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THE SEASONAL RESPONSE OF GRASSLAND TO NITROGEN AT DIFFERENT INTENSITIES OF NITROGEN FERTILIZATION, WITH SPECIAL REFERENCE TO METHODS OF RESPONSE MEASUREMENTS

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Summary

Data are presented to demonstrate the response of grassland to nitrogen during the growing season in relation to different levels and frequencies (intensities) of nitrogen fertilization. The data have been derived from the results of seven field experiments in the years 1972-1975. The different intensities resulted in total applications of about 300 to over 1000 kg N per ha per annum.

Apart from these intensities of nitrogen fertilization, the experimental treatments included different times of nitrogen application during the season, increasing rates of nitrogen at each time of application, and a series of successive harvests after each time of nitrogen application in order to establish growth curves.

The response was first studied in terms of DM increase determined at a specific date, using two different methods, and secondly in terms of days time gain to reach a specific stage of growth.

Some general conclusions are:
- The response to nitrogen is highest in the first half of the season, decreasing with increasing rates of nitrogen application.
- The response is considerably lower with increasing intensity of nitrogen fertilization. This may be caused by a residual effect of the higher nitrogen pretreatment.
- At the end of the season the response at high rates of application can become negative in a high-nitrogen intensity system.

The intensity of nitrogen fertilization affects the optimum rate of nitrogen application for each cut, as is shown at an assumed marginal profitability of 7.5 kg DM per kg N applied.

Finally, an appraisal of cutting at a fixed frequency or at defined stages (e.g. grazing, silage stage) is presented.

Introduction

For the farmer fertilizer nitrogen is generally the most effective management input for manipulating grassland yield within the limitations imposed by the environmental factors like soil type, radiation, temperature and moisture (Morrison et al., 1974). In addition to these environmental factors variations in yield and response to nitrogen can be related to factors such as grass species and varieties, presence of a legume, frequency of defoliation, age of sward, season, and supply of other nutrients (Whitehead, 1970). Amongst these factors knowledge of the seasonal response is important as a tool for farm planning operations (Wieling, 1971).

The influence of nitrogen fertilization on the growth of grass during the season can be studied considering the following factors:
- 1. time of nitrogen application
  The season consists of a sequence of growth periods divided by the dates of nitrogen application and cutting. Each time of nitrogen application provides information on a particular part of the season.
- 2. response to nitrogen at each time of application
  This factor can be assessed by applying different rates of nitrogen at each date and measuring the herbage yield.
- 3. response to nitrogen during the course of growth
  With successive harvests the rate of growth can be determined, thus giving information on the response during each growth period.
- 4. intensity of nitrogen fertilization
  Different levels of nitrogen supply, from the soil or from previous nitrogen applications, can either directly give differences in response to nitrogen, or indirectly via a change in the productivity of the sward. With present-day high rates of nitrogen

* Seconded by the Agricultural Bureau of the Netherlands Fertilizer Industry (LBNM).
** Previously seconded to the Institute for Soil Fertility (IB), Haren (Gr.).

fertilizer in intensive grassland farming it is necessary to know a possible decrease in response at a higher intensity of nitrogen fertilization. 'Intensity' is meant here as a combination of a particular level and number of nitrogen applications throughout the season whereas 'rate' is meant as the amount applied at a specific date.

Over the period 1970-1975 the seasonal response of grassland to nitrogen was studied in field experiments by the Research and Advisory Institute for Grassland Husbandry (PR) and the Institute for Soil Fertility (IB). This article summarizes the results of the seven experiments based on cutting at a 'grazing' stage of growth viz. four PR-trials, all at one intensity of nitrogen fertilization, two IB-trials at two intensities and one IB-trial at four intensities of nitrogen fertilization. The experiments were located in various parts of the Netherlands (Figure 1). Some of the results have already been reported elsewhere (Minderhoud et al., 1976; Van Burg, 1977; Prins & Van Burg, 1977; Prins & Van Burg, 1979).

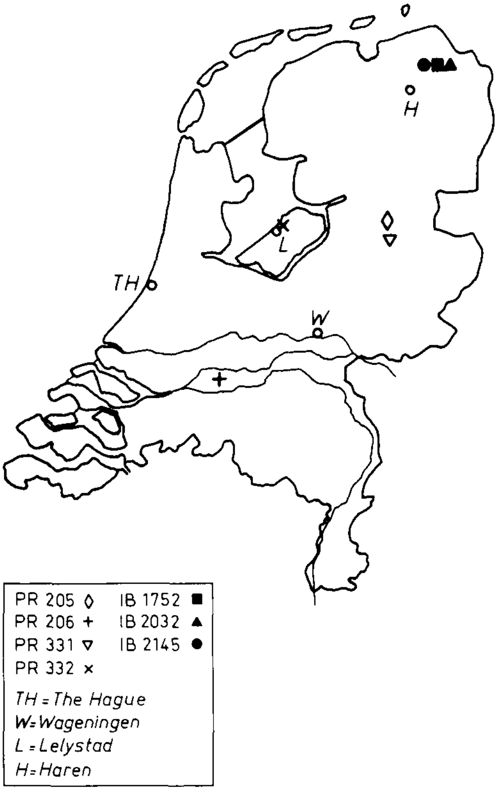


Figure 1. Location of the PR- and IB-trials in the Netherlands.

Choice of experimental methods and analysis of results

When studying the seasonal response to nitrogen the management can be based on either a fixed cutting frequency ('set date') or cutting at defined stages ('set stage' : grazing, silage or hay stage, or a combination of these stages). Advantages and disadvantages of both systems will be discussed later on in this article.

In order to simulate practical farming circumstances it is preferable to cut at defined stages of growth. In our experiments plots were cut at a yield of about 2 t DM per ha, the 'standard' grazing-stage of growth. Only with the IB-trial 1752 the first and fourth cuts were taken at a later stage (over 3 t DM per ha, see Appendix I).

Since an increase in the rate of nitrogen application generally accelerates grass growth, the grazing stage of growth is attained sooner with increasing intensity of nitrogen fertilization. Consequently, the higher intensity (higher nitrogen pretreatment) results in more 'standard' cuts and thus in more times of nitrogen application during the season than the lower intensity.

Time-of-nitrogen application blocks were allocated at random and numbered S1, S2 etc. in order of starting time. In order to study the response to nitrogen properly one requires growth curves for each rate of N. The time-of-application blocks were therefore subdivided into plots for the different rates of nitrogen and for successive harvests.

The response to nitrogen at each time of application was determined at rates of 0, 40, 80 and 120 kg N per ha. Only with IB 1752 also the rate of 200 kg N per ha was included. Herbage was harvested successively at intervals of about 6 to 12 days to establish the growth curves. The number of successive harvests varied from about 5 to 7 early in the season to 2 to 6 at the end of the season.

In all experiments the common intensity of nitrogen fertilization was 80 kg N per ha per standard cut. This corresponds with an intensive (I) system of nitrogen fertilization. In the IB-trials also an extensive (E) system of nitrogen usage was investigated by applying 40 kg N per ha at each standard cut. Finally, in IB-trial 2145 also rates of 60 and 120 kg N per ha at each standard cut were included, corresponding to an intermediate (P) and a very intensive (Z) system of nitrogen usage (Table 1).

To clarify these complicated experiments, the schemes and growth curves of some selected systems of the IB-trial 2145 are given in Table 2 and Figure 2, respectively. This type of experiment has been described in more detail by Prins & Van Burg (1979). Data on nitrogen application and measured DM yields per cut and per season are shown in Appendix I.

Table 1. General data of trial sites and intensities of pretreatment nitrogen fertilization.

Expt no.	Year	Location	Soil	0-5 cm pH-KCl	0-5 cm org. matter %	Rate of nitrogen application per standard cut, kg ha^{-1}; in parentheses number of cuts: E	P	I	Z
PR 205	1973	Nieuwleusen	sand	5.0	5.5			80 (6)	
PR 206	1973	Bruchem	clay	6.7	3.1			80 (6)	
PR 331	1974	Heino	sand	4.7	3.6			80 (6)	
PR 332	1975	Lelystad	clay	7.1	6.1			80 (6)	
IB 1752	1972	Ten Boer	clay	6.3	13.8	40* (7)		80* (8)	
IB 2032	1973	Ten Boer	clay	6.2	15.0	40 (7)		80 (8)	
IB 2145	1974	Ten Boer	clay	5.8	14.4	40 (6)	60 (7)	80 (8)	120 (9)

* The spring applications for the E- and I-systems of IB 1752 were 80 and 120 kg N per ha, respectively.

Table 2. Scheme of the extensive (E) and intensive (I) nitrogen fertilization systems of IB 2145 during 1974.

Date of N-appl.	Time-of-application blocks of E- and I-systems: S1	ES2	ES3	ES4	ES5	ES6 *
11/3	0,40,80,120 M1-M5	40	40	40	40	40
6/5		0,40,80,120 M1-M5	40	40	40	40
4/6			0,40,80,120 M1-M5	40	40	40
8/7				0,40,80,120 M1-M5	40	40
5/8					0,40,80,120 M1-M5	40
9/9						0,40,80,120 M1-M3

	S1	IS2	IS3	IS4	IS5	IS6	IS7	IS8 *
11/3	0,40,80,120 M1-M5	80	80	80	80	80	80	80
26/4		0,40,80,120 M1-M5	80	80	80	80	80	80
20/5			0,40,80,120 M1-M5	80	80	80	80	80
17/6				0,40,80,120 M1-M5	80	80	80	80
8/7					0,40,80,120 M1-M5	80	80	80
26/7						0,40,80,120 M1-M3	80	80
14/8							0,40,80,120 M1-M3	80
9/9								0,40,80,120 M1-M2

* Area of time-of-nitrogen application blocks decreasing with decreasing number of successive harvests (M1, etc.).

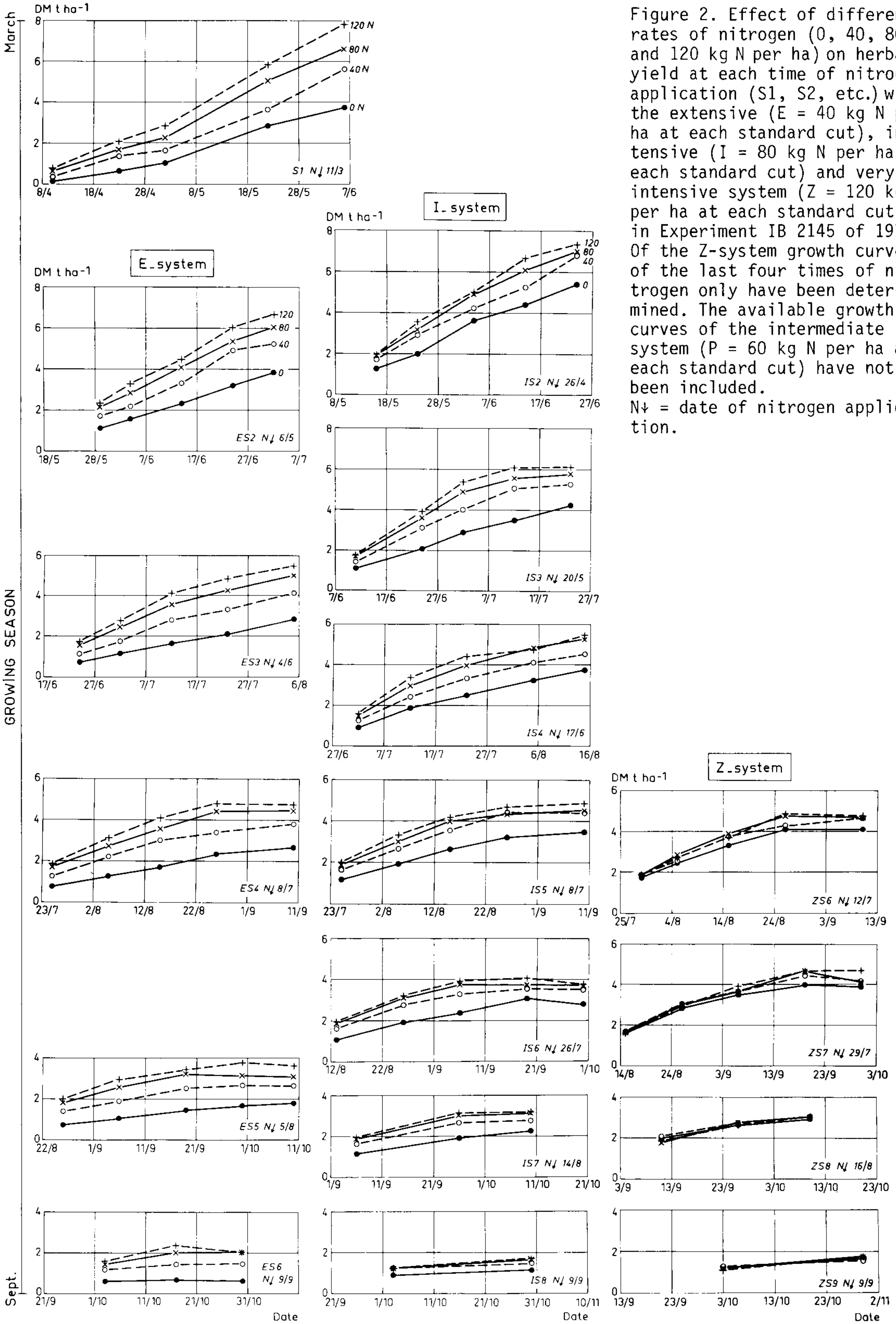


Figure 2. Effect of different rates of nitrogen (0, 40, 80 and 120 kg N per ha) on herbage yield at each time of nitrogen application (S1, S2, etc.) with the extensive (E = 40 kg N per ha at each standard cut), intensive (I = 80 kg N per ha at each standard cut) and very intensive system (Z = 120 kg N per ha at each standard cut) in Experiment IB 2145 of 1974. Of the Z-system growth curves of the last four times of nitrogen only have been determined. The available growth curves of the intermediate system (P = 60 kg N per ha at each standard cut) have not been included.
N↓ = date of nitrogen application.

The field experiments were carried out on permanent grassland on clay and sandy soils (Table 1). Lolium perenne was the dominant grass species of the swards which were either free from weeds and clover (IB-trials) or had nil to 1 % clover (PR-trials).

Nitrogen was applied as calcium ammonium nitrate (23 % N in 1972 and 26 % N thereafter). The first application was in spring in mid or late March, subsequent applications took place immediately after each cut. Phosphorus and potassium were applied for each standard cut in adequate amounts. The rates used for the second and following cuts in PR-trials 205, 206 and 331 were, however, slightly below the recommended rates as indicated by soil analysis.

Cuts were made at about 4 cm above ground level with a motor mower.

The effect of different rates of nitrogen may be determined 1) as 'vertical' and 2) as 'horizontal' N-effects.

1) at a specific date, measuring the DM production of the different treatment at one point in time (vertical N-effect).

This kind of determination of DM production is used in most experiments. In our trials it was possible to use two ways of analysis of the vertical N-effect:

A. by determining the DM yields at a fixed number of days after each time of application of the different rates of nitrogen. Arbitrarily the N-effect at 30 days after nitrogen application has been chosen as this fitted all seven trials at the I-system of nitrogen intensity as well as the IB-trials at the E-system. See the diagrammatic presentation in Figure 3a.

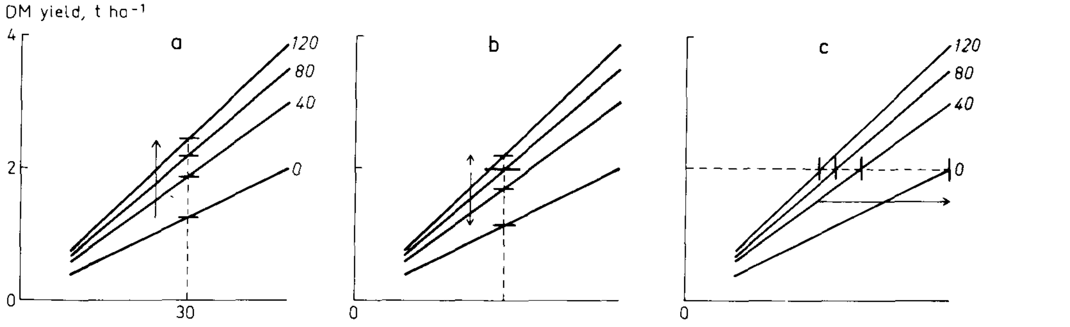
B. by taking a particular yield level at one rate of nitrogen application as reference for the other rates. For this kind of analysis the yield of 2 t DM per ha obtained with 80 kg N per ha has been chosen for the E- and I-systems of nitrogen intensity of the three IB-trials.
See for explanation Figure 3b.

2) at a particular yield level, measuring the number of growing days to reach a particular production stage like the grazing, silage or hay stage (horizontal N-effect). Such a measurement may provide the basis for the planning of a grazing/cutting scheme for the farmer. For this way of analysis the number of growing days to reach the standard grazing stage (2 t DM per ha) has been arbitrarily chosen for the I-system of all seven trials and for the E-system of the three IB-trials. See for explanation Figure 3c.

The vertical and horizontal N-effects can be read from the growth curves. For example, Figure 2 shows the growth curves after each time of application with the E- and I-systems as well as the last four times of application with the Z-system of IB-trial 2145. Of this trial the response to nitrogen at the end of the season will also be discussed in detail later in this paper.

The data for the vertical and horizontal N-effects have been calculated after establishing the best line of fit for each growth curve, generally a quadratic equation.

Figure 3. Schematic presentation of growth curves after application of 0, 40, 80 or 120 kg N per ha
(a) vertical N-effect measured as DM yields at 30 days after nitrogen application,
(b) vertical N-effect measured as DM yields against the reference yield of 2 t DM per ha with the 80 kg N rate of application, and
(c) horizontal N-effect in number of days required to attain 2 t DM per ha, the standard grazing stage.



Results

1. Vertical N-effect

A. DM yields at 30 days after nitrogen application

From the growth curves the increases in DM yields in the ranges 0 to 40, 40 to 80 and 80 to 120 kg N at 30 days of growth have been determined for the I-system (Figure 4). The initial application (S1) has not been included as it was not possible to use the date '30 days after the spring application of nitrogen' because of the low rate of growth early in the season. Figure 4 shows that
- the largest response to nitrogen occurred in the first half of the season
- the responses decreased with increasing rates of nitrogen application
- a negative response occurred towards the end of the season with the 80 to 120 kg N increment
- the variation in nitrogen response was considerable. The variation in response not only occurred in the PR-trials at different locations but also in the IB-trials at neighbouring fields in the same location but in different years. This variation occurred apart from the variation in DM yield at 0 N after 30 days of growth.

When we examine the three IB-trials separately and also determine the increase in DM yield with the E-system it is possible to assess the effect of the intensities of nitrogen fertilization on the response to nitrogen at 30 days after application.
For this purpose the average response of three IB-trials has been calculated at specific application dates throughout the season (Table 3).
It is evident that
- throughout the season DM yields at the 0 N rate were higher with the I-system
- the response to nitrogen was lower with a high (I-system) than low (E-system) nitrogen pretreatment. In the range 0 to 120 kg N the DM increase was about 1.4 t per ha from May to July with the I-system and about 1.8 t per ha from May to August with the E-system
- the response to nitrogen decreased towards the end of the season. With applications of 80 and 120 kg N per ha on 20 September the response in the I-system was even negative (see also Figure 4)
- the variation in response to nitrogen, as mentioned above, was largely compensated by the level of DM production at 0 N. This can be shown, for example, by adding the DM yield at 0 N and the DM increment 0 to 120 N at different times of application for both the E- and I-system.

The lower response to nitrogen, reported here, may be caused by the residual effect of the higher nitrogen pretreatment of the I-system. In this connection it should be kept in mind that in August the nitrogen pretreat-

Figure 4. Response to nitrogen expressed as yield increase for the 0→40, 40→80 and 80→120 kg N increments at 30 days after application. I-system of all PR- and IB-trials.

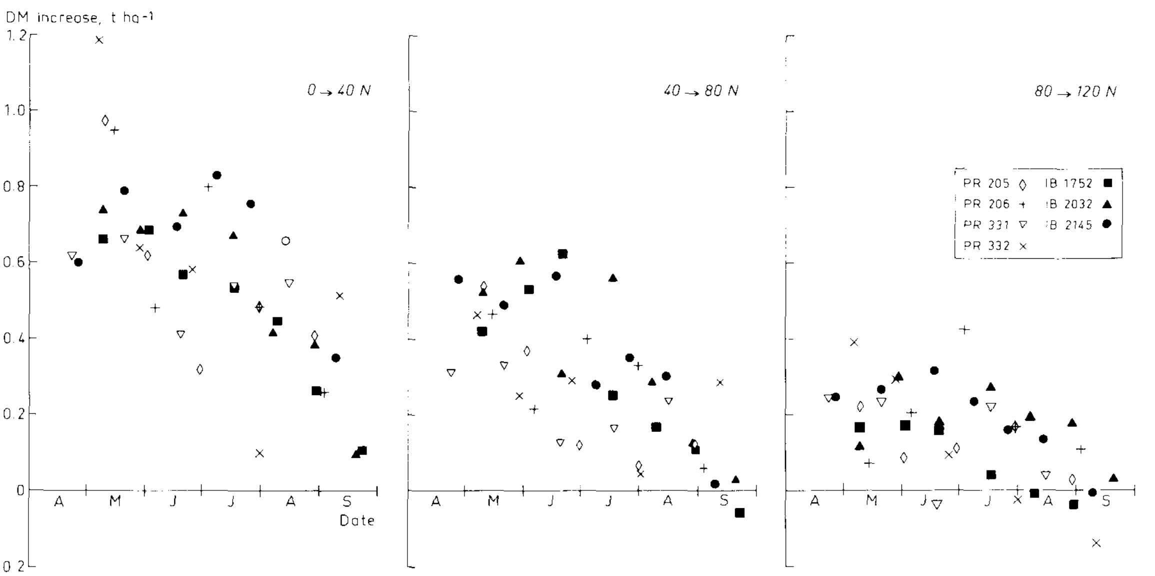


Table 3. Effect of time of nitrogen application and intensity of nitrogen fertilization on yield at 0 N and on yield increase between rates of nitrogen (kg DM per ha), measured 30 days after nitrogen application. Vertical N-effect, method A (see text). Average of three IB-trials.

Date of N-application	Intensity of nitrogen fertilization	Yield level at 0 N	0→40 N	40→80 N	80→120 N	0→120 N
10/5	E	1800	725	575	300	1600
	I	2250	675	525	200	1400
1/6	E	1700	825	650	350	1825
	I	2300	725	500	225	1450
1/7	E	1500	875	650	375	1900
	I	2200	700	450	200	1350
1/8	E	1200	850	575	325	1750
	I	1900	575	325	150	1050
1/9	E	750	700	400	200	1300
	I	1350	350	125	50	525
20/9	E	500	375	250	100	725
	I	850	150	-25	-25	100

ment with the I-system was already near 500 kg N per ha against near 200 kg N with the E-system.

We have arbitrarily determined the response to nitrogen at 30 days after application. From the course of the growth curves at the different rates of nitrogen application with the E- and I-systems it can generally be derived that with shorter growing periods this response is smaller and with longer growing periods larger than the values quoted above.

B. DM yields measured against the 2 t DM reference yield with the 80 kg N rate of application

With the previous method it was not possible to include the first time of application (S1). By using a constant yield as reference, however, the effect of the spring application of nitrogen can also be measured.

Table 4 shows the yield differences calculated from the three IB-trials at the E- and I-systems of nitrogen fertilization.

Table 4. Effect of intensity of nitrogen fertilization on yield increase (kg DM per ha) in the ranges 0→40, 40→80 and 80→120 kg N per ha, measured throughout the season against the reference yield of 2 t DM per ha at the 80 kg N rate of application. Vertical N-effect, method B (see text). Average of three IB-trials.

Date of harvesting	Intensity of nitrogen fertilization	0→40 N	40→80 N	80→120 N	0→120 N
1/5	E	{ 525 *	{ 535 *	{ 320 *	{ 1380 *
	I	560 *	465 *	275 *	1300 *
1/6	E	535	460	260	1255
	I	495	360	170	1025
1/7	E	555	420	220	1195
	I	450	285	100	835
1/8	E	600	420	205	1225
	I	410	225	60	695
1/9	E	660	425	215	1300
	I	390	190	55	635
1/10	E	735	500	245	1480
	I	380	170	90	640

* Differences between E and I because of curve fitting.

The E- and I-systems were contrasting in their response: with the E-system the response was fairly even throughout the season, even increasing towards the end of the season; with the I-system the response to nitrogen slowly decreased throughout the season. The latter is most likely caused by the residual effect of the higher level of nitrogen fertilization during the pretreatment period.

Method A, measuring the response after 30 days, showed a decrease in response to nitrogen from beginning to end of the season with both systems (Table 3). This decrease was related to the decrease in growth rate from beginning to end of the season, implying a decreasing production at 30 days of growth. Later in the season it took the 80 kg N rate of application more days than earlier in the season to reach the reference yield of 2 t DM per ha (method B). These longer growing periods did not change the response to nitrogen as was shown by the E-system (Table 4).

2. Horizontal N-effect or time gain

From the growth curves the time gain to attain the standard grazing stage (2 t DM per ha) has been determined for the increments 0 to 40, 40 to 80 and 80 to 120 kg N per ha with the I-system of all seven trials (Figure 5). The time gain
- was greatest at the lower nitrogen increment (0 to 40 kg N)
- was greater in spring than in summer, but was greatest towards the end of the season
- showed the greatest variation at the lower increment.

When also considering the time gain with the E-system it is possible to assess the effect of intensity of nitrogen fertilization. For this purpose the average time gain of the three IB-trials has been calculated after N application at certain dates throughout the season (Table 5). It is evident that, besides the factors mentioned above:
- throughout the season the number of days to reach 2 t DM per ha at 0 N was smaller with the I-system
- the time gain was greater at a generally low nitrogen level, as represented by the E-system.

These effects were presumably caused by the residual nitrogen in the plant-soil system of the intensively fertilized swards.

We have arbitrarily chosen the time gain at reaching the standard grazing stage of growth (2 t DM per ha). From the growth curves, as given in Figure 2, it generally follows that at lower yield levels the time gain is smaller and at higher yield levels larger than the ones quoted above because of a still continuing diverging of the response curves and/or decreasing rates of growth with time.

For planning and modelling purposes it is necessary to work with averages. It is notable that the variation in response to nitrogen between different locations and years was considerable, as was shown by the effect of the nitrogen increments in Figures 4 and 5.

Figure 5. Response to nitrogen expressed as time gain for the 0→40, 40→80 and 80→120 kg N increments to reach the standard grazing stage (2 t DM per ha). I-system of all PR- and IB-trials.

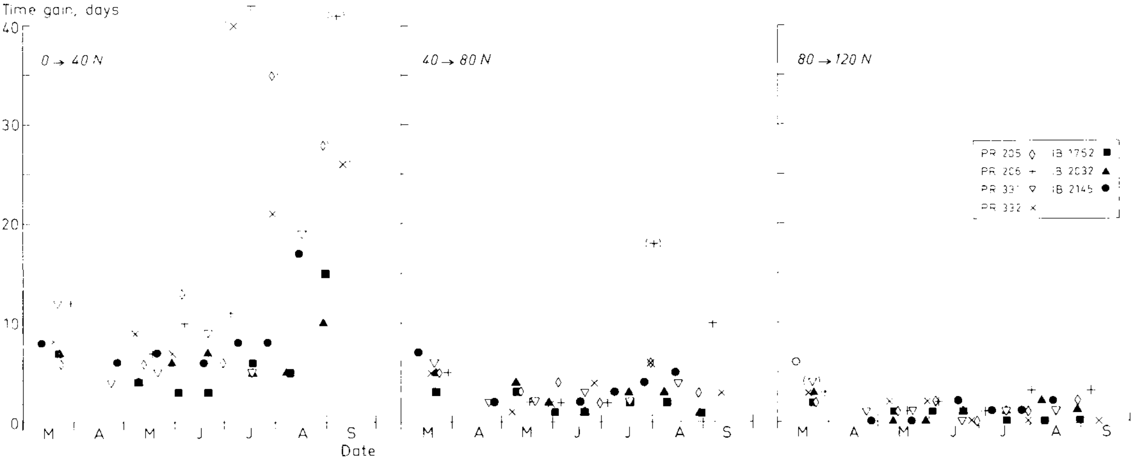


Table 5. Effect of time of nitrogen application and intensity of nitrogen fertilization on A. number of days to reach a production stage of 2 t DM per ha at 0 N and B. on days time gain in the ranges 0→40, 40→80, 80→120 and 0→120 kg N per ha to reach 2 t DM per ha. Horizontal N-effect (see text). Average of three IB-trials.

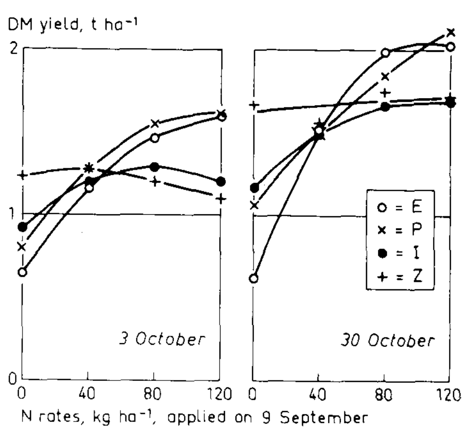
Date of N-application	Intensity of nitrogen fertilization	A	B			
		0 N	0→40 N	40→80 N	80→120 N	0→120 N
10/3	E	64*	8	7*	4	19*
	I	63*	8	5*	4	17*
1/4	E	51	7	4	3	14
	I	48	6	4	3	13
1/5	E	40	8	2	2	12
	I	34	5	3	1	9
1/6	E	36	10	3	2	15
	I	27	5	2	1	8
1/7	E	40	14	5	2	21
	I	27	6	2	0	8
1/8	E	51	20	10	2	32
	I	34	8	2	1	11
20/8	E	62	25	15	3	43
	I	42	11	3	1	15

* Slight differences between E and I because of curve fitting.

3. Response to nitrogen at the end of the season

Details on the residual effects of high nitrogen pretreatments have been given in this article and also previously (Prins & Van Burg, 1977). An extreme example can be found towards the end of the 1974 season with the four intensities of nitrogen fertilization of IB-trial 2145 when already 200, 360, 560 and 960 kg N per ha had been applied, respectively. For all systems the last time of application was 9 September. At that date the swards of the four intensities of nitrogen fertilization differed in appearance, becoming more open with increasing intensity. This was mainly because grass species like *Poa annua*, *Poa trivialis* and *Poa pratensis* nearly had disappeared, whereas the percentage of *Lolium perenne* had remained fairly constant. At both successive harvests DM yield at 0 N was highest with the highest nitrogen pretreatment: a positive effect of the residual nitrogen. Compared with the yield of the E-system, the residual effect was about 10-20 kg N with the P-system, 20-30 kg N with the I-system and about 50 kg N with the Z-system (Figure 6). Fresh applications of 80 or 120 kg N showed a small negative response on 3 October and nil or a small positive response on 30 October on the plots of the I- and Z-system. However, the grass of the E- and P-systems showed a considerable positive response, giving the highest yields. It is presumed that the fresh applications harmed the grass of the I- and Z-systems and did not harm the grass of the E- and P-systems. The negative effect of the fresh

Figure 6. Effect of intensity of nitrogen fertilization on response to nitrogen at two successive harvests towards the end of the season. Total nitrogen pretreatment rates of the E-, P-, I- and Z-systems till 9 September 1974 were 200, 360, 560 and 960 kg N per ha, respectively.



applications seems to have disappeared after 3 October. Namely between 3 and 30 October the growth rate of the grass of the I- and Z-systems was about the same as that of the E- and P-systems with sufficient nitrogen. The strong response of the E- and P-systems to nitrogen at the end of the season agrees well with the low levels of mineral nitrogen in the soil while in the I- and Z-systems mineral nitrogen had clearly accumulated in the soil (Prins, 1980).

General considerations

In the following we take first a closer look at the appraisal of the cutting system used in our experiments and secondly at the optimum rate of nitrogen application at each cut.

1. Appraisal of cutting at a set stage or a set date

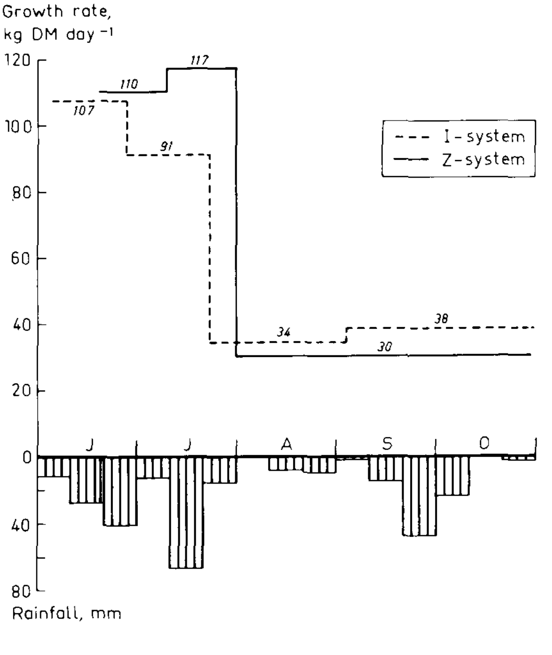
It has been mentioned above that in order to simulate farming conditions as closely as possible, cutting according to a specific stage of utilization, whether for grazing, silage- or hay-making, is preferable. This necessitates cutting at a set stage as against a set date with a fixed cutting frequency. When aiming for a grazing or a silage stage it is not possible to work continuously with a fixed cutting frequency of, for example, four or six weeks. As has been shown by results of this and previous research (Alberda & Sibma, 1968; Behaeghe, 1968; Corrall, 1968) growth rate decreases from beginning to end of the season. This means a longer period of growth towards the end of the season before reaching the required stage. When working with different rates of nitrogen application, growth is faster at higher rates and consequently yield at a certain date is larger than at lower rates. Large yields may, especially in early season, considerably affect the production of following cuts (Ennik, 1980; Garwood, 1980).

When choosing the cutting management in grassland experiments one has to take advantages and disadvantages into consideration. Cutting according to a fixed series of dates is, of course, easier as regards the organization of the work. An apparent advantage with set dates is also that cutting and fertilizing take place on the same day for all treatments. At set stage, however, treatments differ in dates of cutting and subsequent fertilizing, and weather conditions at these dates may influence the treatment results. An example of considerable influence of the weather is presented in Figure 7.
The effect of the weather was in this case larger than the effect of the applied nitrogen. Similar results have been reported by Garwood (1980).

It can be concluded that the system of cutting at a set stage is good as long as weather conditions for the different treatments are more or less equal. If not, it may be better to choose the system of set dates with the same weather conditions at cutting and fertilizing.

Whatever system for assessing the response to nitrogen is chosen one should in any case be aware of the disadvantages of that system and the results should be interpreted critically.

Figure 7. Example of an effect of weather conditions around the date of cutting and fertilizing on the subsequent response to nitrogen of the I- and Z-systems with 80 and 120 kg N per ha at each cut, respectively. The rainfall in mid-July promoted regrowth of the I-grass after cutting on 22 July 1975; the drought period from late July onwards hampered regrowth of the Z-grass after cutting on 31 July 1975. (Results of the long-term trial IB 2146, a follow-up of the annual trials mentioned in this paper.)



2. Optimum rate of nitrogen application

The purpose of the study of the seasonal response to nitrogen is to establish guidelines for the optimum rate of nitrogen application per cut depending on the usage of the herbage. This means integrating vertical and horizontal effects and taking possible residual effects into consideration. The optimum rate of nitrogen can be determined by the economics of the applications, keeping in mind factors like the maintenance of the sward productivity, the quality of the harvested grass or the amount of mineral nitrogen in the soil.

As regards the economics, the optimum rate of nitrogen can be read from the response curves at each time of application by assuming a marginal profitability at a yield whereby the response is still 7.5 kg DM per kg N applied. This is an average of the values 5.7, about 7, and 10 as used by Thomas (pers. comm.), Voigtländer & Voss (1977) and Morrison (1980), respectively. Of course, this value may be modified with changes in price of feed or fertilizer.

By connecting the points of marginal profitability at the different response curves it is possible to read at each time of nitrogen application the optimum rate of nitrogen required to obtain DM yields of, say, one up to five tonnes per ha. As an example of this method the response curves and the dotted line connecting the points of marginal profitability at the response curves of the first time of application (S1) of IB-trial 1752 are presented in Figure 8. In this way the optimum rates of nitrogen application have been determined for the E- and I-systems for all times of application (Table 6). So for the grazing stage of growth (2 t DM per ha) an application of 80-100 kg N per ha appeared throughout the season to be profitable in a 'continuous' low-N situation (E-system). In a high-N situation (I-system) for the grazing stage of growth the application had to decrease from 100 to 40 kg N during the

Figure 8. Example of the determination of the optimum rate of nitrogen application assuming a marginal profitability of 7.5 kg DM per kg N, in the spring of 1972, IB 1752, when rates up to 200 kg N per ha had been applied. By following the dotted lines connecting the intercepts, the optimum rates of nitrogen application can be read at different stages of growth.

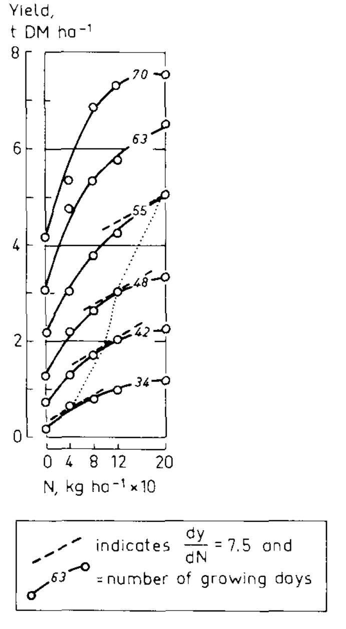


Table 6. Effect of intensity of nitrogen fertilization (E- and I-system) on the amount of fertilizer nitrogen required to meet the economic response of 7.5 kg DM per kg N at different yield levels, depending on the date of nitrogen application. IB 1752, 1972. Yields of pretreatment cuts are listed in Appendix I.

System	Time of N-application	Date of N-application	Nitrogen pretreatment kg ha^{-1}	DM yield level, t ha^{-1}				
				1	2	3	4	5
E	S1	21/3	0	60	100	120	160	200
	S2	12/5	80	40	80	100	120	140
	S3	7/6	120	40	80	100	100	120
	S4	1/7	160	40	100	120	120	140
	S5	4/8	200	40	80	120	160	200
	S6	30/8	240	40	80	100	-*	-
	S7	22/9	280	40	-	-	-	-
I	S1	21/3	0	60	100	120	160	200
	S2	9/5	120	40	60	80	100	120
	S3	2/6	200	20	40	80	100	100
	S4	20/6	280	20	40	80	100	120
	S5	17/7	360	0	40	60	80	100
	S6	9/8	440	0	40	60	80	-
	S7	30/8	520	0	40	80	-	-
	S8	22/9	600	0	-	-	-	-

* Yield not reached due to lateness in season.

season. For the silage and hay stages, rates were higher in both situations. Overall the difference in optimum rates between the E- and I-systems was about 20 kg N in May and June, and about 40 kg N per ha thereafter.

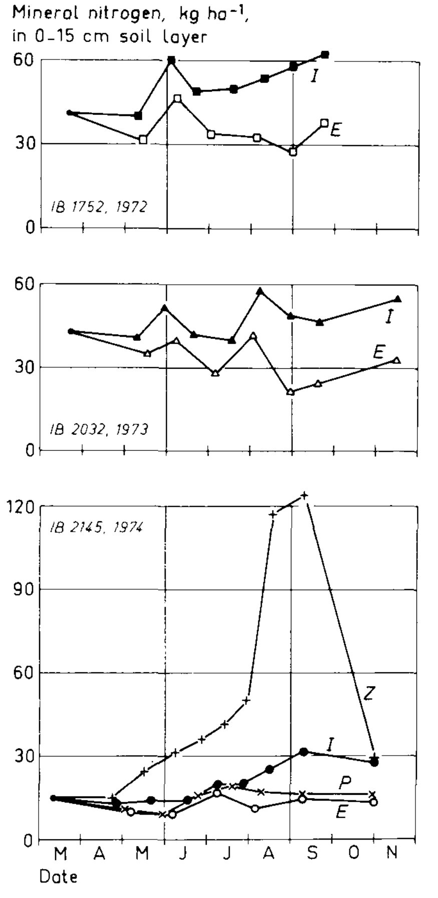
Table 6 can, however, not directly be used for advisory purposes. The difficulty is that, for example, once a rate of 120 kg N has been applied in a low-N situation to obtain a yield of 3 t DM per ha, the situation is no longer low-N and a possible residual effect has to be taken into account for the next application. Moreover, one has to take the cutting regime into account which in our example of IB 1752 included cutting at silage and grazing stage.

Still, Table 6 supports the general conclusion in the Netherlands that the first application of nitrogen should be the highest. Subsequent applications should be decreased in line with the decrease in the rate of grass growth.

As regards the difference between the E- and I-systems of 20 kg N in May and June, and of 40 kg N thereafter (see above), we can report that the latter value has been determined earlier in the IB-trials, following another way of calculation (Prins & Van Burg, 1977). It can be concluded from Figure 6 that with the intermediate P-system of nitrogen fertilization (60 kg N per ha at each cut) the residual effect is smaller than with the I-system. Likewise, the residual effect with the Z-system (very intensive, 120 kg N per ha at each cut) is considerably larger.

For different systems of grassland utilization it should be possible to construct a scheme with optimum rates of nitrogen application which take account of the nitrogen supply by the soil and the residual nitrogen over the season. However, at present it is not possible to predict the nitrogen supply by the soil through mineralization, nor is there a quick method to determine the nitrogen status of the sward. Knowledge of the nitrogen status of the sward seems essential to be able to predict the residual effect. In this article the experiments demonstrated this residual effect already after the first application (e.g. Table 2), while the difference between the quantity of mineral nitrogen in the upper 15 cm of soil of the E- and I-systems was minimal (less than 10 kg N per ha, Figure 9). From late July onwards the difference in the soil mineral nitrogen increased to 15-30 kg N per ha. Figure 9 clearly shows how in 1974 the applications of 120 kg N per ha at each cut (Z-system) increased the mineral nitrogen in the soil from the second cut onwards, up to a level of over 120 kg N per ha in the upper 15 cm in early September. Subsequent heavy rains reduced this large amount of mineral nitrogen to the level of the I-system in the same layer. It is notable that accumulation of mineral nitrogen in the soil was negligible with the P-system, even up to the end of the season when already a total amount of 420 kg N per ha had been applied (Figure 9, 1974).

Figure 9. Effect of intensity of nitrogen fertilization on changes in quantity of mineral nitrogen in the upper 15 cm of soil during the growing season. E, P, I and Z represent intensities of 40, 60, 80 and 120 kg N per ha at each cut, respectively. The higher the rate of nitrogen the more frequent the grass has been cut and fertilized as is shown by the number of symbols indicating the dates of cutting and fertilizing.



So the residual effect of the I-system can only partly be explained by an increase in soil mineral nitrogen compared with the E-system. Therefore we have to assume that after a large application of nitrogen, part of the nitrogen is stored in stubble and roots, and is available for the regrowth. This is in line with earlier findings by Dilz (1966). It may be a suggestion to obtain an increase in the rate of regrowth by establishing a reserve of nitrogen in the stubble-root-soil system at the beginning of the season and exploiting this reserve during the remainder of the season.

Maintaining the sward productivity is an important factor in the nitrogen response studies. In our experiments the yield potential per cut of the swards of the E- and I-systems was the same till the last time of application. This is illustrated nicely, for example, in Figure 2 when on 8 July 1974 the fourth and fifth times of application of the E- and I-systems coincided, respectively, and the same maximum yields were attained. However, the regrowth yields after the last time of application were not always as high with the I-system as with the E-system, as was, for example, shown in Figure 6.

All these results have been obtained in annual experiments. Recently it has been observed that very high rates of nitrogen application in one season may affect the productivity of the sward in the following season (Prins, 1978).

In practice farm management is geared towards an optimal grass production at the right time of the season, in accordance with the requirements of the livestock and the maintenance of the swards. Planning of the grassland production on the basis of our results and of those of, for instance, Boxem (1973) and Van Steenbergen (1977) may make management decisions for the utilization of the grassland easier. Here reference may be made to the concept of planning in grassland management based on certain production stages as described by Wieling (1977). These experiments have demonstrated variable responses to nitrogen imposed by differences in soil type, water supply, botanical composition, age of sward etc. These results have mainly been obtained in cutting experiments which may have a different response to nitrogen than grazing experiments (Boxem, 1973; Jackson & Williams, 1979).

It would seem that only by analyzing the results of many cutting and grazing experiments, conducted under different circumstances of climate, soil type and defoliation/fertilization regimes, it may be possible to establish more refined guidelines for the optimum rate of nitrogen application at different times of the season.

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Appendix I. Dates of nitrogen application and dates of mowing; DM yields (t ha^{-1}) of cuts preceding series S2, S3 etc. and of last successive cut of last series; intensities of nitrogen application: E-, P-, I- and Z-systems with rates of 40, 60, 80 and 120 kg N per ha at each cut, respectively.

Expt. System	Series S1	S2	S3	S4	S5	S6	S7	S8	S9	Last cut	Total yield	Total applied kg ha^{-1}
PR 205 -I												
	23/3	12/5	4/6	29/6	30/7	29/8				24/10		480
		2.47	2.33	1.65	1.32	1.52				2.75	12.04	
PR 206 -I												
	29/3	18/5	6/6	4/7	1/8	6/9				31/10		480
		2.57	1.83	2.55	2.59	1.68				2.46	13.68	
PR 331 -I												
	21/3	23/4	21/5	20/6	17/7	16/8				30/10		480
		2.19	2.51	2.42	1.73	2.36				2.94	14.15	
PR 332 -I												
	19/3	7/5	30/5	26/6	30/7	11/9				30/10		480
		2.12	2.33	2.11	1.57	1.07				2.69	11.89	
IB 1752-E												
	21/3	12/5	7/6	1/7	4/8	30/8	22/9			9/11		320*
		3.18	1.48	1.99	2.82	1.87	0.89			0.89	13.12	
IB 1752-I												
	21/3	9/5	2/6	20/6	17/7	9/8	30/8	22/9		9/11		680*
		3.31	1.66	2.26	3.48	1.86	1.61	1.13		1.36	16.67	
IB 2032-E												
	22/3	16/5	7/6	5/7	2/8	29/8	19/9			12/11		280
		2.52	2.09	1.76	2.36	1.66	1.08			1.25	12.72	
IB 2032-I												
	22/3	9/5	29/5	20/6	17/7	7/8	29/8	19/9		12/11		640
		2.40	2.13	2.20	2.48	2.28	1.58	1.72		1.36	16.15	
IB 2145-E												
	11/3	6/5	4/6	8/7	5/8	9/9				30/10		240
		2.13	2.22	2.11	1.97	1.95				1.48	11.86	
IB 2145-P												
	11/3	2/5	29/5	24/6	18/7	9/8	9/9			30/10		420
		2.09	2.59	1.83	2.16	1.82	2.27			1.68	14.44	
IB 2145-I												
	11/3	26/4	20/5	17/6	8/7	26/7	14/8	9/9		30/10		640
		1.72	2.45	2.32	2.20	1.88	1.84	1.99		1.67	16.07	
IB 2145-Z												
	11/3	22/4	15/5	7/6	26/6	12/7	29/7	16/8	9/9	30/10		1080
		1.94	2.36	2.20	2.34	2.22	1.70	1.80	1.50	1.72	17.78	

* The spring applications were 80 and 120 kg N per ha in the E- and I-system, respectively.