaren een produktiedaling optreedt; onder gunstige omstandigheden kan echter tenslotte weer een produktieniveau worden bereikt dat dat van het jonge grasland benadert. De desbetreffende perioden worden veelal aangeduid met achtereenvolgens: kunstweideperiode, sukkelperiode en blijvendgraslandperiode.

Genoemd produktieverloop ontstaat vooral doordat een aantal belangrijke produktiefactoren met het ouder worden van het grasland verandert; het betreft hier met name: het organische-stofgehalte van de grond, de activiteit van de bodemvruchtbaarheidverhogende bodemorganismen (in het bijzonder regenwormen) en het optreden van voor graslandplanten schadelijke organismen en, mogelijk ook, stoffen. Daarnaast kan ook het onvermogen van de ingezaaide soorten en rassen om zich in voldoende mate levenskrachtig in de grasmat te handhaven een rol spelen.

De gevolgen van de veranderingen van deze produktiefactoren voor de produktiviteit van het grasland kunnen versterkt of verzwakt worden door verandering van de overige, niet aan de leeftijd van het grasland gebonden, produktiefactoren als bemesting, gebruikswijze en weersomstandigheden.

Een scheiding van de invloed van beide categorieën factoren is mogelijk door de opbrengsten van jong en oud grasland, gedurende een reeks van jaren, met elkaar te vergelijken.

Grasland dat voor zijn stikstofvoorziening geheel of grotendeels is aangewezen op symbiotische N-binding en dus op de aanwezigheid van vlinderbloemigen en grasland dat vooral van stikstof wordt voorzien door N-bemesting, reageren in het algemeen verschillend op veranderingen van de leeftijdsgebonden produktiefactoren.

Inzaai van grasland op akkerbouwgrond vormt in het algemeen de beste uitgangssituatie voor het verkrijgen van klaverrijk grasland; de geringe N-levering door de grond en de afwezigheid van klavermoeheid zijn gunstig voor de klaver. Doordat klaver echter gevoelig is voor allerlei ongunstige edaphische, klimatologische en gebruiksfactoren en de N-levering door de grond en de kans op klavermoeheid met het ouder worden van het grasland toenemen, loopt het klaver percentage veelal na verloop van tijd terug. Ook de inzaai van soorten met een korte levensduur, met name Trifolium pratense, kan mede een oorzaak vormen van de afname van het klaverpercentage. Teruggang van de klaverbezetting heeft op grasland waar de N-voorziening uit andere bronnen gering is, een duidelijke opbrengstdaling ten gevolge.

Daar in het hedendaagse Nederlandse grasland klaver geen belangrijke rol speelt bij de N-voorziening, werd bij de onderhavige proeven in het algemeen geen klaver ingezaaid.

Gras ingezaaid op akkerbouwgrond gaf, indien de geringere N-levering door de grond werd gecompenseerd door N-bemesting, vaak een hogere bruto-opbrengst dan heringezaaid grasland.

Er werden aanwijzigingen verkregen dat het ontbreken van ziekten en plagen, vooral aaltjes en insektelarven, hierbij een belangrijke rol speelde. De resultaten van een beperkt aantal pot- en veldproeven, leerden echter dat met behulp van gewasbeschermingsmiddelen (nematiciden met insekticidewerking en fungiciden) weliswaar een vermindering van de betreffende schadelijke organismen en de door hen veroorzaakte aantastingen kon worden bewerkstelligd, doch dat hiermee de verschillen tussen op akkerbouwgrond ingezaaid en heringezaaid grasland niet overbrugd konden worden.

Herinzaai van grasland met een goede botanische samenstelling resulteerde in het algemeen niet in een verhoging van de bruto-opbrengst; mede door een tijdelijke vermindering van het assimilerend bladoppervlak lag de bruto-opbrengst van het heringezaaide grasland gemiddeld genomen zelfs iets lager. Door de relatief grote gevoeligheid van het jonge ingezaaide gras voor ziekten, dierlijke plagen, onkruiden en ongunstige weersomstandigheden, vooral droogte, kan dit verschil zelfs groot zijn; in een aantal gevallen slaagde de herinzaai zelfs zodanig slecht, dat herhaling noodzakelijk was. In de praktijk kan ook de verlaagde draagkracht van het jonge grasland voor weidend vee en voor trekkers en werktuigen nadelig zijn.

Verlaging van het organische-stofgehalte van graslandgrond, door tijdelijke verbouw van akkerbouwgewassen of ingrijpende profielveranderingen, resulteerde bij een sub-optimale N-voorziening in een duidelijke verlaging van de bruto-opbrengst van het hierop ingezaaide grasland. Op de onderhavige proefvelden, die meestal gelegen waren op goed vochthoudende gronden en die bovendien ruim van fosfaat waren voorzien, bleek een geringere N-levering door de grond de voornaamste oorzaak van de lagere opbrengst te zijn. Door extra kunstmeststikstof toe te dienen aan het op de organische-stofarme grond ingezaaide grasland waren de hier bewerkstelligde opbrengstdepressies te verhelpen; of echter op deze manier op het organische-stofarme grasland even hoge maximale bruto-opbrengsten kunnen worden verkregen als op het organische-stofrijke grasland kon, door het ontbreken van optimale N-giften, niet worden nagegaan.

Door akkerbouwgewassen te verbouwen kon een deel van de in graslandgrond opgehoopte stikstof worden gemobiliseerd en voor gewasgroei worden gebruikt. De op deze manier bewerkstelligde verlaging van het organische-stofgehalte van de grond resulteerde echter in een geringere N-levering door de grond bij het hierna ingezaaide grasland. Hierdoor was bij toepassing van klaverarm grasland de N-behoefte tijdens de graslandperiode groter. Een kwantitatieve vergelijking van de tijdens de akkerbouwperiode te besparen en de tijdens de grasland periode extra benodigde N-hoeveelheid kon bij het onderhavige onderzoek niet worden uitgevoerd.

Een benutting van de in graslandgrond opgehoopte stikstof bleek niet mogelijk door (frequent) herinzaai toe te passen.

De door de voorvrucht grasland bewerkstelligde opbrengstverhoging bij akkerbouwgewassen berustte vrijwel geheel op een betere N-levering door de grond en was ook door middel van N-bemesting te verkrijgen.

De negatieve gevolgen van een verlaagd organische-stofgehalte van de grond voor grasland, deden zich vrijwel vanaf de inzaai gevoelen en namen met het ouder worden van het grasland asymptotisch af. Gedurende de kunstweideperiode waren deze gevolgen dan ook groter dan tijdens de sukkelperiode. Een laag organische-stofgehalte van de grond kan dus wel de oorzaak zijn van een lage produktiviteit van het grasland gedurende de sukkelperiode, doch niet van een produktiedaling bij de overgang van kunstweide- naar sukkelperiode.

Als mogelijke oorzaken voor laatstgenoemde daling kunnen worden genoemd: de afwezigheid van een voldoend actief bodemleven, het uit het bestand verdwijnen van de ingezaaide grassen en waarschijnlijk ook het optreden van grasmoeheid.

De afwezigheid van regenwormen resulteerde in een ongunstige fysische toestand van de grond en in de vorming van een viltlaag (AO-laag). Onder voor grasland gunstige omstandigheden in O. Flevoland, resulteerde dit gemiddeld genomen in een lagere bruto-opbrengst. De draagkracht van het grasland was bij afwezigheid van regenwormen echter het grootst. De verkregen resultaten illustreren dat het optreden van de sukkelperiode mede een gevolg kan zijn van een onvoldoend actieve regenwormpopulatie. Dit kan zich voordoen bij inzaai op gronden waar een zodanig kleine regenwormpopulatie aanwezig is dat de gevolgen van het achterwege blijven van een anthropogene grondbewerking niet dan wel niet tijdig in voldoende mate kan worden verholpen door regenwormen. Een dergelijke situatie kan zich echter ook voordoen indien de omstandigheden voor de regenwormen ongunstig zijn, dan wel met het ouder worden van het grasland ongunstig worden. Welke rol andere bodemorganismen hierbij spelen werd niet onderzocht.

In hoeverre grasmoeheid bij het optreden van de sukkelperiode een rol speelt, is niet uit de verkregen resultaten op te maken. Indien de relatief hoge produktiviteit van op akkerbouwgrond ingezaaid grasland inderdaad geheel of grotendeels kan worden toegeschreven aan het ontbreken van grasmoeheid, is een effect van grasmoeheid op het optreden van de sukkelperiode te verwachten.

Het uit het bestand verdwijnen van de ingezaaide grassoorten en -rassen is mogelijk doordat kortlevende soorten worden ingezaaid, doordat van de ingezaaide overblijvende soorten onvoldoend persistente, ziekte- en plaagresistente, wintervaste en/of concurrentiekrachtige rassen worden gebruikt en/of de groeiomstandigheden voor de ingezaaide soorten ongunstig zijn of worden. Indien dit verdwijnen zodanig snel gebeurt dat open plekken ontstaan, dan kan de produktiviteit van het grasland sterk teruglopen. Indien de verdwijnende ingezaaide soorten en rassen echter direct worden vervangen door andere, dan wordt de vermindering van de produktiviteit van het grasland bepaald door het verschil in produktiviteit van de betreffende planten. Onder de huidige omstandigheden gebeurt veelal dit laatste; de meestal vastgestelde relatief geringe dalingen van de bruto-opbrengsten, met name onder beweidingsomstandigheden, zeggen echter onvoldoende omtrent een mogelijke teruggang van de landbouwkundige waarde van het grasland; hiervoor zijn gegevens omtrent de dieropbrengsten nodig.

De eventuele stijging van de produktiviteit van het grasland aan het eind van de sukkelperiode kan een gevolg zijn van een verdergaande stijging van het organische-stofgehalte van de grond, de vorming van een actief bodemleven, een verbetering van de botanische samenstelling en mogelijkerwijze een vermindering van de grasmoeheid.

Vooral door verhoging van de N-bemesting en door verbetering van de levensduur van de gebruikte grasrassen, in het bijzonder van de veelal sterk dominante Lolium perenne, is de sukkelperiode een duidelijk minder groot probleem gaan vormen bij de aanleg van blijvend grasland dan vroeger veelal het geval was. Generaliseerbare kwantitatieve gegevens hieromtrent zijn echter niet beschikbaar.

Overdosering van de bemesting, vooral stikstof, een onjuist gebruik (te diep afmaaien, oogsten van te zware sneden, te lange veldperioden bij het hooien) en foutieve toediening van organische mest, vooral drijfmest, vormen een nieuwe bedreiging voor de botanische samenstelling en de produktiviteit van het grasland.

10 References

Ahlgren, H.L. (1952). Comparisons of the productivity of permanent and rotation pasture on plowable land.
Proc. of the sixth Int. Grassland Congress, Vol. I, Pennsylvania State College: 356-362.

Aldrich, D.T.A. & M.S. Camlin (1978). Experience of changes in sward composition and productivity from evaluation of species and varieties.
In: Changes in sward composition and productivity. Eds. A.H. Charles & R.J. Haggar. Occ. Symp. no. 5, Brit. Grassl. Soc.: 85-91.

Altena, S.C. van & J.W. Minderhoud (1972). Keimfähige Samen von Gräsern und Kräutern in der Narbenschicht der Niederländischen Weiden.
Z. Acker- u. Pflanzenbau 136: 95-109.

Andries, A. & L. Carlier (1976). Grasland- en groenvoederwinning op het intensieve weidebedrijf.
Meded. Rijksstation voor Plantenveredeling te Merelbeke nr. 419.

Andries, A. & A. van Slijcken (1965). The effect of different methods of improving the botanical composition of permanent pasture.
Neth. J. Agric. Sci. 13: 114-119.

Anonymus (1971). Graszaadmengsels en grasrassen in Nederland.
Instituut voor Rassenonderzoek van Landbouwgewassen (IVRO), Wageningen. Jaarverslag 1971: 38-40.

Anonymus (1978). Grassen voor grasland; beweidingsproefvelden.
Rijksinstituut voor het Rassenonderzoek van cultuurgewassen (RIVRO), Wageningen. Jaarverslag 1978: 71-73.

Arens, R. (1963). Beiträge zur langjährigen Entwicklung von Mähweide-Ansaaten unter besonderer Berücksichtigung der kritischen Saatstärken.
Forschung und Beratung, Reihe B. Wissenschaftliche Berichte der Landwirtschaftlichen Fakultät der Univ. Bonn; Heft 8.

Arens, R. (1971). Neuanlage von Dauergrünland.
In: E. Klapp. Wiesen und Weiden. Paul Parey, Berlin and Hamburg: 326-373.

Baker, H.K. & G.L. David (1963). Winter damage to grass.
Agriculture 70: 380-382.

Barenbrug, J.T. (1908). Money in grasses.
Barenbrug, Burgers & Co Arnhem (Holland).

Barrow, N.J. (1969). The accumulation of soil organic matter under pasture and its effect on soil properties.
Austr. J. Exp. Agric. and Anim. Husb. 9: 437-444.

Bates, G.H. (1948). An investigation into the cause and prevention of deterioration of leys.
J. Br. Grassld. Soc. 3: 177-184.

Baur, Gg. (1940). Versuche zur Neuanlage von Dauergrünland.
I. Saatzeit, Getrenntanbau von Ober- und Untergras, verschiedene Saatmischung. II. Artenzahl, Saatmenge.
Pflanzenbau 16: 435-458.

Behaeghe, T. & M. Slaats (1968). Kompetitie tussen plantensoorten in jong grasland.
I.R.S.I.A./I.W.O.N.L.; Verslagen over Navorsingen; werkzaamheden van het Nationaal Centrum voor Grasland- en Groenvoederonderzoek nr. 35 (dec. 1968): 93-144.

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 (Gent).

Bergh, J.P. van den (1968). An analysis of yields of grasses in mixed and pure stands.
Agric. Res. Rep. 714; PUDOC, Wageningen.

Camlin, M.S. & R.H. Stewart (1976). The assessment of persistence and its application to the evaluation of early perennial ryegrass cultivars.
J. Br. Grassld. Soc. 31: 1-6.

Camlin, M.S. & R.H. Stewart (1978). The assessment of persistence and its application to the evaluation of mid-season and late perennial ryegrass cultivars.
J. Br. Grassld. Soc. 33: 275-282.

Chestnutt, D.M.B. (1974). Effect of the ratio of ryegrass to timothy in the seeds mixtures on herbage yield in the presence and absence of white clover.
XII Int. Grassl. Congress, Moscow; vol. I, part II: 634-641.

Clement, C.R. & T.E. Williams (1967). Leys and soil organic matter. II. The accumulation of nitrogen in soils under different leys. J. agric. Sci. Camb. 69: 133-138.

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, 6: 335-341.

Collins, D.P. & W.E. Murphy (1978). Effect of sward composition on animal output. In: Changes in sward composition and productivity. Eds. A.H. Charles and R.J. Haggar. Occ. Symp. no. 10, Brit. Grassland. Soc.: 93-100

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). Developmental genetics. In: Report of the Welsh Plant Breeding Station for 1971. Aberystwyth: 7.

Copeman, G.J.F. (1964). Winter-kill of grasses 1962-63. Report on investigation and research 1963. North of Scotland College of Agriculture, School of Agriculture, Aberdeen: 8.

Couch, H.B. (1962). Diseases of turfgrasses. Reinhold Publ. Corp. New York.

Daalen, C.K. van (1935). Gras- en klaverproefveld van den Heer P. Kok te Hoogland. Rijkslandbouwproefvelden op grasland in Utrecht en Z.O.-Noord Holland in 1933 en 1934. Utrecht: 65-70.

Daalen, C.K. van (1937). U 44. Gras- en klaverzaadproefveld van den Heer P. Kok te Hoogland. Rijkslandbouwproefvelden op grasland in Utrecht en Z.O.-Noord Holland in 1935 en 1936. Vianen: 54-56.

Daalen, C.K. van (1943). Proeven met gras- en klavervariëteiten; U 44 (1931). Rijkslandbouwproefvelden op grasland in Utrecht en Z.O.-Noord Holland in 1937 tot en met 1939 Utrecht: 39-40.

Davies, W. (1949). Permanent grass and leys in Britain. Report fifth Int. Grassland Congress: 179-190.

Davies, W. (1952). The grass crop; its development, use, and maintenance. E. and F.N. Spon Ltd., London.

Davies, W. (1960). The grass crop; its development, use, and maintenance. 2nd Ed; E. and F.N. Spon Ltd., London.

Dibb, C. & R.J. Haggar (1978). Evidence of effect of sward changes on yield.
In: Changes in sward composition and productivity. Eds. A.H. Charles and R.J. Haggar. Occ. Symp. no. 10. Brit. Grassland Soc.: 11-23.

Dreidax, L. (1931). Untersuchungen über die Bedeutung der Regenwürmer für den Pflanzenbau.
Archiv für Pflanzenbau 7: 413-467.

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

Edwards, C.A. (1983). Earthworm ecology in cultivated soils.
In: Earthworm ecology; from Darwin to Vermiculture. Ed. J.E. Satchell. Chapman and Hall, London: 123-137.

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

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

Elema, J. (1920). Sukkeljaren.
Tijdschrift van den Algemeenen Bond van Vereenigingen van oud-leerlingen van inrichtingen voor landbouwonderwijs, II (5): 121-125.

Elema, J. (1924). Bijzondere Plantenteelt door J.Z. ten Rodengate Marissen. Vijfde deel: Grasland.
J.B. Wolters, Groningen, Den Haag.

Elgersma, A & B. Scholte (1982). Vergelijking van de registratiekenmerken van twee rassen van Engels raaigras (Lolium perenne L.) na 15 jaar weiland gebruik.
Proefverslag Vakgroep Landbouwplantenteelt, Grasland- en Onkruidkunde van de Landbouwhogeschool te Wageningen.

Ennik, G.C. (1972). Dry matter yield response of pasture grass to application of Nemafos (thionazin).
Neth. J. agric. Sci. 20: 81-96.

Ennik, G.C. (1980). Persistentie van nieuwe selecties van Engels raaigras.
Nederlandse Vereniging voor Weide- en Voederbouw; Gebundelde Verslagen nr. 20: 18-29.

Ennik, G.C. (1982). De bijdrage van witte klaver aan de opbrengst van grasland.
Landb.k. Tijdschr./PT 94: 363-369.

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

Ennik G.C., M. Gillet & L. Sibma (1980). Effect of high nitrogen supply on sward deterioration and root mass.
Proc. int. Symp. Eur. Grassland Fed. on The role of nitrogen in intensive grassland production; PUDOC, Wageningen: 67-76.

Epple, K. (1962). Fruchtfolgeverhältnisse in Baden-Württemberg.
Diss. Landwirtschaftlichen Hochschule Hohenheim.

Falke, F. (1920). Die Dauerweiden, Bedeutung, Anlage und Betrieb derselben unter besonderer Berücksichtigung intensiver Wirtschaftsverhältnisse. Verlag M & H. Schaper, Hannover.

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

Garwood, E.A. & K.C. Tyson (1978). Productivity and botanical composition of a grazed ryegrass/white clover sward over 24 years as affected by soil conditions and weather.
In: Changes in sward composition and productivity; Eds. A.H. Charles and R.J. Haggar. Occ. Symp. no. 10; Brit. Grassland Soc.: 41-46.

Gooijer, H.H. de (1973). Wat gebeurt er met ons grasbestand?
Stikstof nr.73: 552-556.

Gooijer, H.H. de (1975). Verslag van een oriënterend onderzoek naar de aard en oorzaak van beschadigingen van de grasmat en de gevolgen voor de botanische samenstelling (IBS 1557).
Karteringsverslag nr. 165; IBS, Wageningen.

Green, J.O. & A.J. Corrall (1965). The testing of grass varieties in swards with clover: the effect of grass seed-rate on comparisons of gross yield.
J. Br. Grassld. Soc. 20: 207-211.

Guyer, H. (1964). Die Umwandlung von Kunstwiesen in naturwiesenähnliche Bestände.
Schweizerische Landw. Forschung 3(1): 88-92.

Harmsen, G.W. & D.A. van Schreven (1955). Mineralization of organic nitrogen in soil.
Adv. in Agron. VII: 299-398.

Hart, M.L. 't (1947). De variatie van de opbrengst van het grasland in Nederland.
Maandblad voor de Landbouwvoorlichtingsdienst 4(7): 1-10.

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

Hébert, J. (1966). Opening of the discussion on paper presented by Woldendorp, Dilz and Kolenbrander.
In: Nitrogen and grassland. Proc. of the first Gen. Meeting of the Eur. Grassl. Fed., Wageningen, 1965; PUDOC, Wageningen: 69-74.

Heinonen, R. (1953). 'Soil factors affecting the permanence of pasture growth'.
Agrogeologisia Julkaisuja No. 61.

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. (1973b). Gruenlandumbruch und Neuansaat.
Z. Acker- u. Pflanzenbau 138: 150-170.

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

Hoogerkamp, M. (1975). Elytrigia repens and its control in leys.
Proc. Eur. Weed Res. Soc. Symp. Status, Biology and Control of Grassweeds in Europe: 322-329.

Hoogerkamp, M. (1980). De ophoping van organische stof onder grasland en de gevolgen hiervan voor de stikstofvoorziening van het gras.
Stikstof no. 95/96: 363-367.

Hoogerkamp, M. (1984). The effect of earthworms (Lumbricidae) and "grass sickness" on the productivity of grassland.
CABO-verslag no. 52; Wageningen.

Hoogerkamp, M. & J.W. Minderhoud (1966). Herbage production of permanent grassland, resown grassland and leys, with special reference to the "years of depression".
Proc. of the 10th Int. Grassl. Congr.: 282-287.

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; resultaten van het grondwaterstandsproefveld CI 1300 te Kerkwijk.
Meded. nr. 116; PAW, Wageningen.

Huntjens, J.L.M. (1972). Immobilization and mineralization of nitrogen in pasture soil.
Thesis Wageningen; PUDOC, Wageningen.

Idle, A.A. (1975). Grassland surveys in England 1939-1959.
J. Br. Grassld. Soc. 30: 111-120.

Jenkin, T.J. (1930). Perennial rye-grass at Aberystwyth.
The Welsh J. of Agric. VI: 140-165.

Jenkin, T.J. (1949). Progress in breeding herbage plants in Great Britain.
Rep. of the fifth Int. Grassl. Congress: 95-100.

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. (1943). Über Bodenlockerung, Umbruch und Hungerjahre von Grünlandflächen.
Pflanzenbau 19: 72-84.

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

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

Klapp, E. (1965). Grünlandvegetation und Standort nach Beispielen aus West-, Mittel- und Süddeutschland.
Paul Parey, Berlin and Hamburg.

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

Klitsch, Cl. (1932/'33). Ein Beitrag zur Umbruchfrage des Grünlandes vom Standpunkte der Bodenphysik.
Pflanzenbau 9: 216-228 and 262-273.

Kmoch, H.G. (1952). Über den Umfang und einige Gesetzmäszigkeiten der Wurzelmassenbildung unter Grasnarben.
Z. Acker- u. Pflanzenbau 95:363-380.

Kupers, L.J.P. (1981). Ontwikkelingen in vruchtwisselingsonderzoek. Themadag vruchtwisseling.
PAGV Lelystad; themaboekje nr. 2: 48-59.

Low, A.J. (1950). Rate of build-up of water-stable aggregates and soil crumb structure.
Trans. Fourth Int. Congress of Soil Sci. III (9) 13; Amsterdam: 9-13.

Mann, H.H. (1938). Investigations on clover sickness.
The J. of Agric. Sci. 28: 437-455.

Maenhout, C. (1981). Vruchtwisseling en bodempathogenen.
In: Themadag vruchtwisseling. PAGV Lelystad; themaboekje nr. 2: 38-47.

Müller, G. (1951). Zur Umbruchfrage von Grünland.
Z. Acker- u. Pflanzenbau 93: 464-493.

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.
Proc. of the XI Int. Grassland Congress; Queensland, Australia; Queensland University Press: 465-468.

Orr, J. (1928). The "mat" in grassland.
J. Minist. Agric. 35: 60-63.

Peel, S. (1978). The effect of botanical composition on the utilized metabolizable energy output of permanent grassland farms.
In: Changes in sward composition and productivity. Eds. A.H. Charles and R.J. Haggar. Occ. Symp. no. 10; Brit. Grassland Soc.: 47-54.

Prendergast, J.J. & J.J. Brady (1955). Animal output of reseeded grass. Part. I. The effects of strain of seed on the total output of grassland over a four-year period, and the effects of strain of seed and nitrogen treatment on annual output.
J. Br. Grassld. Soc. 10: 169-176.
Part II. Effects of seed strain and nitrogen treatment on the seasonal output and botanical composition of herbage, and on the live-weight gain of animals maintained entirely on the experimental plots throughout the grazing season in 1953.
J. Br. Grassld. Soc. 10: 213-228.

Prins, W.H. (1983). Limits to nitrogen fertilizer on grassland.
Thesis, Wageningen.

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

Richardson, H.L. (1938). The nitrogen cycle in grassland soils: with especial reference to the Rothamsted Park Grass Experiment.
The J. of Agric. Sci. 28: 73-121.

Rippel-Baldes, A. (1952). Grundrisz der Mikrobiologie.
Zweite Auflage; Springer-Verlag, Berlin, Göttingen, Heidelberg.

Rovira, A.D. & E.L. Greacen (1957). The effect of aggregate disruption on the activity of microorganisms in the soil.
Austr. J. Agric. Res. 8: 659-673.

Russell, E.W. (1961). Soil conditions and plant growth. 9th Ed.; Longman, London.

Russell, J.S. (1960). Soil fertility changes in the long-term experimental plots at Kybybolite, South Australia.
I. Changes in pH, total nitrogen, organic carbon, and bulk density.
Austr. J. Agric. Res. II, 6: 902-926.

Russell, M.B. & H.A. Mac Donald (1949). Soil structure and its importance for permanent and temporary pastures.
Rep. fifth Int. Grassl. Congress; Noordwijk: 40-46.

Sampson, K. & J.H. Western (1954). Diseases of British grasses and herbage legumes.
2nd Ed; Univ. Press, Cambridge.

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

Scheijgrond, W. & H. Vos (1960). Beschouwing over de standvastigheid der grassen.
Landb.k. Tijdschrift 72: 544-554.

Scheijgrond, W., H. Vos & A. Sonneveld (1955). Vergelijking van enkele typen Engels raaigras in een kunstweide onder beweidingsomstandigheden.
Landbouwvoorlichting 12(4): 181-190.

Scheijgrond, W., H. Vos en A. Sonneveld (1958a). Witte klaver in kunstweiden.
Kali 36: 219-225.

Scheijgrond, W., H. Vos & A. Sonneveld (1958b). Ervaringen met vlinderbloemigen in kunstweiden.
Landb.k. Tijdschrift 70: 802-816.

Schneider, K. (1927). Soll man Dauerweiden und Dauerwiesen von Zeit zu Zeit umbrechen?
Jahrb. über Neuere Erfahrungen auf dem Gebiete der Weidewirtschaft und des Futterbaues 9: 114-121.

Sonneveld, A. (1948a). De wintervastheid van Engels raaigras.
Maandbl. Landbouwvoorl. d. 5.1: 31-36.

Sonneveld, A. (1948b). Aanleg van grasland en teelt van graszaad.
CILO, Wageningen, Jaarverslag: 16-22.

Sonneveld, A. (1950). Het gedrag van weidetypen en handelszaad van Engels raaigras (project 29).
Verslag CILO over 1949; Wageningen 1950: 29-32.

Sonneveld, A. (1951). Aanleg van blijvend grasland.
In: Grassen en granen; W.E.J. Tjeenk Willink, Zwolle: 194-196.

Spaull, A.M., R.O. Clements & P.G. Mewton (1983). The effect of root-ectoparasitic nematodes on grass establishment and productivity.
Proc. of the 9th Gen. Meeting of the Eur. Grassl. Fed.; Reading 5-9 Sept. 1982. Ed. A.J. Corrall. Occ. Symp. no. 14. Br. Grassld. Soc.: 310-311..

Stapledon, R.G. (1939). The establishment and maintenance of temporary leys.
In: The temporary ley. Welsh Plant Breeding Station. Series H, no. 12. Cambrian News, Aberystwyth: 130-150.

Steen, E. (1966). The effect of fertilizer nitrogen and clover nitrogen on the yield of herbage in Scandinavia.
In: Nitrogen and grassland. Proc. of the First Gen. Meeting of the Eur. Grassl. Fed., Wageningen 1965; PUDOC, Wageningen: 77-83.

Stockdill, S.M.J. (1959). Earthworms improve pasture growth.
N.Z.J. Agric. 98: 227-234.

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 (1): 61-67.

Thomas, P.T. (1969). Herbage breeding.
In: Grass and forage breeding Ed. Ll. Philips and R. Hughes. Occ. Symp. no. 5, Br. Grassld. Soc.: 1-4.

Tischler, W. (1955a). Effect of agricultural practice on the soil fauna.
In: Soil Zoology; Proc. of the Univ. of Nottingham, Sec. Easter School in Agricultural Science. London, Butterworths Sci. Publ.: 215-230.

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

Troughton, A. (1962). The "mat" of hill swards.
J. Br. Grassld. Soc. 17: 233-236.

Vetter, H. (1966). Opening of the discussion on paper presented by Williams and Clement.
In: Nitrogen and grassland; Proc. of the First Gen. Meet. of the Eur. Grassl. Fed., Wageningen 1965. PUDOC Wageningen: 46-51.

Visscher, J. (1981). Vergelijking van rassen van Engels raaigras onder beweidingsomstandigheden.
In: Verslag 1981 Stichting onderzoekcentrum voor de rundveehouderij in Limburg, Noord-Brabant en Zeeland, "Cranendonck" te Soetendonk: 30-32.

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

Walker, T.W., B.K. Thapa & A.F.R. Adams (1959). Studies on soil organic matter: 3. Accumulation of carbon, nitrogen, sulphur, organic and total phosphorus in improved grassland soils.
Soil Sci. 87: 135-140.

Whitehead, D.C. (1970). The role of nitrogen in grassland productivity.
Commonw. Agric. Bur.; Bulletin 48.

Wijk, A.L.M. van (1980). Playing conditions of grass sports fields.
Agric. Res. Rep. 903, PUDOC Wageningen.

Williams, T.E. (1980). Herbage production: grasses and leguminous forage crops.
In: Grass, its production and utilization. Ed. W. Holmes; Blackwell Oxford, London, Edinburgh, Boston and Melbourne: 6-69.

Woldendorp. J.W. (1963). The influence of living plants on denitrification.
Thesis Wageningen; H. Veenman en Zonen N.V. Wageningen.

Zürn, F. (1971). Grünlandumbruch - Neuansaat - Hungerjahre?.
Mitt. der DLG 42 (14-10-1971): 1082-1084.

11 Appendix

Description of the experimental fields.
pg = old grassland; yg = young grassland; o.m.c.= organic matter content of the soil.

Experiment number, year of sowing, soil type and type of activity	Approximate N dressing (kg N ha^{-1} per year)	Number of replicates
E1 (1966; clay soil)		
.Sowing grass seed	0/180/360	2
- a mixture (A and B)[1]		
- no (C)		
.Sowing different varieties		
- modern varieties (A)		
- old varieties (B)		
.N dressing		
E2 (1970; sandy soil)		
.Resowing with different "mixtures"	219/275/320 (1st year) 200/274/341 (2nd year)	4
- a complex mixture (30 kg ha^{-1})[2]		
- <u>Lolium perenne</u> (25 kg ha^{-1})		
.N dressing		
E3 (1970; sandy soil)		
.Resowing with different "mixtures"	101/126/176 (1st year) 59/129/204 (2nd year)	4
- a complex mixture (30 kg ha^{-1})[2]		
-<u>Lolium perenne</u> (25 kg ha^{-1})		
.N dressing		

E4 (1969; 30 fields)		
on various soil types		
(in 1974 15 fields)		
.(Re)sowing with different "mixtures"	decision farmer	2
- a complex mixture (30 kg ha^{-1})[2]		
- Lolium perenne (25 kg ha^{-1})		
E5 (1965; clay soil)		
.Differences in o.m.c. by changing the profile	0/180/360	2
- pg		
- yg with a high o.m.c.		
- yg with a low o.m.c.		
.N dressimg		
E5a (field experiment). Continuation of E5 in 1980, but all treatments were fertilized with the same amount of N.		2
E5b (pot experiment). In 1979 soil from E5 was collected from the layers 0-10 and 10-20 cm and used in a pot experiment (Mitscherlich pots grown with Lolium perenne and not dressed with N).		2
E6 (1975; sandy soil)	212/379	
.Planting rhizomes of Elymus repens	(average)	4
- no		
- about 30 pieces with two nodes per m^2		
.Heaviness of the 1st cut		
- 1-2 t dry matter ha^{-1}		
- 4.4-5.0 " "		
- 7.3-7.7 " "		
.N dressing		

1) 20 kg Lolium perenne, 5 kg Festuca pratensis, 2.5 kg Poa pratensis and 5 kg Phleum pratense.

2) 49% Lolium perenne; 6% Poa trivialis; 4% P. pratensis; 14% Festuca pratensis; 14% Phleum pratense and 13% Trifolium repens.

The experimental fields were mainly grazed. All the treatments and variants were grazed or cut at the same time; if grazed the whole experimental field was available for the grazing animals.

Yields were measured by cutting strips with a mowing machine just before pasturing or cutting; fresh grass yields, dry matter yields and protein yields were assessed.

The botanical composition of the sward was recorded by estimating the coverage of the soil by the seperate species in the field (E4), or by determining the dry weight percentages of the species (one sample mostly composed of about 50 subsamples).