INTERNATIONAL 7th GRASSLAND CONGRESS

Palmerston North, New Zealand
November 1956

PAPER No. 3

SESSION No. 1: MACRO- AND MICRO-CLIMATIC FACTORS IN PASTURE PRODUCTION

Wednesday 7 November 1956, 3.50 p.m.

Root Development of Grassland with Special Reference to Water Conditions of the Soil

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ROOT DEVELOPMENT OF GRASSLAND WITH SPECIAL REFERENCE TO WATER CONDITIONS OF THE SOIL

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In the "Beemster" polder, a typical marshland of the western Netherlands, it was found in dry summers and even during summers with a normal precipitation that drought phenomena occurred in old grassland with a water table of 1 metre below the surface, whereas arable crops under the same conditions remained flush.

This induced us to compare the root development of grassland with that of winter wheat in this polder during the dry summer of 1949, when the wheat was in the stage of maximum root development.

The soil of the grassland had a clay content (particles $< 16\ \mu$) of 45 per cent. The layer of 8-50 cm below the surface consisted of numerous, nut-like, compact small lumps, separated by narrow air sheets. The occurrence of these aggregates was a consequence of shrinkage of the soil due to loss of water and to a bad soil structure.

Now part of the root system was found in the air spaces between the small soil lumps where only little water was available. Within the compact and fairly dry lumps mostly deformed roots were present which also could dispose of only small quantities of water. As contrasted with the layer of 8-50 cm, the top layer of 8 cm had a favourable structure. The subsoil below 50 cm was more sandy and had a higher moisture content. No nut-like aggregates had been formed there.

The profile of the wheat plot was similar to that of grassland, except that due to repeated ploughing the nut-like soil here was found only below 20 cm. The top layer of 20 cm had a good structure.

The development of the roots on these two plots proved to be fundamentally different (see Fig. 1). In the top layer more roots were formed in the grassland than on the wheat plot. In the grassland the root weights decreased gradually with increasing depths. In the moist subsoil below 50 cm only very few roots were found on the grassland, whereas the wheat plot had many more roots developed in it.

In the summer of 1949 the layer with the nut-like structure as well as the top layer of 8 cm of the grassland had lost much water. The same was true for the upper layer of the wheat plot to a depth of 50 cm. This had no adverse effect on the supply of water to the wheat, since this crop had developed enough roots in the permanently moist subsoil below 50 cm. The grass, however, with only few roots in that moist layer, had developed poorly. In the subsoil below 50 cm the root weight of the grass amounted to 3.8 per cent of the total root weight against 28.4 per cent in the case of wheat. For the roots formed below 20 cm these values were 18 and 38 per cent respectively.

The yield of the grass could in a dry period be increased 400 per cent by raising the water table to a height of 40 cm below the surface. As a result the soil did not shrink and a satisfactory contact between roots and soil was achieved.

Since clay soils are highly variable and the one in the Beemster is characterised by a deviating structure, the question arises whether the restricted root growth in the subsoil, as observed in the Beemster polder, occurs in all clay soils. For the study of this question some of

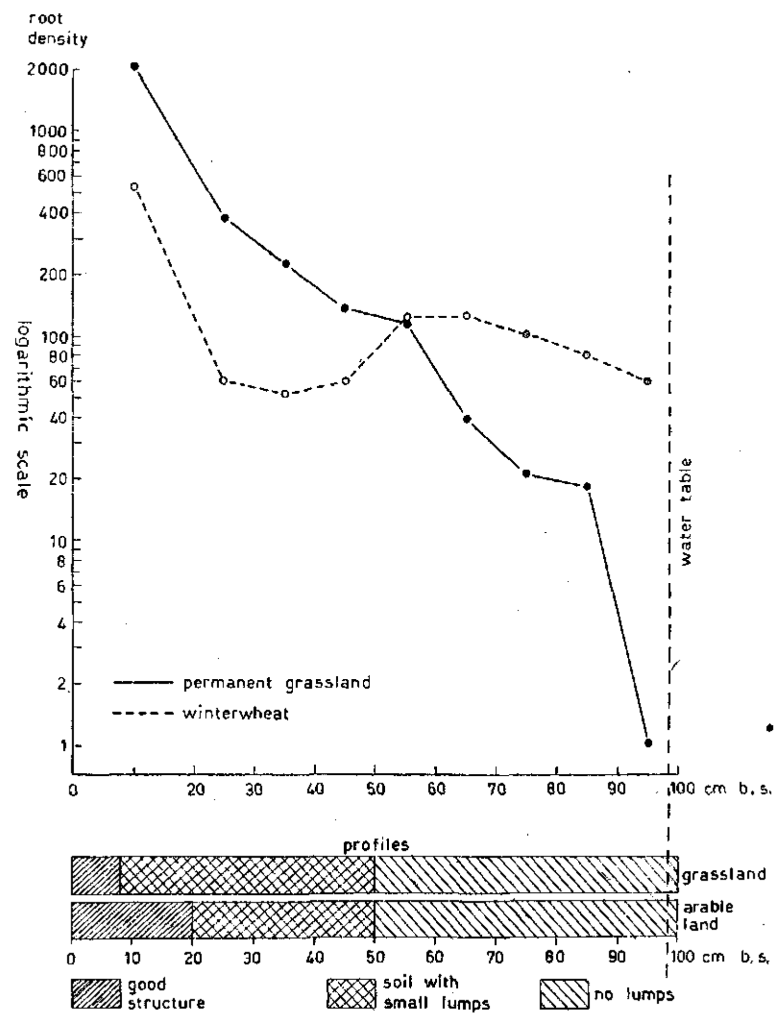

Fig. 1—Root development of grassland and of winter wheat in the "Beemster" polder in 1949. (Root density = mg of dry roots per dm^3 of soil.)

the results obtained at an experimental field on river basin clay soils with different water tables of the Central Institute of Agricultural Research at Wageningen (Netherlands) could be used. River basin soils are characterised by a thick clay layer consisting of from 70 to 80 per cent of clay particles < 16 μ.

Before this trial was laid out the level of the water table on this field was rather high, fluctuating between 50 and 80 cm below the surface of the soil. However, preceding the definite fixation of the water table at the different levels in 1954 the whole plot had been intensively drained to a much greater depth during several months in 1953. The object of this trial was to determine which levels of the water table are optimal for grassland and for arable crops respectively.

On the grassland part of this experimental field the authors studied the root development in the summer of 1955 on plots with water tables at 25, 65 and 140 cm below the surface. During the preceding winter and spring it had, for technical reasons, twice been necessary to lower the water table to a depth of 140 cm; i.e., from 9 to 26 November 1954 and from 5 to 20 April 1955. Later the ground water could be kept constant at the desired levels with a fluctuation of only a few inches.

On the part of the trial with arable crops in 1954 an investigation was carried out on the root development of oats. On 6 March 1954, shortly before the sowing of this crop, the ground water levels were here adjusted to 40, 65, 95 and 140 cm below the surface.

Moreover a series of observations about root development of old grassland was carried out on 10 plots spread over the same river basin clay with ground water levels fluctuating around 43, 70 and 103 cm below the surface.

The effect of the height of the water table on the development of roots and on the productivity of the grassland might vary according to differences in botanical composition of the sward, which in its turn can be influenced by the level of the water table. However, this interaction was not significant either on the experimental field, where *Lolium perenne* and *Poa trivialis* were the dominating species, or on the scattered plots, where *Lolium perenne* and *Cynosurus cristatus* were the main grasses. The variation in botanical composition of the vegetation was in any case too small to have a paramount influence on the habit of the root system and on the development of the grass.

For a better understanding of the results of the root investigation on the above-mentioned experimental fields some data obtained in a field trial with varied groundwater levels of the Agricultural Experiment Station at Groningen will first be given. This trial was laid out on heavy marine clay soil (a thick layer with 64 per cent particles < 16μ) in the area of the reclaimed inlet "Dollard". On this trial only arable crops were cultivated. In 1944 and 1953 the root development of winter wheat was studied here with water tables of 40, 60, 90, 120 and 150 cm below the surface. The yields of both grain and straw in both years were higher the deeper the water table had been fixed, with a significant depression on the plots with the deepest drainage. This depression, however, was the result of lodging of the wheat. This general trend shows that even at the lowest level of the water table the crop was not adversely affected by lack of water. Other arable crops on this field trial behaved similarly.

Parallel with the yields, the N content of grain and straw also proved to be higher the deeper the plot was drained, and the same was true also for the depth of rooting and to a certain extent for the total amount of roots in the subsoil (Table 2). By means of N fertilisation experiments it could be demonstrated that the increased yields were due to a better availability of nitrogen on the deeply drained plots.*

Also the volume of the air-filled space in the topsoil (0-20 cm) some years after adjustment of the ground water levels proved to increase from the plots with a water level of 40 cm via those with a water level of 60 to plots with levels of 90 cm or deeper below the surface. In the range from 90 to 150 cm the air content in the topsoil was equally high and seemed to be independent of the depth of the water table. In the subsoil (below 20 cm) the air volume as well as the root depth increased with increasing depth of the water table over the whole range from 40 to 150 cm below the surface. From these data it seems probable that the increasing nitrogen uptake and yield of the crop with increasing depth of the water table has been partly due to the increasing activity of the deeper roots as a result of the improving aeration of the subsoil.

There was in this experiment another phenomenon accentuating the significance of aeration for root development. Comparison of the amount of air in the soil and the development of roots on the

TABLE 1 – Field Trial with Winter Wheat on Clay Soil in the Dollard Region: Water Table at 40 cm Below Surface

Depth of the Layers Below the Surface	Average % (by vol.) of Air in the Soil		Weight of the Roots (Kg D.M./Are)		% of Total Weight of Roots in Different Layers		
	June 1943	Sept. 1955	July 1944	July 1953	July 1944	July 1953	
0-20 cm ...	7.0	8.0	7.2	10.3	64.9	92.0	
20-40 cm ...	7.5	0.2	2.1	0.8	18.8	7.1	
							water table
40-50 cm ...	10.7	0	1.2	0.1	10.8	0.9	
50-60 cm ...	10.8	0	0.6	0.01	5.4	0.1	
60-70 cm ...	9.0	0	sp	0	sp	—	
70-80 cm ...	7.0	0	0	0	—	—	
40-80 cm ... (groundwater)	—	—	1.8	0.11	16.2	1.0	

1 are = 100 m².

*A paper discussing this matter will soon be published by J. W. van Hoorn and J. W. Minderhoud.

Table 2

	CEREALS						PERMANENT GRASSLAND				
	Winter Wheat, Field Trial on Clay in the Dollard Region				Oats, Field Trial on River Basin Clay		River Basin Clay	Field Trial on River Basin Clay		Observation Plots on River Basin Clay	
	1944 water table (cm)		1953 water table (cm)		1954 water table (cm)		1953 water table at 50 to 80 cm (polder level)	1955 water table (cm)		1953 water table (cm)	
	40	90	40	90	40	95		40	100	43	103
Either yield of grain + straw, or total yield of grass for a whole season relative	100	128	100	169	100	106	—	100	94	100	79
Maximum depth of rooting (cm below surface)	70	100	60	110	90	110	120	80	90	80	120
Total weight of roots (kg D.M./are)	11.1	12.8	11.2	15.1	11.3	9.9	52.7	66.0	55.5	38.5	50.4
Weight of roots in 0-20 cm	7.2	7.0	10.3	8.8	9.1	5.9	47.3	57.6	47.3	35.0	44.6
Weight of roots from 20 cm downward	3.9	5.8	0.9	6.3	2.2	4.0	5.4	8.4	8.2	3.5	5.8
Weight of roots below 20 cm as % of total weight	35.1	45.3	8.0	41.7	19.5	40.4	10.2	12.7	14.8	9.1	11.5
Weight of roots (kg/are) below the water table	1.8	0.05	0.11	0.10	0.76	0.30	—	4.0	0.20	1.0	0.30
Weight of roots below the water table as % of total weight of roots	16.2	0.04	1.0	0.7	6.7	3.0	—	6.1	0.4	2.6	0.6

In the yields the dry matter is given.

1 are = 100 m².

plots with the highest water level in 1944 (i.e., shortly after the trial was laid out) and some 10 years later (Table 1) made it evident that in the beginning rather much air was found both above and below the water table, while later scarcely any air was present in the same layers. Apparently much air was trapped in the soil when the level of the water table was raised in 1943. Later this air gradually disappeared, and then a small amount of roots was found beneath the water table. In the layer between 20 and 40 cm the entire structure of the soil proved to have deteriorated gradually. This in its turn adversely influenced root development. It therefore seems to be justifiable to conclude that during the first years on this trial the plants on the plots with the highest ground water level due to the still relatively high amount of roots were provided with more nitrogen than in later years. Accordingly the depression of the yields by a high water level was much more pronounced in 1953 than in 1944.

In the above-mentioned study of the root systems on the experimental fields and scattered observation plots the root weights in consecutive layers of 10 cm each were determined. Cylindrical borings with a diameter of 7 cm on the arable land and on the grassland were collected. From these samples the roots were isolated by washing away the soil on a fine screen. Rhizomes and stolons were removed. Finally the roots were weighed after they had been dried at 75° C.†

The root density decreased progressively with increasing depth. In a few cases a slight increase was observed in the subsoil on deeply drained plots, but this increase soon again turned into a decrease. The standard error of the mean for each layer was in all cases less than 10 per cent.

It is not possible to give all our data in this short paper. In Table 2 only enough of these data are collected to elucidate the trends in the development and root distribution on the plots with various water levels. The root weights are given in kg per are (1 are = 100 m^2), approximately corresponding with 1/100 of the weights expressed in pounds per acre.

In Table 2 only data about plots with water levels of nearly 40 and 90 cm below the surface were included, because these values give a good idea of the influence of the depth of the water table upon root development over the whole range. On the experimental fields the water tables of 40 and 90 cm were really available except on the grassland experimental field. The root data of this field, mentioned in Table 2, therefore have been determined by graphical interpolation.

†Washing away the soil from clay samples is very laborious. A method was therefore developed whereby the soil samples after they had been dried at 105° C. were soaked for at least half a day in a solution of ½ per cent. or more of sodium pyrophosphate. Thus the soil became dispersed and washing it out was facilitated.

Table 2 shows that the depth of rooting of *wheat* on Dollard clay soil increased with the depth of the groundwater level. On plots with the high water table at 40 cm the roots proved to have penetrated some 20 to 30 cm beneath that level, whereas on plots with the groundwater level at 90 cm this value was found to be only 10 to 20 cm. Still deeper groundwater levels were scarcely reached by the roots. The total root weight increased with the depth of the groundwater level, except for a small decrease on the deepest water level (150 cm). This increase is caused by an augmentation of the roots in the subsoil below 20 cm where the water table is lowered. On plots with groundwater levels of 90 cm and more below the surface the root weights in the subsoil were practically the same in 1944 and in 1953. This, however, was not the case with a groundwater level of 40 cm. The total amount of roots below 20 cm was in 1944 found to be 3.9 kg per are, but in 1953 only 0.9 kg. This difference, which is also reflected in the amount of roots in the subsoil expressed as a percentage of the total root weight (being 35.1 and 8.0 respectively for the two years considered), is the result of better aeration in 1944. Consequently more roots could in that year penetrate into the subsoil than in 1953, when the air in the soil below 20 cm had completely disappeared (see Table 1). In 1944 on the plots with the highest groundwater level 1.8 kg roots per are (or 16.2 per cent of the total amount of roots) was found beneath the water table, against only 0.11 kg (or 1 per cent) in 1953. It has already been mentioned that the unfavourable root distribution on the plots with the 40 cm level in 1953 adversely influenced the uptake of nitrogen and the yield of the crop. On plots with a groundwater level of 90 cm or more the possibilities for nitrogen uptake were considerably better, due to deeper rooting of the plants.

In both years the yield of wheat on the Dollard clay soil increased with the depth of the water table. The same response has been found with *oats* on river basin clay, although to a less extent. It is noteworthy that on the river basin clay soil the total weight of the oat roots proved to be higher on plots with a high water table than on those with a low one, just contrary to what was observed on the Dollard clay soil with wheat (Table 2). Similar cases have formerly been observed under comparable conditions, even for one crop. No relation could be found then between such a deviating root development and the yield of the crop. However, apart from this discrepancy, the general trend in the root data of wheat on Dollard clay is much the same as that of oats on river basin clay. With both crops a reduction of root weight in the top 20 cm of soil and an increase in the subsoil below 20 cm were found with descending groundwater level. Also the percentage of the amount of roots found in the subsoil proved to be considerably higher with a deep water level than with a high one with both wheat and oats.

There is also a remarkable conformity in the behaviour of the roots of oats in 1954 and of wheat in 1944 at the highest water level

(40 cm). Both experimental fields had in the years mentioned just recently been laid out. The experimental field with oats was drained very deeply in 1953, but the final groundwater levels were adjusted briefly before sowing on 6 March 1954. It is therefore understandable why this crop formed a considerable amount of roots (0.76 kg roots per are or 6.7 per cent) below the groundwater level. The soil below that level presumably still was rather rich in air.

It appears from a comparison in Table 2 of the root data of the *cereals* with those of *old grassland* that in both groups the maximum depth of rooting was greater with a low groundwater table of 90 to 100 cm than with a high one. The depth of penetration of grass roots is at corresponding water levels certainly not inferior to that of the roots of cereals.

On the other hand marked differences in *root distribution* between grasses and cereals become apparent, not only, as shown by Table 2, with water tables at 40 and 100 cm below the surface, but also with lower water levels. In the upper 20 cm the root weights of grassland exceed those of cereals considerably on all levels of the groundwater. The percentage of the total amount of roots found in the subsoil beneath the level of 20 cm is at all levels of the water table smaller than that of cereals. There is, however, one exception. The percentage of the total amount of roots formed in 1953 by wheat on plots with a water table at 40 cm was extremely low, as a result of bad aeration of the soil on these plots of the 10-year-old experimental field (see Table 1). Yet the pronounced accumulation of roots in the topsoil, especially in the turf, and a relatively inconsiderable root development in deeper layers must be recognised as characteristic for grassland. This phenomenon has also been observed in the Beemster and it had already been reported by several other investigators (e.g., Klapp, 1943) and ascribed mainly to the repeated defoliation of the grass by grazing and haymaking.

It is remarkable that the percentage of roots of grass in the subsoil, contrary to that of cereals, increases only slightly with progressively descending water table, due to the fact that the bulk of the grass roots is always restricted to the topsoil. This holds true even for very deeply drained land. Consequently the inability of permanent grassland to develop a strong root system in the subsoil brings about a poor morphological adaptation of the root system to a lowering of the water table. A similar result was obtained by one of us with old grassland on clay and on sandy soils when samples of this grassland have been transferred as monolytes into wide concrete cylinders. In these cylinders different water levels have been adjusted. In this experiment the grass roots again proved to be accumulated in the topsoil, especially so with the deepest water level used (80 cm). The subsoil percentage of the total root weight was very low in both soils. It was only 2 and 3 per cent higher at a water table of 80 cm than at that of 20 cm in sand and in clay respectively (Frankena and Goedewaagen, 1942).

An exceptional position is occupied by the experiment with grassland in the river basin clay soil in 1955. Here the root weight in the subsoil on the plots with groundwater tables of 40 and of 100 cm respectively amounted to nearly the same value, i.e., 8.4 and 8.2 kg per are. This is remarkable, since the root weights in the subsoil in other experiments showed an increase with descending groundwater level, as is evident in Table 2.

This exceptional behaviour might be a result of the deep drainage of the experimental field from 4 to 20 April 1955. It is a well-known fact observed by several workers that in the spring many young roots are formed on grassland (Stuckey, 1941; Brown, 1943; Jacques and Edmond, 1952). These roots can penetrate deeply into the subsoil. Apparently the grass on this field trial had developed a fairly dense root system in the subsoil during the period of deep drainage in April 1955. Part of these roots later became submerged when the groundwater was raised. It therefore becomes evident too why in this experiment, according to Table 2, on the plots with the highest water level not less than 6 per cent of the roots were found below the water table. In agreement with our experience on the Dollard clay in 1944 it might be presumed that here much air was trapped in the soil when the water level was raised on 20 April.

From comparison in Table 2 of the results for 1955 and 1953 of the grass experiment on river basin clay it will be evident that the root weight in the subsoil increased from 5.4 in 1953, when the experiment was not yet started, to about 8 kg per are in 1955. This holds true also for separate layers of the subsoil. It is surprising that the roots in 1953 had reached a depth of 120 cm (Table 2), but in fact the roots in that year practically did not penetrate below the level of 70 cm, since only traces of roots have been found below that level. It may be taken for granted that in 1955 the conditions for the development of roots in this experiment were considerably better than in 1953. Before this experiment was started the water table on the whole plot was rather high, fluctuating between 80 and 50 cm below the surface. This certainly was not favourable for the growth of the roots. However, the poor development of roots in the subsoil in 1953 cannot be explained by this, since before the experiment started the whole plot in that year was drained very deeply from January until September. Yet the conditions were not entirely the same in 1955 and 1953. In the latter year the level of the water was not kept constant throughout the whole year and, besides that, the grass was not given the same care as in 1955.

While on the grassland experimental field in 1955 the water level was kept constant, it was very variable in all the years on the observation plots. A high water table during the winter was followed in 1953 by a fall in the spring and subsequently by a gradual rise during the summer until the high water level in the winter was reached again. It is possible that a rather slow fall of the groundwater in the spring retarded the penetration of the roots into deeper layers. This, however, is only a supposition, since the root development on the observation plots has not been recorded regularly.

That the percentage of roots of grass in the deeper layers was considerably less than that of cereals was observed both on the grassland experimental field and on the observation plots. One wonders what would be the consequences of this on the water supply for these plants. The cereals definitely had not shown any symptoms of shortage of water on the clay soil; whereas Minderhoud on grassland got the highest yields during dry weather on plots with the highest water table, but during wet periods on plots with the lowest water level. Thus it may well be considered certain that the grassland suffered from drought in periods of low rainfall. Though not providing a complete proof, this observation still renders it highly probable that the different behaviour of plants on arable land and on grassland is related to their different distribution of the root mass in the soil. This supposition is supported by a recent investigation of G. P. Wind (1955), who has studied the pF-values in different layers on river basin clay soils of both grassland and arable crops. His conclusion is that "old grass cannot extract as much water from the subsoil as arable crops can".

Since during rainy periods the yields of grass on the clay soils were higher the deeper the soil was drained, it must be assumed that a high water table inevitably interferes with the requirements of the grass. Minderhoud has directed attention to the possibility of a lack of nitrogen nutrition when the water table is high. The content of crude protein of the crop proved to be lower with higher water tables than with a low one, even during a dry spell. As already mentioned, a similar relation was observed for wheat on Dollard clay. Here the inferior depth of rooting and the reduced root density in the subsoil on the plots with high water levels can, at least partly, readily be made responsible for curbing the nitrogen uptake. For grassland, with its accumulation of nearly all roots in the topsoil, this explanation seems to be less applicable, yet the general trend might hold true also for grassland (see the root data of the observation plots in Table 2). On the grassland experimental field the circumstances for a good nitrogen supply seem in 1955 to have been favourable, as here, in spite of a high water table, a dense root system was found in the subsoil. It should be kept in mind, however, that on plots with a recently adjusted high water level the air content in the rooted layer below the water table, although rather high, is inferior to that of the corresponding layer on more deeply drained plots. This can in rainy periods adversely affect the yield on badly drained grass fields, since the activity of the roots in the too wet and poorly aerated soil becomes hampered. In dry periods on deeply drained land even on clay soil water deficiency becomes the predominant factor, presumably because of the low root percentage in the subsoil. The consequence is that under these conditions the highest yields are attained on land with a fairly high water table.

It might be possible to combine an optimal supply of water to grassland with a good aeration of the soil by an interruption of the deep drainage of the land a few times during the dry part of the year by short periods with a much higher level. The effect of such a treatment perhaps could become comparable with the results we have obtained with irrigation of deeply drained and permeable grassland. The yield on the temporarily flooded part of the plot was considerably higher than on the dry part. In the upper layer of the soil the density of roots was the same on both parts, but in the subsoil it was nearly twice as high on the irrigated part as on the other. The percentages of the total mass of roots found in the subsoil demonstrate this difference spectacularly, as in July they were 16.1 against 8.5 and one month later 18.9 and 11.1 in the irrigated and the non-irrigated parts respectively.

Therefore, if a proposed intentional fluctuation of the groundwater level in the summer would have a similar effect on the development of roots in the subsoil, the structure of the soil in the deeper layers also should be improved, at least if no peptisation and swelling of the soil should be the result of this treatment.

Postscript

We have tried to restrict this paper to dealing with the results of our comparative investigation concerning the development of roots on grassland and on arable land. The related agricultural and pedological data have only been mentioned if unavoidable for a correct interpretation of our results. The agricultural and pedological part of this research will in 1957 be published in the "Netherlands Journal of Agriculture" by J. W. van Hoorn and J. W. Minderhoud.

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