Accumulation of organic matter under grassland and its effects on grassland and on arable crops

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Abstract

HOOGERKAMP, M. (1973) Accumulation of organic matter under grassland and its effects on grassland and on arable crops. Agric. Res. Repts (Versl. landbouwk. Onderz.) 806, ISBN 90 220 0481 3, (v) + 24 p., 11 tbs, 9 figs. Eng. Summary.

In 18 trials on grassland throughout the Netherlands sown on a soil low in organic matter, organic matter started accumulating soon after sowing and usually continued for a long time until the equilibrium of old grassland was attained. The rate of accumulation was asymptotic.

The yield of arable crops and of grassland with a low clover content was higher, the higher the content of organic matter in the soil. This effect was almost entirely due to an increased nitrogen supply from the soil. The same effect could be attained by a heavier nitrogen dressing. No residual effect of the organic matter (e.g. decreased drought sensitivity) could be demonstrated.

If these changes in the content of organic matter in the soil occurred near the surface, the effects on the yield were greater than deeper in the profile.

1 Introduction

Under otherwise identical conditions, content of organic matter in mineral soil is usually much higher under grassland than under arable crops (Wiggers, 1950; Köhnlein, 1959; Kortleven, 1963; Cooke, 1970). Despite the often much lower bulk density under grassland, the amount of organic matter is also higher (Hoogerkamp & Minderhoud, 1966).

Amounts and contents of organic matter under grassland and in arable soil vary widely, since they are subject to many factors, such as moisture content, acidity and nutrient status of the soil, soil type, and climate ('t Hart, 1950; Wiggers, 1950; Kononowa, 1958; Köhnlein, 1959; Grigo, 1961; Heinonen, 1962; Kortleven, 1963; Bremner, 1965; Janick et al., 1969). Consequently, there is considerable scatter of values in grassland and arable soil. Accumulation of organic matter under grassland and decomposition after ploughing up for arable are usually asymptotic. Rates vary widely (Richardson, 1938; Köhnlein, 1957; Jackmann, 1964; Vetter, 1966). Organic matter usually decomposes more rapidly under arable than it accumulates under grassland (Smith, 1942; 't Hart, 1950; Köhnlein, 1957).

Many theories have been put forward for the differences in organic matter between grassland and arable, but none have been completely proved. The differences in vegetation type, in the proportion of the year for which the crop covers the soil and in tillage are important (Harmsen, 1951; Theron, 1951; Harmsen & Van Schreven, 1955; Barrow, 1957; Rovira & Greacen, 1957; Frecks & Puffe, 1958; Greacen, 1958; Woldendorp, 1963; Huntjens, 1971).

Organic matter may be important in plant growth, influencing, for instance, structure and water-holding and exchange capacity of soil. Accumulation or decomposition of organic matter may alter these growth factors. Moreover accumulation will fix minerals, some of which may be limiting for plant growth, whereas decomposition will increase their availability.

The favourable effect of soil rich in organic matter for growth of arable crops is well known and is exploited in several ways (e.g. ley farming). For grassland itself, however, the benefit is taken for granted (Davies, 1952; Zürn, 1970).

A good understanding of the correlation between organic matter in the soil and grassland productivity is essential, since its mass fraction is frequently decreased, for instance by reseeding, deep-ploughing, covering with sand, or temporary growing of arable and horticultural crops.

To repair some gaps in data on organic matter under grassland, in an extensive series of experiments, the following were investigated:

- rate of accumulation
- effect of nitrogen fertilizer on accumulation
- effect of a change in organic matter content of the soil on forage production and botanical composition
- effect of depth of the layer rich in organic matter on forage production
- effect of amount of organic matter accumulated under grassland on subsequent arable crops (rotation) and grassland (reseeding)
- extent to which the organic matter effect could be due to mineralization of nitrogen in the soil and could be offset by provision of nitrogen dressings.

2 Methods

In experimental fields throughout the Netherlands mass fraction of organic matter was brought to certain levels at different depths by growing different crops (grassland or arable crops), by varying the depth of tillage (rotavation or digging), by inverting soil layers within the same experimental field, by removing soil with a high or low content of organic matter or by adding such soil from elsewhere. The test crops (grass or arable crops) were grown at different nitrogen levels (Table 1).

Contents of organic matter and total nitrogen were estimated in dry soil (grassland 0–5 cm and arable land 0–18 or 0–20 cm) each year by ignition (if very low, by elementary analysis) and by Kjeldahl digestion, respectively. On a few fields (E3, E5 and E8), soil structure was assessed (total pore space and air content).

Where grass was the test crop, production of fresh herbage, dry matter and crude protein were estimated in sample strips cut before turning cattle onto them or in areas protected from grazing, for instance by cages. All treatments of each trial field were dressed with the same amounts of fertilizers at the same time.

Arable crops, sample plots were harvested; for cereals grain yield was estimated and for potatoes tuber yield (fresh and often dry matter, sometimes crude protein).

There were two to six replicates, but usually four.

Table 1. Brief scheme of the trials. Further details available from I.B.S., postbus 14, Wageningen, the Netherlands. ac = arable crops; pp = permanent pasture; p = pasture; yp = young pasture; om = organic matter.

Trial No.	Soil type	Test crops and soil treatments	Approximate N-dressing to test crops kg/ha/year
E1	heavy basin clay soil	a. pp b. yp at 3 om levels	0, 100, 200, 300
E2	sand on moist peat soil	yp with peat subsoil at 6, 12 and 18 cm	100, 200, 300
E3	rather heavy marine clay soil	a. pp b. yp on pp rotavated or buried to 20 cm or 40 cm	0, 100, 200, 300
E4	sandy soil	a. p after 3 years of p b. p after 3 years of ac	120, 180, 240, 300
E5	sandy soil	p reseeded every 2, 4, or 8 years	150, 300

Table 1. Continued.

Trial No.	Soil type	Test crops and soil treatments	Approximate N-dressing to test crops kg/ha/year
E6	sandy soil	a. pp b. yp on pp rotavated or buried to 20 cm deep	0, 100, 200, 300, 400, 500
E7	heavy basin clay soil	a. pp b. yp on pp buried to 5, 12 or 20 cm	at first 70, later 70 and 220
E8	rather heavy marine clay soil	a. pp b. yp at 2 levels of om	0, 180, 360
E9	sandy soil	yp on soil rich in om in the layer 0–10, 25–35 or 50–60 cm	0, 100, 200, 300
E10	sandy soil	a. 4 year-old p b. 1 year-old p (reseeded a)	50, 100, 175
E11	sandy soil	a. 4 year-old p b. 1 year-old p (reseeded a)	175, 240, 300
E12	sandy soil	a. potatoes after 3 years of p b. the same after 3 years ac	potatoes: 0, 40, 60, 80, 100, 140, 180
E13	sandy soil	a. potatoes, rye and oats after 3 years of meadow b. the same after 3 years ac	potatoes : 0, 20 ..., 300 rye : 60 oats : 0, 25, 50, 75
E14	sandy soil	a. potatoes, rye and oats after 6 years ac b. the same after 3 years p c. the same after 6 years p	potatoes: 0, 30 ..., 330 rye : 0, 25, 50, 75 oats : 0, 25, 50, 75
E15	reclaimed peat soil	a. potatoes after 1 year p b. potatoes after ac	0, 20, 40 ..., 180
E16	sandy soil	a. potatoes, rye and oats after 3 years p b. the same after 3 years of ac	potatoes: 0, 20 ..., 180 rye and oats: 60 and 70 resp.
E17	sandy soil	a. potatoes, rye and oats after 3 years of p b. the same after 3 years of ac	potatoes: 0, 30 ..., 270 rye and oats: 0, 25, 50, 75
E18	heavy basin clay soil	yp and pp with watertables at 25, 40, 50, 65, 95 or 140 cm	0, 70, 220, 360
E19	in greenhouse: plastic pipes (⌀ 30 cm, 100 cm), with light marine clay soil	a. N at 0 cm b. N at 25 cm (Lolium perenne)	60
E20	light marine clay soil	yp	100, 230, 360

3 Results and discussion

3.1 Grassland

3.3.1 Accumulation of organic matter and nitrogen under grassland

The method of soil analysis used proved not accurate. Variation between replicates and over a short while in the same plot was wide relative to actual changes (Table 2).

Since 0.1% nitrogen corresponds to 500–700 kg/ha and normally not more than 50–100 kg/ha accumulates in a year, the variation[1] allowed use only of samples from fields where conditions remained constant over many years (Fig. 1).

Despite the scattering of the points, nitrogen in the soil seemed to remain constant under old grassland but gradually to increase under young grassland. The same occured in the organic matter contents. Amounts of organic matter and nitrogen under old grassland remained constant only when conditions such as water table, soil acidity and botanical composition of the sward remained constant.

Table 2. Content of total N(% w/w) in the soil of 16 subplots (10 m × 2 m) in Trial E3 in the layer 0–5 cm on 20 and 25 November 1959.

Treatment	Replicate (20 Nov.)				Replicate (25 Nov.)			
	1	2	3	4	1	2	3	4
Old grassland	1.04	1.07	1.12	1.12	1.06	1.12	1.16	1.14
Young grassland; rotavated	0.55	0.59	0.61	0.52	0.60	0.62	0.61	0.58
Young grassland; buried to 20 cm	0.34	0.33	0.34	0.34	0.32	0.32	0.36	0.36
Young grassland; buried to 40 cm	0.27	0.29	0.28	0.27	0.29	0.28	0.30	0.26

1. The following possible causes of this variation can be mentioned:
- sampling of different soil layers; always the same layer was sampled (0–5 cm), but since the soil is subject to shrinkage and swelling there is a risk that at each sampling a different soil mass is sampled. Especially in grassland, where the organic matter content decreases sharply at increasing depth of the layer, this may have a great effect on the value determined. The relevant error can be reduced by deeper sampling, but then the organic matter accumulation, which occurs mainly in the uppermost centimeters) will be difficult to examine and measure.
- variation within the experimental field (Table 2)
- sampling and analysis errors (Maton et al., 1960).

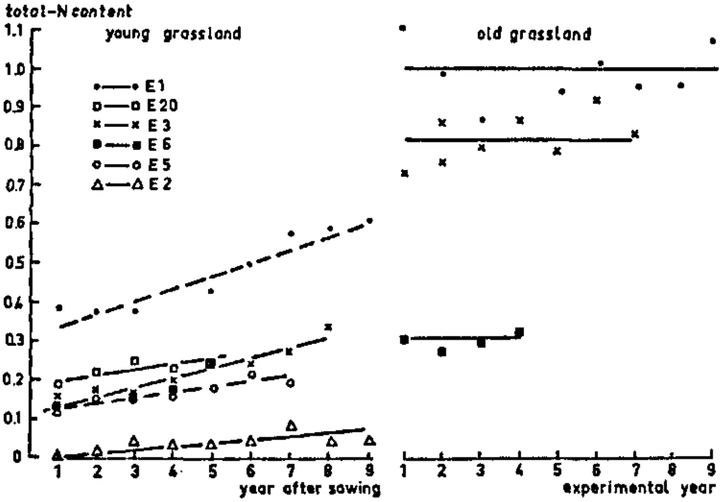

Fig. 1. Content of nitrogen (weight) in soil under sown grassland with an initially low content (0-5 cm).

Accumulation of organic matter and nitrogen in our trials (E1, E2, E3, E18, E20) and in those of others (Koornneef, 1945; 't Hart, 1950; Russell, 1961; Jackmann, 1964; Van der Boon et al., 1970) was less the deeper the layer in the profile. In E18, for instance, old grassland in comparison to arable accumulated 2050 kg N/ha in the layer 0–5 cm, 1250 kg in the layer 5–10 cm and 500 kg in the layer 10–20 cm; about 56% of the total in the layer 0–5 cm. This proportion varied widely; in the present field trials, from 30 to 80%. Due to the increase in bulk density of the soil with depth, this proportion is usually smaller than the contents of organic matter and nitrogen suggest. Root distribution in the profile and the activity of burrowing animals (worms and moles) are important in this. 't Hart (1950) found on average that about 60% of the nitrogen accumulated in the layer 0–5 cm.

Most results from Fig. 1 and those mentioned in Sections 3.1.2 and 3.2 indicate that the accumulation under young grassland poor in organic matter sets in just after sowing and not, as Köhnlein (1959) assumed, a few years later, at the beginning of the years of depression (Hoogerkamp, 1974b).

On the heavier soils (E1 and E3), the increase was somewhat more rapid than on the light soils (the other experiments of Fig. 1), perhaps through the inhibitory effect of clay minerals on mineralization (Kortleven, 1963), or perhaps also through the lower initial content (compared with old grassland).

Since the trials on young grassland poor in organic matter were briefer than required to attain the equilibrium of old grassland, the accumulation process could not be studied thoroughly (the transition between young and old grassland in Fig. 1 is missing). But in a few trials with different initial contents the trends of the organic matter and nitrogen curve (Fig. 2) were asymptotic as demonstrated by other authors (e.g. Richardson, 1938).

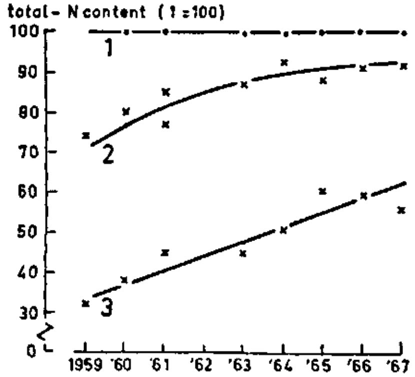

Fig. 2. Relative content of nitrogen total N (%) in soil under grassland with different initial organic matter contents to that of plots of old grassland in the same field. 1 = equilibrium level of old grassland (put at 100); 2 = a somewhat decreased content under young grassland; 3 = considerably decreased content under young grassland. (E_1; layer 0–5 cm).

However the layer initially 0–5 cm may become thicker by accumulation of debris from the sod or may, in the initial period, become thinner by compaction, the soil being no longer tilled and being trodden under hooves. The layer may also become loosened and mixed with subsoil by burrowing animals such as worms and moles. Thus the layer sampled at different moments often is not identical. If the change in bulk density is not allowed for, the contents of organic matter and of nitrogen are exaggerated (e.g. on E1, bulk density was on young grassland poor in organic matter 1.30 kg/dm^3 and on old grassland 0.64 kg/dm^3). Calculations by 't Hart (1950), Minderhoud (1959) and Van der Boon (1967) based on constant volumes by weight, resulted in values which were too high. In E5 for instance content of nitrogen in the layer 0–5 cm increased from 0.12% to 0.19% in seven years; but bulk density decreased from 1.18 to 1.06 kg/dm^3. The annual increase in amount of nitrogen was therefore, less than 59 kg/ha as would be expected at constant bulk density of 1.18 kg/dm^3. For the same reason (expansion of the initial layer) calculations based on contents as well as on bulk density give an underestimate of accumulation of organic matter and total nitrogen. The actual annual accumulation of nitrogen in this experimental field (E5) may have been between 43 and 59 kg/ha. If 60% of the nitrogen accumulation occur in the layer 0–5 cm, annual accumulation of nitrogen is 72–98 kg/ha. 't Hart (1950) and Williams & Clement (1966) obtained larger amounts (110 and 135 kg N/ha, respectively). Of course there are considerable differences between trials, shown also by published data collected by Vetter (1966) (40–1300 kg/ha).

The effect of soil mixing by burrowing animals is unknown.

An attempt was made to eliminate the expansion effect by applying a marking layer (red gravel, coloured beads, nylon netting) at a certain depth in the profile. The first two materials, however were shifted by burrowing animals, the nylon netting raised difficulties during sampling. Attempts to characterize the initial layer by the content of the minerals present in it had to be stopped, because it was too time-consuming.

The annual amount of nitrogen applied (up to 300 or 500 kg/ha) had no distinct effect on the accumulation of organic matter and nitrogen or on the equilibrium values. Russell (1961); Theron (1965); Owensby et al. (1969); Van der Boon et al. (1970) and Cooke (1970) found corresponding results. Neither was the C/N quotient demonstrably affected.

Nitrogen utilization (% of nitrogen applied in the crop), averaging 40 to 50% at the same clover percentage, was hardly affected by content of organic matter in the soil, if at all (3.2). Thus, a more rapid accumulation of organic matter does not necessarily decrease nitrogen utilization.

The difference between nitrogen output and proportion of fertilizer nitrogen denitrified (Woldendorp, 1965) cannot be accounted for by immobilization.

3.1.2 Effect of different contents of organic matter in the soil on gross yield of grassland

In studies on the effect of content of organic matter on the productivity of grassland, confusion should be avoided of differences in contents of organic matter caused by factors directly affecting grass growth (e.g. drainage, soil type). In studies on the correlations in fields, such a situation occurs and frequently there is little or no relation between content of organic matter and yield ('t Hart, 1947 and Jagtenberg, 1962). In the present study, differences in content of organic matter were established within one and the same experiment. Under these conditions and in contradiction to the findings of Zürn (1971) and the supposition of Davies (1952), grass growth and yields were distinctly affected (Fig. 3a and b).

At all nitrogen levels, the dry matter and crude protein yield increased with content of organic matter; also with increases of organic matter above the equilibrium for old grassland (Treatment 1 in Trials E1 and E8).

The extent of this positive response to a higher content of organic matter varied

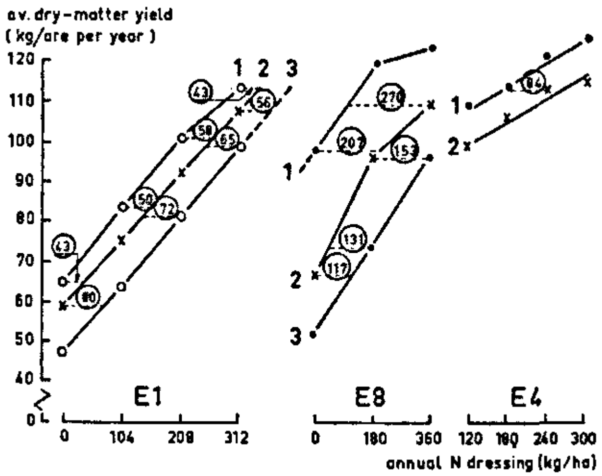

Fig. 3a. Effect of a difference in content of organic matter in the soil on average annual yields of dry matter (kg/ha). Treatment 1, 2 and 3: decreasing organic matter contents[1]. The encircled data are discussed later.

rather widely in the separate cuts and annual yields. At different rates of nitrogen, this was usually similar. Sometimes at the lowest rate of nitrogen differences were smaller because of the white clover present, the percentage being higher as content of organic matter in the soil was lower. In general, with good growth of clover a difference in content of organic matter need have little or no effect on yield. (In these present field trials, white clover grew only moderately, as often happens in the Netherlands).

With small dressings the experimental design too influences differences in response: all the treatments of the same trial were always grazed simultaneously by the same cattle, the plots with the lowest yields receiving, therefore, more faeces and urine than in separate grazing of the treatments. Thus, differences in organic matter effect were partly masked.

At the highest rates of nitrogen response sometimes was lower because nitrogen was no longer growth-limiting. At first on the organic matter rich treatment.

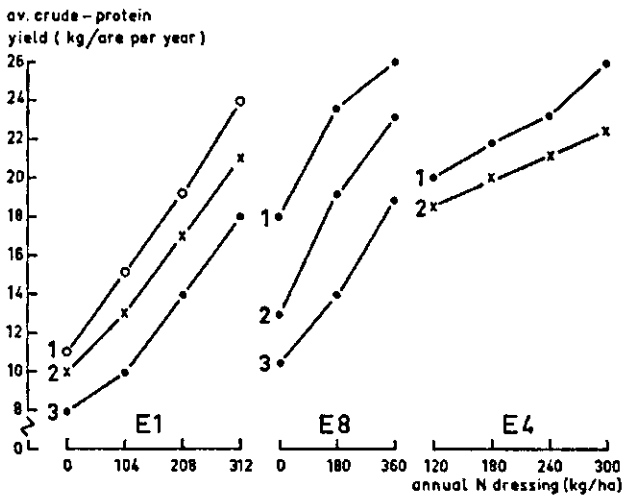

Fig. 3b. Effect of a difference in content of organic matter in the soil on average annual yields of crude protein (kg/ha). Treatment 1, 2 and 3: decreasing organic matter contents.[1]

1. Initial organic matter contents (%) in different layers.

Experiment										
E1 Treatments				E8				E4		
	1	2	3		1	2	3		1	2
0– 5 cm	20.6	20.9	12.3	0–10 cm	6.9	7.5	1.9	0–25 cm	3.5	3.3
5–10 cm	19.3	17.2	6.6	10–20 cm	7.0	5.1	1.3			
10–15 cm	17.3	13.3	12.7	20–30 cm	6.9	2.1	1.5			
15–20 cm	14.0	5.6	6.5	30–40 cm	6.3	1.3	1.3			

Whether differences in yield were still to be observed at optimum dressings could not be established, since such high rates were not applied. (Technically, this was not possible because differences in growth of the treatments in one trial would have caused excessive differences in grazing quality). Such yield differences would not be expected because of the decreasing organic matter effect in the studied range of nitrogen rates and because the positive effect of a higher content of organic matter was mainly due to a larger supply of nitrogen, as will be discussed later.

The positive effect of organic matter was obvious immediately after sowing, contrary to 't Hart's (1947 and 1949) supposition. Frequently, it was even greatest immediately after sowing, decreasing gradually as the grassland matured (Fig. 4).

The increase in yields of the enriched treatment (1) and the decrease in yields of the poor treatment (3) diminished gradually (asymptotically) as the grassland matured, the difference from grassland with organic matter near equilibrium level getting smaller and smaller. On the poor treatment (3) this decrease in organic matter effect was almost parallel to the increase in content of organic matter in the layer 0–5 cm. There were too few soil analyses from the enriched treatment (especially from the larger layers) to support such a statement.

Nitrogen fertilizer did sometimes have an immediate effect on the yield differences between the levels of organic matter, as discussed before, but a long-term effect could not be established. Contents of organic matter and nitrogen in the soil were not affected by rate of nitrogen (Section 3.1.1). Neither was an after-effect of the nitrogen applied demonstrated. In trial E1, for instance, after different nitrogen treatments for seven successive years, there was no residual effect in the eighth year when all plots received 100 kg/ha.

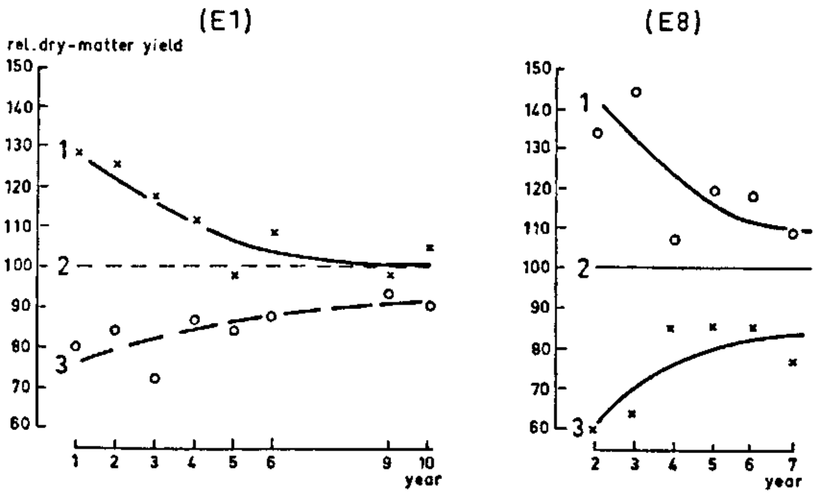

Fig. 4. Relative annual yields of dry matter (Treatment 2 = 100). Treatment 1 = increased content of organic matter; 2 = content of organic matter near equilibrium level; 3 = decreased content of organic matter.

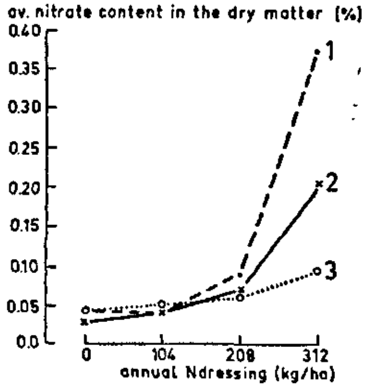

Fig. 5. Average content of nitrate nitrogen in dry matter (weighted means). Trial E1. 1, 2, 3: decreasing contents of organic matter in the soil.

The positive organic matter effect was mainly due to a greater nitrogen supply from the soil as seen by the following:

1. Colour of the grass, crude protein content in the grass, clover development in the stand and production distribution in the year all responded to an increase in content of organic matter in the soil in a similar way as to an increase in nitrogen rate.
2. The nitrate content in the grass, a good indicator of its nitrogen status (Dijkshoorn, 1958 and Van Burg, 1962), was higher, the higher organic matter in the soil (Fig. 5).

On the treatments with little or no nitrogen dressing nitrate accumulation was negligible; at higher and, especially at the highest rate, however, accumulation did occur, the more so, the higher the content of organic matter in the soil.

3. At the same nitrogen yield, the dry matter yield was independent of the level of organic matter (Fig. 6).

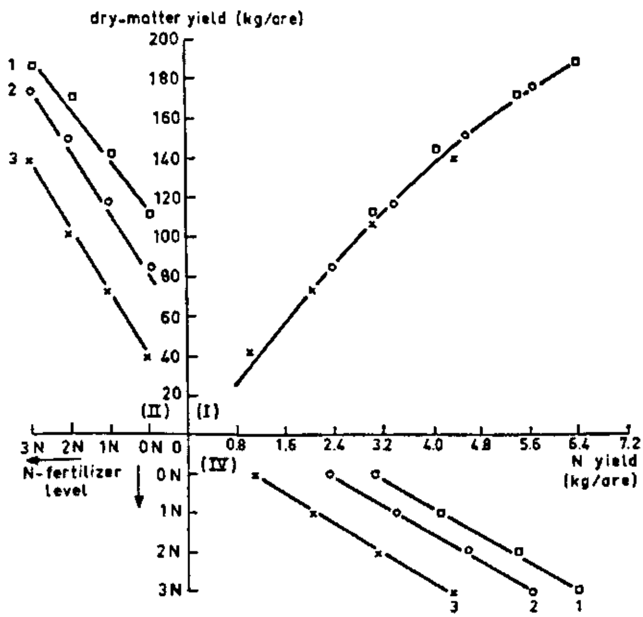

Fig. 6. Relation between yields of dry matter and nitrogen (I), nitrogen dressing and yield of dry matter (II) and nitrogen dressing and nitrogen yield (IV) for averaged yields of the first cut in Trial E1: 1, 2 and 3 decreasing contents of organic matter in the soil.

The differences in yield of dry matter (II) are due to a difference in nitrogen yield (IV) because at the same nitrogen yield, yields of dry matter were equal in all the treatments (I) (De Wit, 1953 and 1957 and Frankena & De Wit, 1958). This was observed repeatedly in the yield of the individual cuts and in the total annual yields. A higher yield of nitrogen could be effected by increasing the rate or the content of organic matter in the soil (IV). The parallelism of the lines (IV) shows that there was no distinct interaction between rate of nitrogen and content of organic matter in the soil if there is little clover and nitrogen is growth limiting (see also Fig. 3).

The differences in nitrogen yield caused by differences in content of organic matter were as shown in Table 3.

Table 3. The differences in nitrogen yield (kg/ha/year); 1, 2 and 3: decreasing contents of organic matter in soil. Averages for all years.

Differences between levels	Experiment		
	E1 (9 years)	E8 (6 years)	E4 (3 years)
1–2	36	66	43
2–3	49,5	66	

Results do not clearly show whether these lower yields of nitrogen at a lower level of organic matter of the soil are due to a lower mineralization, to greater immobilization or to greater losses of nitrogen (leaching and denitrification). Since utilization of fertilizer nitrogen when there was little clover and when nitrogen was growth limiting is about the same at all levels of organic matter (Fig. 3 and Fig. 6 IV), lower mineralization seems to be responsible.

Of the processes removing nitrogen from the soil, only nitrogen in the crop removed was estimated, so that it could not be calculated how much less nitrogen was mineralized because of lower contents of organic matter. The differences in yields (Table 3) indicated at most the minimum amounts.

At a lower content of organic matter in soil, the restricted supply of nitrogen from the soil could be compensated almost entirely by nitrogen dressing, but the amounts required for compensation were considerable (Fig. 3, encircled data).

As already shown (Fig. 4), these differences in requirement decreased with the ageing of the grassland, as the content of organic matter in soil approached the equilibrium of old grassland.

A general estimate could not be made of the differences in nitrogen requirement, for instance, for a unit difference in content of organic matter or nitrogen, because there were too few trials and because of differences in management of the various fields. The results, however, indicate that nitrogen requirement may vary considerably from year to year and from place to place. Net mineralization per unit content of organic matter or of nitrogen varied widely too, contrary to the conclusion of Walker et al. (1956). For instance in trial E8, the absolute difference between the treatments

Table 4. Effect of content of organic matter in the soil on the content of water available to the plant (pF 2.0–pF 4.2) (%) in soil, (E8).

Layer	Soil high in organic matter content	Soil low in organic matter content
0–10 cm	25.2	11.6
10–20 cm	27.3	14.6
20–30 cm	25.3	14.9
30–40 cm	27.1	16.6

in content of organic matter in the soil was appreciably smaller than in trial E1, whereas the difference in nitrogen yield as well as in requirement was often greater.

Other effects of organic matter than through nitrogen supply on production of dry matter could hardly be established. For instance, there was no reliable difference in drought sensitivity despite the distinct effect of content of organic matter on moisture-holding capacity of the soil (Table 4).

The yield differences obtained in dry periods could be traced back also to differences in nitrogen supply, which could be eliminated by nitrogen dressing. In the trials, however, there were good water-retaining clay soils; on dry sandy soil or in drier weather, the situation may be different.

How far the supply to the grass of nutrients other than nitrogen in the organic matter, (e.g. P, K), was affected by a change in the content of organic matter in the soil could not be established, since sufficient of these nutrients was supplied for optimum grass growth in all treatments. These elements are, however, much less important than nitrogen because of the lower contents of these elements in organic fraction of soil, the importance of the mineral fraction in supply and because grass requires less of these elements.

3.1.3 Influence of depth of the layer rich or poor in organic matter

The depth of the layer with different amounts of organic matter had a distinct effect on yield; if nearer the surface the yields generally differed more.

In reseeded grassland, yield losses generally occurred when surface soil with a high content of organic matter was buried deeper in the profile: for instance in trial E3, average yield of dry matter from the first cuts were if rotavated 165, if buried to 20 cm 145 and if buried to 40 cm 99 kg/ha.

Also after levelling grassland by moving surface soil from the higher parts of the field to lower parts (e.g. furrows and ditches), yield losses may occur (Table 5).

The detrimental effect of decreasing organic matter in the surface soil was greater than the positive effect of increasing the relevant content in deeper layers.

These yield losses from burying organic matter varied considerably; in general they were greater on heavier soils than on lighter. There was no clear limiting depth at which the adverse effect appeared; usually, however, it was around 15–20 cm.

Table 5. Yield increases and yield decreases (kg/ha) resulting from a change in profile layers (1) over 5 years. On plot B the layer 10–20 cm was exchanged with the layer 0–10 cm of plot D (So plot B received the layer 0–10 cm of plot D). On plot C the original profile was almost unchanged (rotavated permanent pasture)

	Annual N dressing (kg/ha)				
	0	100	200	300	Average
Yield increase (B–C)	4090	6620	5430	3430	4890
Yield decrease (C–D)	8680	9450	7550	6390	8020
Difference	4590	2830	2120	2960	3130

The cause of the detrimental effect of depth of the organic matter in the profile was a less adequate nitrogen supply to the grass (Fig. 7).

The decrease in nitrogen supply, which could be compensated by increasing the nitrogen dressing could be caused, for instance, by: inadequate uptake (more open rooting system (Hoogerkamp, 1974a), increased leaching and decreased mineralization. Over and against this negative effect of burying organic matter deep in the ground, the crop was often somewhat less sensitive to drought (Table 6).

This benificial effect is due to a better nitrogen supply from the soil, because nitrogen cannot be absorbed in dry periods from the topsoil; the N in the wetter subsoil is important then. Arguments are:

– in dry periods the nitrogen yield was higher in the deep-buried treatment of Trial E3, while the dry matter yield at the same nitrogen yield was almost the same for all treatments.

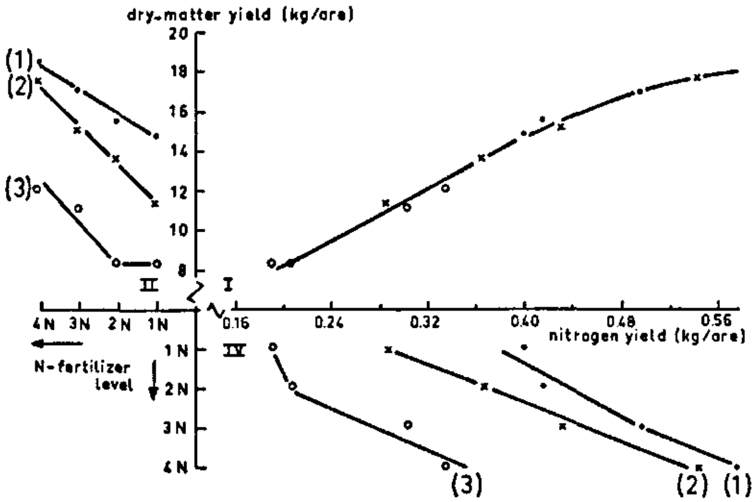

Fig. 7. Effect of depth of the organic matter rich layer on the relation between yields of nitrogen and dry matter. First cut from E3; (1) rotavated; (2) buried to 20 cm; (3) buried to 40 cm.

Table 6. Effect of depth of burying the old sward before reseeding; relative yield of dry matter in dry and normal years (Buried 5 cm = 100) (E7).

	Buried 5 cm	Buried 12 cm	Buried 20 cm
Dry years	100	105	111
Other years	100	102	100

Table 7. Effect of nitrogen injection on the grass yield (g/pipe) in a dry period (E19).

	Fresh material	Dry matter
Nitrogen at 25 cm	44.5	15.7 (35.2%)
Nitrogen at 0 cm	25.1	10.5 (41.9%)

– in the watertable trial (E18), drought damage in young grassland was mainly expressed as nitrogen deficiency. If the depth of organic matter in the soil profile was equal, the lower the water table the lower the yield of dry matter, but at the same nitrogen yield the yield of dry matter was the same with all water tables (Hoogerkamp & Woldring, 1967).

– by nitrogen injection into the subsoil (E19), the drought damage could be decreased (Table 7); in other periods of the trial, yields were the same or higher with nitrogen placed at the surface.

Garwood & Williams (1967) and Penman (1970) came to the same conclusions, because in their trials evapotranspiration remained optimum until long after grass growth had sharply decreased. Garwood & Williams (1967) found also a positive effect from injecting nitrogen into the subsoil. Besides nitrogen, some other nutrients may decrease to a minimum (Hagan et al., 1959). Of course, this applies only as long as water in subsoil is not minimum.

However, in these trials, the positive effect of a rich subsoil in dry periods was distinctly less than the negative effect of a poor surface soil in periods with a more adequate moisture supply (Table 5). In the Netherlands, moist weather predominates. Vervelde & Meyerman (1950); Gliemeroth (1952); Klapp (1952) and De Wit (1953), found corresponding results for arable crops.

3.2 Arable crops

In the arable trials, mostly on sandy soil, contents of organic matter and nitrogen in the soil were nearly always distinctly increased by including grassland in the crop rotation (Table 8).

These increases could not be accurately estimated because of the weaknesses in the soil analysis (Section 3.1.1).

Accumulation of organic matter in the soil benifited growth and yield of the arable crops in all the ley-arable trials, except one (E15) (Table 9).

Table 8. Effect of including grassland in an arable rotation on contents of organic matter and nitrogen (in brackets) in the soil.

	Trial			
	E 4	E 16	E 13	E 14
Sampled layer	0–25 cm	0–15 cm	0–18 cm	0–20 cm
Crop rotation				
Arable crops	3.3 (0.21)	2.8	4.3 (0.14)	2.5 (0.10)
Ley (3 year)	3.5 (0.25)	3.3	4.4 (0.15)	2.9 (0.10)
Ley (6 year)				3.2 (0.10)

Table 9. Comparison of average yields of arable crops grown in rotation with grassland or arable crops (kg/are).

Trial	Test crop	Yield with continuous arable (kg/ha)	Yield increase on ley/ arable treatment	
			absolute (kg/ha)	relative (%)
E12	potatoes (1st year)	29600	5900	20
E13	potatoes (1st year)	33800	3800	11
	rye (2nd year)	4240	110	3
	oats (3rd year)	4340	0	0
E14 (3 y. grassl.)	potatoes (1st year)	35800	4100	11
	rye (2nd year)	3310	590	18
	oats (3rd year)	4020	530	13
E14 (6 y. grassl.)	potatoes (1st year)	35800	6100	17
	rye (2nd year)	3310	860	26
	oats (3rd year)	4020	1090	27
E15	potatoes (1st year)	54300	1700	-3
E16	potatoes (1st year)	29500	5500	19
	rye (2nd year)	3010	740	25
	oats (3rd year)	5090	120	2
E17	potatoes (1st year)	31900	4100	12
	rye (2nd year)	3410	600	18
	oats (3rd year)	3150	180	6

The yields and yield differences varied widely. Of the many factors only a few could be analysed in these experiments. It was found that a longer grassland period and a shorter period between ploughing in the grassland and growing the test crops (E13, E16 and E17), in general resulted in a higher yield increase.

Increasing the rate of nitrogen of exclusively mown grassland (E13) did not increase yield of the following arable crops; an insufficient compensation of the removed P, K or Mg even resulted in a lower yield (Table 10).

Table 10. Effect of difference in annual nitrogen dressing (kg/ha) to ley over three years on the average yield (kg/ha) of the following arable crops (E13).

N dressing (for 3 years)	N dressing minus N removed with the grass	Yield of arable crops		
		potatoes (1st)	rye (2nd)	oats (3rd year)
140	44	39200	4400	4500
280	94	37200	4200	4300
420	145	36400	4400	4300

Despite the increasing difference between amount of nitrogen applied and that removed as dressings increased, there was certainly no aftereffect of the nitrogen. This corresponds with the statement that a difference in nitrogen dressings to grassland in the studied ranges, does not cause distinct differences in accumulation of organic matter or nitrogen (Section 3.1.1–2). Neither did Wheeler (1958); Williams et al. (1960) and Widdowson et al. (1964) find any increase in yield of test crop on meadow as more nitrogen was applied. These authors and also Hammerton & Edwards (1965) observed, however, that on pasture there was a positive aftereffect of dressing; whether this was a result of a difference in nitrogen contents of the soil, in mineralization rate of the organic matter, or in inorganic nitrogen in the soil (or any other factors) could not be ascertained from their results. Hence the best likely reason is a higher content of inorganic nitrogen in the soil.

At increasing rates of nitrogen to the arable test crops, their yields were also higher; the yield increase in the ley-arable treatment over that of arable, however, was usually less. This effect was greatest in the first test crop (potatoes) (Table 11).

Despite the wide range of nitrogen rates, it was difficult to establish an optimum rate for potatoes. Therefore the results do not allow any conclusion about a residual effect (other than a greater nitrogen supply) of the grassland; however, at the highest nitrogen rate in all experiments, the ley-arable treatment yielded more than the arable treatment, perhaps because the nitrogen supply of the ley-arable treatment was greater, but also possibly because the nitrogen supply was better distributed in the growing season or perhaps because another growing factor was involved. The residual effect, if any, in these trials was small; however, it could have been greater, for instance, on drought-sensitive soils and on soils of poor structure (Low, 1955). Insufficient rotation of arable crops, including grassland in the rotation, may also cause yields increases due to a decrease in various diseases (Hanley et al., 1964; Ledingham & Chinn, 1964; Heard, 1965; Stone, 1968).

The relation between yields of nitrogen and of dry matter also showed that nitrogen mineralization in the soil was the main factor in the difference between rotation treatments (Fig. 8).

Besides a greater nitrogen supply, in this trial, another unknown factor was involved; one affecting growth, when the nitrogen dressing exceeded the optimum for perma-

Tabel 11. Effect of nitrogen dressing to potatoes on the yield of this crop (tonne/ha) in the arable treatment (A) and on the increase in yield with the ley-arable treatment (D).

Experiment and treatment	N-dressing																					
	0	20	30	40	60	80	90	100	120	140	150	160	180	200	210	220	240	260	270	280	300	330
E12 A	17			29	25	25		30	37	37			38									
E12 D	6.8			3.3	9.7	10.5		8.0	3.6	2.8			2.4									
E13 A	20	25		27	29	30		30	32	35		36	36	38		38	38	41		42	44	
E13 D	10.2	5.6		6.3	5.8	6.6		8.0	7.2	4.0		3.6	4.4	4.0		5.3	6.6	1.9		3.1	2.6	
E14 A	24		33		33		33		38		37		43		41		38		37		39	34
E14 D	12.6		0.7		5.2		6.0		3.9		5.5		0.9		3.9		7.2		7.5		4.8	4.5
E16 A	10	17		22	29	32		34	36	38		38	39									
E16 D	11.3	8.9		8.6	7.4	4.4		4.8	3.0	1.8		3.5	1.4									
E17 A	21		26		30		32		35		35		36		35		35		35			
E17 D	8.4		6.2		6.1		4.9		5.7		3.7		3.0		0.6		1.1		1.1			

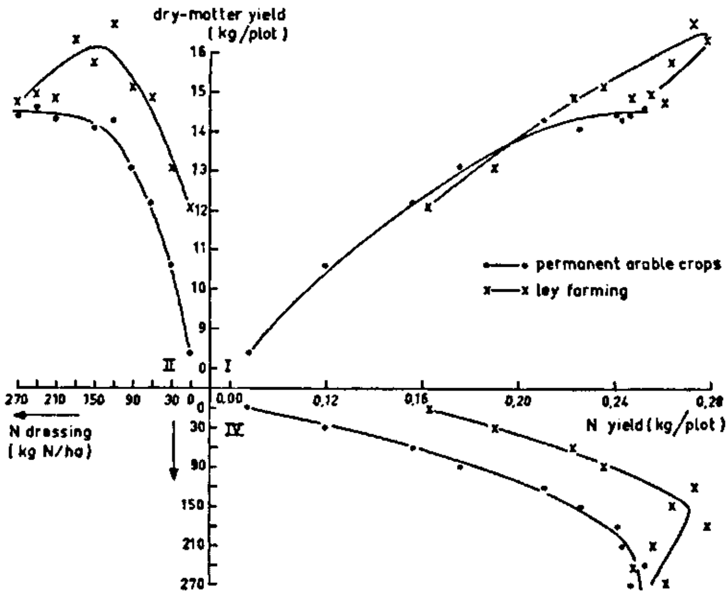

Fig. 8. Relation between yields of dry matter and nitrogen (I), nitrogen rate and yield of dry matter (II), and nitrogen rate and nitrogen yield (IV) of the first test crop (potatoes) (E17).

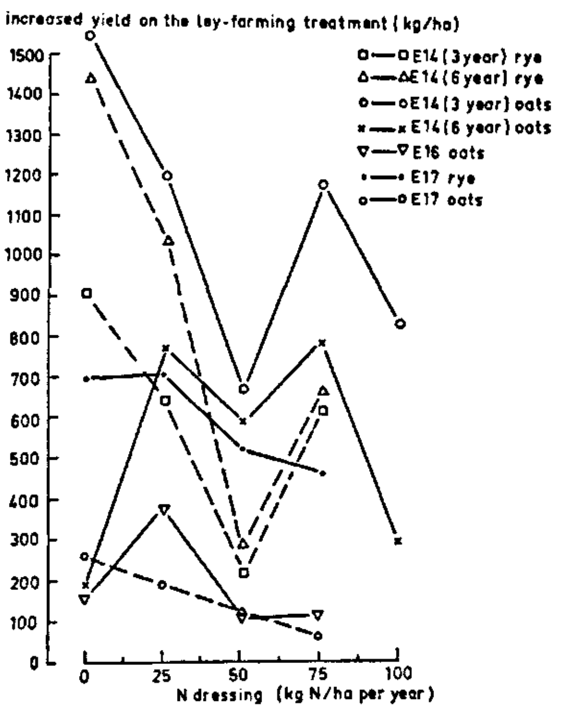

Fig. 9. Relation between nitrogen rate to the test crop and the yield difference in this crop after the ley-arable treatment.

nent arable. Neither is the cause of the decrease beyond the optimum for the ley-arable treatment (II and IV) known.

In the normal application range of nitrogen rates, the differences in yields between the ley-arable and the arable treatment could, however, be completely compensated by applying more nitrogen to the treatment with the lowest content of organic matter in soil: the arable treatment. With a basic dressing of 40 kg/ha, a three-year ley allowed an economy of, on average, 60 kg/ha for the first arable crop, potatoes; at higher basic rates this amount decreased.

The later (2nd and 3rd) test crops (rye and oats) gave about the same results. The yields were higher and the yield differences (absolute as well as relative) on the ley-arable treatment were lower if nitrogen dressing to the test crops was greater. The decrease in yield differences, however, were lower than with potatoes (Fig. 9).

These results give no evidence whether, besides the N supply, there is any other (small) residual effect of the preceding grassland.

If the basic nitrogen dressing be low (40 kg/ha), an average of 20 (second test crop) and 10 kg/ha (third test crop) could be economized on the ley-arable treatment to obtain the same yield as on the permanent arable. As with the potatoes, these amounts varied widely not surprisingly in view of the many factors affecting these processes, e.g. type of arable crop, fertilizer rate, management and botanical composition of the grassland, soil type, weather, method of destroying the sward (Van den Brand, 1962; Grootenhuis, 1961).

By including grassland, the organic matter content of the soil increases temporarily. After ploughing up the sward, mineralization increases, organic matter content drops and the soil contains more mineral nitrogen. When nitrogen is minimum, the test crop will grow better. The residual effect is usually small. Several other authors obtained similar results for other crops too, soil types and climatic conditions (Pätzold, 1958; Te Velde & Cleveringa, 1959; Hood, 1960; Lewis et al., 1960; Clement & Williams, 1960; Clement, 1961; Te Velde, 1962; Boyd, 1968; Cooke, 1970).

The increased mineralization after ploughing up the grassland is not a direct result of tillage but rather of the type of crop grown (arable crops instead of grassland); the most tillage does is to initiate mineralization more rapidly. If tillage is omitted, the same result will often be obtained (Woldendorp, 1963; Huntjens, 1972; Arnott & Clement, 1966; Jeater & McIlvenny, 1965; During et al., 1963). When the arable test crops were replaced by grassland (reseeding of grassland) this did not occur (Hoogerkamp, 1974a).

The conclusion that the aftereffect of grassland is mainly caused by a greater nitrogen supply from the soil and merely saves fertilizer nitrogen implies a considerable limitation in the advantages of the ley-arable system. All the more so, since the amount of fertilizer economized on the arable crop must in any case be applied to the grassland phase (Section 3.1.2); unless the nitrogen supply is provided by a legume.

Summary

Under grassland sown on a soil with less organic matter than the equilibrium of old grassland, organic matter starts to accumulate just after establishment, especially (on average about 60% of the total) in the layer 0–5 cm, decreasing deeper in the soil. The rate of accumulation, which shows an asymptotic trend, was not affected by the amount of nitrogen applied and seemed somewhat higher on the heavier soils than on the lighter soils.

Because of difficulties in the sampling technique, estimates of changes in organic matter were unreliable. Because of decreases in bulk density of the soil, the amount of organic matter accumulating was less than the increase in the contents suggest.

The accumulation of organic matter was mainly and directly due to the presence of a grass sward (for instance in periods of growth, the grass added considerable amounts of nitrogen-poor carbohydrates to the soil) and not to lack of tillage. Reseeding did not generally give a net mineralization of organic matter (Hoogerkamp, 1974a).

Under grassland sown on soils with organic matter above the equilibrium for old grassland, this content decreased to equilibrium.

The gross yields of grassland were higher, the higher the content of organic matter in the soil. The increase in yields at contents above the equilibrium value for old grassland as well as the reduced yields at contents below this value decreased asymptotically as the grassland aged.

The effect of the higher content of organic matter was almost entirely due to a better supply of nitrogen from the soil; the yield differences could be eliminated by applying more nitrogen to the grasslands with a lower content of organic matter. A general estimate of the extra net mineralized amount (e.g. per percent of organic matter or of total nitrogen) was not possible. A residual effect of the organic matter (e.g. decreased drought sensitivity) was not demonstrable. The immobilization of phosphate and potassium by accumulation of organic matter was not studied.

Since the equilibrium level of organic matter under grassland, under otherwise similar conditions, is higher than under arable crops, accumulation of organic matter in ley-arable farming will occur during the grassland phase and a decrease in organic matter content with the following arable crop. Accumulation of organic matter, mainly through a better supply of nitrogen, may benefit yields of the arable crops after ley. The greater net mineralization under the arable crops caused a great requirement for nitrogen in the following grassland with a low legume percentage.

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References

Arnott, R. A. & C. R. Clement, 1966. Weed Res. 6: 142–157.
Barrow, N. J., 1957. Aust. J. agric. Res. 8: 617–34.
Boon, J. van der, 1967. Stikstof 53: 148–52.
Boon, J. van der, A. Das & A. Power, 1970. Stikstof 65: 173–84.
Boyd, D. A., 1968. Rep. Rothamsted exp. Stn 1967, Harpenden, p. 316–31.
Brand, G. W. M. van den, 1962. Rapp. 112, PAW Wageningen, p. 121.
Bremner, J. M., 1965. Adv. Agron. 110: 93–149.
Burg, P. F. J. van, 1962. Versl. landbouwk. Onderz. 68.12., p. 131.
Clement, C. R., 1961. J. Brit. Grassl. Soc. 16: 194–200.
Clement, C. R. & T. E. Williams, 1960. Exps Prog. Grassld Res. Inst., Hurley, 12: 97–102.
Cooke, G. W., 1970. The control of soil fertility, London, p. 54.
Davies, W., 1952. The grass crop, its development, use and maintenance, London, p. 318.
Dijkshoorn, W., 1958. Neth. J. agric. Sci. 6: 211–221.
During, C., G. S. Robinson & M. W. Cross, 1963, N.Z. J. agric. Res. 6: 293–302.
Frankena, H. J. & C. T. de Wit, 1958. Landbouwk. Tijdschr. 70: 465–72.
Frecks, W. & D. Puffe, 1958. Z. PflErnähr. Düng. 83: 7–27.
Garwood, Z. H. & T. E. Williams, 1967. J. agric. Sci. 69: 123–30.
Gliemeroth, G., 1952. Z. Acker- u PflBau 95: 1–44.
Greacen, E. L., 1958. Soils Fertil. 21: 339–43.
Grigo, E., 1961. Thesis Bonn p. 56.
Grootenhuis, J. A., 1961. Stikstof 30: 242–92.
Hagan, R. M., Y. Vaadia & M. B. Russell, 1959. Adv. Agron. 11: 77–98.
Hammerton, J. & R. S. Edwards, 1965. J. agric. Sci. 64: 3–9.
Hanley, F., W. J. Ridgeman & R. H. Jarvis, 1964. J. agric. Sci. 62: 47–54.
Harmsen, G. W., 1951. Pl. Soil 3: 110–40.
Harmsen, G. W. & D. A. van Schreven, 1955. Adv. Agron. 7: 700–98.
Hart, M. L. 't, 1947. Maandbl. LandbouwVoorlDienst 4: 306–15.
Hart, M. L. 't, 1949. Rep. 5th Internat. Grassl. Congr. Noordwijk 1949, p. 236–9
Hart, M. L. 't, 1950. Landbouwk. Tijdschr. 62: 532–42.
Heard, A. J., 1965. J. agric. Sci. 64: 329–34.
Heinonen, R., 1962. Maataloustieteellinen Aikakauskirja 34: 26–33.
Hood, A. E. M., 1960. Proc. 8th internat. Grassl. Congr. Reading, 242–4.
Hoogerkamp, M., 1974a. Temporary versus periodically or not reseeded permanent grassland: in press.
Hoogerkamp, M., 1974b. Grünlandumbruch und Neuansaat: in press.
Hoogerkamp, M. & J. W. Minderhoud, 1966. Proc. 10th internat. Grassl. Congr. Helsinki 1966, p. 282–7.
Hoogerkamp, M. & J. J. Woldring, 1967. Neth. J. agric. Sci. 15: 127–40.
Huntjens, J. L. M., 1971. Pl. Soil 34: 393–404.
Huntjens, J. L. M., 1972. Thesis, Wageningen, p. 57.
Jackmann, R. H., 1964. N.Z. J. agric. Res. 7: 445–79.
Jagtenberg, W. D., 1962. Meded. 73, PAW Wageningen, p. 58.

Janick J. et al., 1969. Plant Science, an introduction to world crops, San Fransisco p. 629.
Jeater, R. S. L. & H. C. McIlvenny, 1965. Weed Res. 5: 311–8.
Klapp, E., 1952. Proc. 6th internat. Grassl. Congr. Pennsylvania 1952.
Köhnlein, J., 1957. Landw. Forsch. Sonderh. 9: 20–31.
Köhnlein, J., 1959. Z. Acker- u. PflBau 108: 149–58
Kononowa, M. M., 1958. Die Humusstoffe des Bodens, Berlin, p. 350.
Koornneef, H., 1945. Versl. landbouwk. Onderz. 51, p. 235–466.
Kortleven, J. C., 1963. Thesis, Wageningen, p. 109.
Ledingham, R. J. & S. H. F. Chinn, 1964. Can. J. Pl. Sci. 44: 47–52.
Lewis, A., J. Proctor & A. E. M. Hood, 1960. J. agric. Sci. 54: 310–5.
Low, A. J., 1955. Soil Sci. 6: 175–99.
Maton, A., A. H. Cottenie & A. van den Heide, 1960. Meded. Landbouwk. Centrum toegepaste Physico-Chemie, Rijkslandbouwhogeschool Gent.
Minderhoud, J. W., 1959. Landbouwvoorlichting 16: 24–9.
Owensby, C. E., K. Anderson & D. A. Whitney, 1969. Soil Sci. 108: 24–29.
Pätzold, H., 1958. Z. Acker- u. PflBau 105: 50–60.
Penman, H. L., 1970. J. agric. Sci. 75: 60–103.
Richardson, H. L., 1938. J. agric. Sci. 28: 73–121.
Rovira, A. D. & E. L. Greacen, 1957. Austr. J. agric. Res. 8: 659–73.
Russell, E. W., 1961. Soil conditions and plant growth. London, 9th edn.
Smith, G. E., 1942. Bull. no. 458 Columbia Univ. of Missouri.
Stone, L. E. W., 1965, Ann. appl. Biol. 55: 115–22.
Theron, J. J., 1951. J. agric. Sci. 41: 289–96.
Theron, J. J., 1963. S. Afr. J. agric. Sci. 6: 155–64.
Theron, J. J., 1965. S. Afr. J. agric. Sci. 8: 525–34.
Velde, H. A. te, 1962. Rapp. 118 PAW Wageningen, p. 19.
Velde, H. A. te & C. J. Cleveringa, 1959. Intern Rapp. 33 PAW Wageningen, p. 43.
Vervelde, G. J. & G. C. Meijerman, 1950. Maandbl. LandbVoorlDienst 7: 12–6.
Vetter, H., 1966. Nitrogen and grassland, Wageningen, p. 46–52.
Walker, T. W., A. F. R. Adams & H. D. Orchiston, 1956. Soil Sci. 81: 339–51.
Wheeler, J. L., 1958. J. Br. Grassld. Soc. 13: 196–202, 262–9.
Widdowsen, F. V., A. Penny & R. J. B. Williams, 1964. Exp. Husb. 11: 22–30.
Wiggers, A. J., 1950. Landbouwk. Tijdschr. 62: 455–68.
Williams, T. E., A. J. Heard & M. J. Hopper, 1960. Exps. Prog. Grassld. Res. Inst. Hurley, 12: 47–8.
Williams, T. E. & C. R. Clement, 1966. Nitrogen and Grassland, Wageningen, p. 39–45.
Wit, C. T. de, 1953. Versl. landbouwk. Onderz., 59.4, p. 77.
Wit, C. T. de, 1957. Neth. J. agric. Sci. 5: 284–9.
Woldendorp, J. W., 1963. Thesis, Wageningen, p. 100.
Zürn, F., 1970. Bayer. landw. Jb. 47: 957–72.
Zürn, F., Mitt. dt. LandwGes. 14. 10. 1971, p. 86.