Some environmental aspects of grassland cultivation

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The effects of ploughing depth, grassland age, and nitrogen demand of subsequent crops

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ABSTRACT

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The Netherlands has submitted a derogation under the Nitrate Directives to the European Union (EU) in 2000. In the final opinion by a group of experts about the Dutch derogation, recommendations on ploughing of grasslands were included dealing with i) the depth of ploughing of permanent grassland, ii) the age of temporary grassland and iii) the nitrogen demand of the subsequent crop of temporary grassland. A literature study was carried out in order to provide scientific information on these three issues. No studies were found in literature in which the effects of cultivation depth on nitrogen mineralisation and losses in reseeded grassland were assessed. The results of transformation of grassland into arable land show no clear effects of ploughing depth on N mineralisation. Differences in nitrogen mineralisation after 5 and 3 years temporary grassland are small. Italian and perennial ryegrass, potato, silage maize, winter wheat, and several vegetables have a high nitrogen demand (i.e. >250 kg N ha^{-1}).

Keywords: cultivation, grassland, mineralisation, nitrogen, nitrogen demand, ploughing depth

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Contents

Summary

The Netherlands has submitted a derogation under the Nitrate Directives to European Union in 2000. In the final opinion of a group of experts about the Dutch derogation several recommendations are presented, including three recommendations on ploughing of permanent and temporary grasslands:

- **Recommendation II.8:** "For permanent grassland, to avoid ploughing or any deep working of the soil when reseeding for the renewal of pasture".
- **Recommendation II.9:** "For temporary grassland, to limit to 3 years the duration of the sward, in order to reduce the quantity of accumulated N which will mineralise after ploughing ".
- **Recommendation II.10:** "(For temporary grassland) to plough the sward only in spring followed by a crop with high N demand."

The Ministry of Agriculture, Nature Management and Fisheries (LNV) and the Ministry of Housing, Spatial Planning and the Environment (VROM) in the Hague have asked Alterra and Plant Research International to provide scientific information on these three issues to facilitate the discussion with the EU. In this report three literature reviews are presented dealing with these issues.

No studies were found in literature, in which the effects of cultivation depth on N mineralisation and N losses in reseeded grassland were assessed. However, the results of studies in which grassland was transformed into arable land, show that the risk of N losses after grassland cultivation is not higher after ploughing to a depth of 20-30 cm than after cultivation to a depth of 5-10 cm. Similar effects of the depth of cultivation may be found after cultivation for reseeding of grassland, but the risk of N losses is smaller than when grassland is transformed into arable land, because the reseeded grassland rapidly immobilises N.

The results indicate that differences in N mineralisation after 5 and 3 years temporary grassland are small. Because of the relatively small effect of the length of the grass period on N mineralisation and N losses, the frequency of ploughing is more determining total N losses on the long run. Risk on N losses depends on weather conditions in the year of ploughing the grassland. Increasing the age of temporary grassland from 3 to 5 years means that the number of periods during the rotation with an increased risk of N loss decreases.

Total N mineralisation from soil organic matter and the ploughed sward in the first year after ploughing up temporary grasslands ranges from 127 to 400 kg N ha^{-1}. Crops with an N demand higher than 250 kg N ha^{-1} include Italian ryegrass, perennial ryegrass, potato, silage maize, winter wheat, and several vegetables. Potato and silage maize can be followed by a winter crop. Italian ryegrass, winter rye and fodder radish can be grown as winter crops and have an N uptake of about 40 kg ha^{-1} when the main crop is harvested on 21 September.

1 Introduction

The Netherlands has submitted a derogation under the Nitrate Directives to European Union in 2000. The Directorate-General Environment (DG ENV) and Directorate-General Agriculture (DG AGRI) have asked a group of experts for an opinion about the Dutch derogation. In the final opinion of the group of experts several recommendations are presented, including three recommendations on ploughing of permanent and temporary grasslands:

- **Recommendation II.8:** "For permanent grassland, to avoid ploughing or any deep working of the soil when reseeding for the renewal of pasture".

- **Recommendation II.9:** "For temporary grassland, to limit to 3 years the duration of the sward, in order to reduce the quantity of accumulated N which will mineralise after ploughing ".

- **Recommendation II.10:** "(For temporary grassland) to plough the sward only in spring followed by a crop with high N demand."

The Government of the Netherlands has agreed in a meeting with DG ENV and DG AGRI on 14 March 2002 to provide scientific information to facilitate the discussion about these three issues.

The Ministry of Agriculture, Nature Management and Fisheries (LNV) and the Ministry of Housing, Spatial Planning and the Environment (VROM) in the Hague have asked Alterra and Plant Research International to provide scientific information on the three issues.

In this report three literature reviews are presented, dealing with:
- The effects of ploughing depth on N mineralisation and losses in permanent grasslands;
- The effect of the age of temporary grasslands (< 5 years) on N accumulation and mineralisation;
- The N demand of crops and N mineralisation of ploughed temporary grasslands.

Both results of studies carried out in the Netherlands and in other countries are presented.

2 Effects of ploughing depth

2.1 Common practice in the Netherlands

A recent Dutch study recommended to avoid ploughing and intensive soil cultivation for grassland renewal on peat soils, because of nutrient losses, the limited bearing capacity of the soil after destroying the old sward, and the chance of irreversible drying out of the bare top soil (Aarts *et al.*, 2002). Also on heavy clay soils, ploughing and grassland reseeding is difficult and may give disappointing results. As a consequence, the Dutch Manual for Dairy Farm Management (Anonymous, 1997) recommends minimum soil cultivation for grassland renewal on peat and heavy clay soils. Farmers are well aware of this and statistical data show that ploughing and grassland reseeding on these soil types is only practised at a very limited scale. On the other hand, grassland on sandy or light clay and loam soils, on average, is renovated every 5 or 10 years, often after ploughing (Aarts *et al.*, 2002). On these soils ploughing is recommended for grassland renewal (Anonymous, 1997) because it may (temporarily) improve the physical and chemical quality of the soil, among others by a better distribution of organic matter, and reduce the number of weed plants in the young sward. The better quality of the soil will increase herbage vitality in the first years after renewal, in particular under adverse weather conditions (Aarts *et al.*, 2002; Hopkins *et al.*, 1995). This may reduce N losses by leaching and denitrification.

2.2 Distribution of nitrogen in grasslands

Davies *et al.* (2001) determined the N contents of plant tops and dead and living roots (measured as macro organic matter) in soil layers up to a depth of 40 cm of N fertilised (150 kg N ha^{-1}) old grassland (perennial ryegrass). The plant tops contained 43-66 kg N ha^{-1}, the upper 10 cm of the soil contained 161-235 kg N ha^{-1} and the 10-40 cm layer of the soil contained 35-38 kg N ha^{-1}. The annual N accumulation in the 0-5 cm layer of young grasslands on sandy clay ranged from 28 to 35 kg N ha^{-1} (Hoogerkamp, 1973). The N accumulation in soil layers deeper than 5 cm was small, *i.e.* less than 10 kg N ha^{-1}. The studies of Davies *et al.* (2001) and Hoogerkamp (1973) show that most of the N in grasslands accumulates in the upper 10 cm of the soil and in the stubbles. Thus, increasing the depth of grassland cultivation from 10 to 30 cm has a relatively small effect on the total amount of N which is exposed to disturbance and mineralised.

2.3 Nitrogen mineralisation and losses

Arnott & Clement (1966) found that the dry matter and N yields of spring barley and kale following a grass/clover sward killed with amitrole-T, were similar to those obtained following ploughing. On the herbicide-treated plots, no soil cultivation was practised, and on the ploughed plots, no herbicide was applied. Although there was slightly more inorganic N in the ploughed than in the undisturbed sprayed soil, the rate of N mineralisation was not significantly different. The killed swards were 4 (spring barley) or 10 (kale) years old. This study shows that both after killing of the old sward by herbicide spraying or by soil cultivation, there is a rapid mineralisation of organic N. This is mainly N contained in the living crop.

Zwart *et al.* (1999) assessed the effects of the depth of ploughing of grassland (12 or 25 cm) on a loamy soil on mineral N and N mineralisation with white cabbage as following crop. In-situ measurements of N mineralisation, using the method of Raison *et al.* (1987), showed a statistically significant higher N mineralisation of cultivated grassland at a ploughing depth of 12 cm (295 kg N ha^{-1} $year^{-1}$) than at a ploughing depth of 25 cm (137 kg N ha^{-1} $year^{-1}$), especially in the second half of the growing period (Figure 1). Richter *et al.* (1989) also showed that deeper ploughing slowed mineralisation. Differences in temperature and aeration may have caused these effects of ploughing depth on N mineralisation. The difference in N mineralisation did not result in statistically significant differences in mineral N contents (Figure 1), suggesting that N losses and/or N uptake were higher for ploughing at 12 cm than for ploughing at 25 cm.

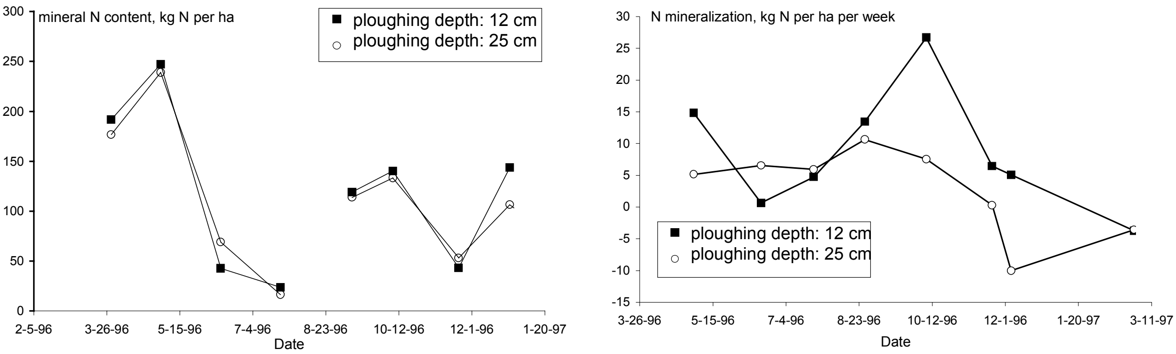

Figure 1. Course of mineral N content (Figure on the left) and in-situ N mineralization (figure on the right) in 0-30 cm layer of arable land (white cabbage) after ploughing grassland to 12 and 25 cm (Zwart et al., 1999).

In a study of Lloyd (1992), the effects of cultivation of grassland on soil mineral N contents and nitrate leaching losses were assessed at eight sites during three years. Cereals (winter and spring wheat and spring barley) were sown after cultivation of grassland. There was no significant difference in soil mineral N contents and nitrate leaching between ploughing to 15-20 cm and minimum tillage to approximately 7.5 cm. Only at one site with high N contents there was a tendency that nitrate leaching was higher after ploughing than after minimum cultivation. It was concluded that shallow cultivation of grassland will lead to similar N losses than a deeper soil disturbance.

The studies of Lloyd (1992), Zwart *et al.* (1999) and Richter *et al.* (1989) indicate that there is no or a small negative effect of the depth of grassland cultivation on N mineralisation, soil mineral N contents and nitrate leaching. In these studies, grassland was transformed into arable land. In the studies of Zwart *et al.* (1999) and Richter *et al.* (1989) there is a tendency that shallow cultivation leads to higher N mineralisation than deep cultivation. This may be due to a higher temperature and better aeration in the upper soil layer.

No studies were found in literature in which the effects of ploughing depth on N mineralisation and N losses were assessed in reseeded (permanent) grassland. Therefore, the effects of ploughing depth on N mineralisation and losses after renewal of (permanent) grassland can only be estimated on basis of the results of the studies conducted by Arnott & Clement (1966), Lloyd (1992), Zwart *et al.* (1999) and Richter *et al.* (1989). When grassland is cultivated and directly reseeded, net N mineralisation and risk of N losses is much smaller than when grassland is transformed into arable land, because the reseeded grassland rapidly immobilises N (Huntjes, 1971). Adams & Jan (1999) and Davies *et al.* (2001) showed that direct reseeding after ploughing of grassland strongly decreases N leaching in comparison to delayed reseeding or leaving the soil fallow. Results of recent research of IGER (UK) indicate that reseeding does not increase N losses if reseeding took place in spring and summer. A closed grass sward has to be formed before the period with a precipitation surplus (Hatch *et al.*, 2002; David Hatch, pers. com.).

If (permanent) grassland in the Netherlands has to be cultivated for renewal, reseeding will be carried out as soon as possible, because any delay decreases herbage yield. The results of the studies in which grassland was transformed into arable land indicate a tendency of a higher N mineralisation after shallow cultivation than after deep cultivation. Similar effects of the depth of cultivation may be found after reseeding of (permanent) grassland, but the effects are probably smaller because of the significant N immobilisation after reseeding.

2.4 Rooting depth and productivity

Rooting depth of a newly sown perennial ryegrass sward is comparable to that of arable crops (Sibma & Ennik, 1988; Ennik *et al.*, 1980). After the first year or the first two years, most of the roots concentrate in the upper part of the soil profile, depending on fertilisation and grassland use. However, a small proportion of total root mass remains in deeper soil layers and may absorb water and plant nutrients, particularly in periods with limited rainfall and/or limited fertilisation rates (as induced by the MINAS system). Van der Meer & van Uum - van Lohuyzen (1986) reported a rather high recovery (66%) of the inorganic N determined in early spring in well drained sand and clay soils to depths of 60-100 cm.

Hoogerkamp (1974) compared productivity of an old grassland sward on a rather heavy clay soil with that of new swards established after different methods and depths of soil cultivation: (1) superficial cultivation with a rotavator, (2) turning the soil with a spading machine to a depth of 20 cm or (3) to a depth of 40 cm. Unfortunately, he did not determine yields in the first year after reseeding. Average dry matter and N yields in the following 6 years were not affected by the method of soil cultivation, although there were differences in individual years. Deep soil cultivation with the spading machine resulted in higher yields in dry years and lower yields in wet years.

2.5 Conclusions

No studies were found in literature, in which the effects of cultivation depth on N mineralisation and N losses in reseeded grassland were assessed. However, the results of studies in which grassland was transformed into arable land, show that the risk of N losses after grassland cultivation is not higher after ploughing to a depth of 20-30 cm than after (shallow) cultivation to a depth of 5-10 cm. In fact, there is a tendency that shallow cultivation causes higher N mineralisation than deeper ploughing, which may be explained by higher temperatures and increased aeration following shallow cultivation. Similar effects of the depth of cultivation may be found after cultivation for reseeding of (permanent) grassland, but the risk of N losses is smaller than when grassland is transformed into arable land, because the reseeded grassland rapidly immobilises N. It has been shown that the young grass crop has a good ability to adsorb N from deeper soil layers.

3 Effects of grassland age

3.1 Nitrogen accumulation

Nitrogen accumulates approximately linearly in young grasslands (<10 years), ranging from 20 to 130 kg N ha^{-1} $year^{-1}$ (Cuttle & Scholefield, 1995; Hassink, 1994; Hoogerkamp, 1984; Tyson *et al.*, 1990; Whitehead *et al.*, 1990). Studies of Hoogerkamp (1973; 1984) in the Netherlands indicate a higher N accumulation in clayey soils (60-120 kg N ha^{-1} yr^{-1}) than in sandy soils (20-70 kg N ha^{-1} yr^{-1}), which is caused by physical protection of organic matter by clay particles. The rate of N accumulation also depends on soil N content (low soil N content > high soil N content), management (high N input > low N input; grazed > cut), and age (young > old) but the separate effects of these factors can not be quantified yet due to lack of experimental data (Velthof & Oenema, 2001).

In a crop rotation experiment with grass and silage maize, Van Dijk *et al.* (1996) determined the DM yield and N content of shoots and roots of 2- and 4- or 6-year-old swards on sandy soils just before cultivation of the sward with a spading machine (Table 1). On average, the 4- and 6-year-old swards contained slightly more N than the 2-year-old swards. This was caused by the higher N content in the roots of the older swards. No differences could be determined between the 4- and 6-year-old sward (van Dijk *et al.*, 1996). The rate of N application slightly increased total N content in the sward. This was mainly caused by its effect on N concentration in stubbles and roots (results not shown).

Table 1. Mean effect of sward age and rate of N application on stubble and root mass and N content just before cultivation in March of 1990-1993. All swards received 30 t cattle slurry ha^{-1} $year^{-1}$ + 100 and 300 kg N ha^{-1} $year^{-1}$ (N1 and N2, respectively) in the preceding years (Van Dijk et al., 1996).

Age of sward	Crop parts	DM, t ha^{-1}		N, kg ha^{-1}	
		N1	N2	N1	N2
2 years	Stubbles	3.5	3.5	74	84
	Roots	5.9	5.9	65	77
	Total	9.4	9.5	138	161
4 and 6 years	Stubble	3.4	3.5	75	83
	Roots	7.5	7.0	91	107
	Total	10.9	10.5	165	189

3.2 Nitrogen mineralisation and nitrogen supply

Whitehead et al. (1990) calculated that the N mineralisation in loamy soils during the first year after ploughing up grassland increased from 201 kg N ha^{-1} for a 3-yr fertilised and grazed sward to 306 kg N ha^{-1} for a 8-yr fertilised and grazed sward. The results were based on field measurements of N contents in unharvested fractions of grasslands of 8 and 15 years, assumptions on effect of ageing and management on these N contents and calculations of N mineralisation using a simple model. The relatively high N mineralisation rates were partly caused by the extremely high amounts of roots (11-16 ton dry matter ha^{-1}) in this study and the disputable assumption that the rate of decomposition of macro-organic matter is the same as that of living biomass. Linearly interpolating the results suggests that N mineralisation after ploughing a 5-year-old sward would be about 45 kg N ha^{-1} higher than that after ploughing a 3-year-old sward. Calculations with the IGER-model NGAUGE (NCYCLE) show differences of less than 15 kg ha^{-1} between N mineralisation after ploughing 3- or 5-year- old swards (Scholefield et al., 1991; Lorna Brown, pers. com.)

In the crop rotation experiment reported by Van Dijk et al. (1996), 2- and 4-year-old grass swards were followed by silage maize. The grass swards described in Table 1 were killed and cultivated by a spading machine in late March or early April (depth about 25 cm) and maize was sown in late April. Table 2 presents the mean N balances of maize crops on experimental plots with different histories. It is shown that the average (apparent) residual effect of the 2-year-old grass sward was 79 kg N ha^{-1} and of the 4-year-old sward 96 kg N ha^{-1}, respectively. This shows a small effect of the age of the grass sward. These residual effects amounted to 50-60% of the N contents of the grass swards just before cultivation (Table 1). Table 2 also shows that there was hardly any residual effect in the second-year maize crop. Table 2 shows rather high values for residual Nmin in the soil after harvesting the maize, but there were no differences between a 2- and a 4-year-old sward. Further reduction of the rate of N application or cultivation of a winter crop after maize appears necessary after a grass period.

Table 2. Nitrogen balances (kg N ha^{-1}) for different rotations of grassland and maize. Averages of 3 years for 2 rates of N application (see text) (derived from Van Dijk et al.*, 1996)[1].*

	continous silage maize	silage maize after a 2-year-old ryegrass sward	silage maize after a 4-year-old ryegrass sward	second-year silage maize after a 2-year-old ryegrass sward
Nmin soil, spring	34	13	12	36
Nmin cattle slurry	80	80	80	80
N-fertiliser (in the row)	13	13	13	13
Total	127	106	105	129
N-yield in the crop	167	203	222	180
Nmin soil, autumn	50	72	69	55
Total	217	275	291	235
Input-output	-90	-169	-186	-106

[1]the N rates to the grass swards in the preceding years were 30 t slurry ha^{-1} year^{-1} + 100 kg fertiliser N ha^{-1} year^{-1}.

In a study of Johnston *et al.* (1994), N offtake in the harvested grains of unfertilised winter wheat increased from 70 to 121 kg N ha^{-1} when the age of the ploughed grassland increased from 1 to 3 years. Increasing the age of the ploughed grassland from 3 to 6 years only slightly increased the N offtake, *viz.* from 121 to 136 kg N ha^{-1}. These results suggest that increasing the age of temporary grassland from 3 to 5 years only slightly increases the amount of mineralised N.

3.3 Nitrate leaching

Johnston et al. (1994) determined the nitrate content in the 0-90 cm layer of sandy loams in October, three months after ploughing grassland in summer. The nitrate contents amounted to 93, 112, 204, 199, 201, and 230 kg N ha-1 for grassland of 1, 2, 3, 4, 5, and 6 years, respectively. These results indicated no or little increase in nitrate content for grasslands older than 3 years. Calculated N losses during winter (October-April) showed similar effects; 118 kg N ha-1 was lost from 2-4 years grasslands and 112 kg N ha-1 from 5-6 years grasslands.

Shepherd et al. (2001) assessed the effects of ploughing and reseeding of N fertilised and grazed (sheep) grassland of different age (2, 5, >50 years) on nitrate leaching in a freely draining silty clay loam soil during winter (Table 3). The amount of rainfall in winter had a much larger effect on nitrate leaching than sward age. The results showed higher leaching losses after cultivation of old grassland (>50 years) than after cultivation of grassland of 2 and 5 years. The results showed no clear differences between cultivated grasslands of 2 and 5 years.

Table 3. Effects of reseeding (ploughing and reseeding) on nitrate leaching below 60 cm from a freely draining silty clay loam during winters of 1995/1996, 1996/1997, 1997/1998 (Shepherd et al., 2001)[1].

Sward age	Treatment	N leached, kg N ha^{-1}			NO_3 concentration at 60 cm depth, mg l^{-1}		
		95/96	96/97	97/98	95/96	96/97	97/98
2 yr	Undisturbed	74	2	5	46.6	14.0	2.8
	autumn 1995 reseeded	66	*	*	35.4	*	*
	spring 1996 reseeded	*	10	1	*	48.2	0.6
	autumn 1996 reseeded	*	26	1	*	34.7	0.6
5 yr	Undisturbed	37	0	1	23.0	1.1	0.5
	autumn 1995 reseeded	60	*	*	32.5	*	*
	spring 1996 reseeded	*	3	1	*	15.4	0.5
	autumn 1996 reseeded	*	10	2	*	13.5	0.8
> 50 yr	Undisturbed	122	3	19	76.5	18.1	9.5
	autumn 1995 reseeded	173	*	*	92.8	*	*
	spring 1996 reseeded	*	5	7	*	24.8	3.5
	autumn 1996 reseeded	*	34	6	*	44.9	3.2

[1]fields were N fertilised and grazed (sheep) during the previous years. Sheep were withdrawn 2 months prior to start of experiment and 60 kg N ha^{-1} was applied to all fields, except the plot that was reseeded in autumn 1995. Thereafter no N fertiliser was applied and grass was cut four times each year. Drainage was 159-186 mm in 95/96, 15-75 mm in 96/97, and 198 mm in 97/98.

3.4 Conclusions

The results indicate that differences in N mineralisation after 5 and 3 years temporary grassland are small. Because of the relatively small effect of the length of the grass period on N mineralisation and N losses (especially on sandy soils), the frequency of ploughing is more determining total N losses on the long run. Risk on N losses depends on weather conditions in the year of ploughing the grassland. Increasing the age of temporary grassland from 3 to 5 years means that the number of periods during the rotation with an increased risk of N loss decreases.

4 Nitrogen demand of subsequent crops

4.1 Nitrogen mineralisation in the year after ploughing temporary grasslands

The N balance calculations derived from results of Van Dijk *et al.* (1996) in the Netherlands indicated a total N mineralisation of 169-186 kg N ha^{-1} after ploughing of grasslands of 2-4 years, of which 90 kg N ha^{-1} was from the soil organic matter (based on the results of continuous maize) and 79-96 kg N ha^{-1} from the ploughed sward (Table 2). The calculated N mineralisation may have underestimated the actual N mineralisation, because the balance calculation did not include denitrification losses. Denitrification lossed on an other sandy soil were less than 30 kg N ha^{-1} (Aarts *et al.*, 2001). This suggests that the total N mineralisation in the study of Van Dijk *et al.* (1996) was about 200-220 kg N ha^{-1} yr^{-1}.

Mineralisation measurements of Zwart *et al.* (1999) in the Netherlands on a loamy soil showed N mineralisation rates of 127 and 295 kg N ha^{-1} $year^{-1}$ after ploughing of grassland at a depth of 25 and 12 cm, respectively. Mineralisation measurements in maize land of De Marke decreased from 385 ± 57 kg N ha^{-1} in the first year to 242 ± 98 kg N ha^{-1} in the second year and 158 ± 36 kg N ha^{-1} in the third year after ploughing of 3-year-old grassland (Aarts *et al.*, 2001).

Measurements of N uptake and N losses and model calculations of Johnston *et al.* (1994) in the UK suggest that total N mineralisation amounted to about 160 kg N ha^{-1} after ploughing of 1-year-old grasslands to about 300 kg N ha^{-1} after ploughing of 3- to 5-year-old grasslands on a sandy loam soil. No results were presented for continuous wheat, so the N mineralisation from the soil organic matter and from the ploughed sward can not be distinguished. Whitehead *et al.* (1990) calculated a N mineralisation in loamy soils in the UK during the first year after ploughing up grassland of 201 kg N ha^{-1} for a 3-yr fertilised and grazed sward to 306 kg N ha^{-1} for a 8-yr fertilised and grazed sward. Vertès *et al.* (2001) calculated N mineralisation rates of 250 to 400 kg N ha^{-1} during the first year after ploughing grassland on a loamy soil in France, using experimental results and a model.

The results show a wide range of total N mineralisation rates in the first year after ploughing up temporary grasslands, ranging from 127 to 400 kg N ha^{-1}. These figures include both N mineralisation from soil organic matter and from the ploughed swards. The wide range is due to differences in experimental conditions (soil type, soil organic matter content, N management, sward age and management) and in the method of estimation of N mineralisation (N balance, models, N uptake, and *in-situ* or laboratory incubations). More experimental data are needed in order to derive accurate estimates of N mineralisation, N supply to the subsequent crop and N losses after ploughing grasslands.

4.2 Nitrogen demand of crops

Table 4 presents N yield, N use efficiency and total N demand of different crops in The Netherlands. The data apply to crops fertilised in conformity with the official recommendations (Smit & van der Werf, 1992). The N use efficiency figures are a measure for the apparent recovery of N from soil (including N from atmospheric deposition) and fertilisers. The N demand indicates the total N supply required to obtain optimal yields. The N supply includes the amount of mineral N in spring, the amount of N from mineralisation and atmospheric deposition during the N uptake period of the crop, and the N applied via fertilisers. It is noted that total N uptake and total N demand of the crops is higher than the figures presented in Table 4, because the amounts of N in stubbles and roots are not included.

In Table 5 the crops are categorised according to their N demand. Crops with a relatively low N demand (*i.e.* < 150 kg N ha^{-1}) are asparagus, bunched carrots, carrots, and witloof chicory. Crops with an N demand higher than 250 kg N ha^{-1} are blanched celery, broccoli, Brussels sprouts, cauliflower, Italian ryegrass, kale, leek, perennial ryegrass, pickling cucumber, potato, red cabbage, savoy cabbage, silage maize, spinach, winter wheat and white cabbage. All other crops have an N demand between 150 and 250 kg N ha^{-1}.

Crops which are harvested relatively early, such as silage maize and potato, can be followed by a winter crop to absorb residual mineral N. Under Dutch conditions, Italian ryegrass, winter rye and fodder radish are the most suitable crops for this purpose. Their N uptake will be about 40 kg ha^{-1} when the main crop is harvested on 21 September, whereas earlier or later harvesting of the main crop will increase or reduce this value with *ca.* 2 kg N ha^{-1} day^{-1} (Schröder, personal communication).

In The Netherlands, grass, silage maize and potatoes are the most common crops after grassland ploughing. Perennial and Italian ryegrass and potato have an N demand higher than 300 kg N ha^{-1} and silage maize of 254 kg N ha^{-1}. Silage maize and potato can be followed by a winter crop, such as Italian ryegrass, winter rye and fodder radish. Research on the experimental farm De Marke showed that N uptake of Italian Ryegrass, as a catch crop after maize, almost equalled the amount of N released during mineralisation from August onwards. In this study the N mineralisation was measured *in-situ* and 92% of the measured mineralised N was recovered in the leaves, stubbles and roots (Aarts, 1994).

4.3 Conclusions

- Total N mineralisation from soil organic matter and the ploughed sward in the first year after ploughing up temporary grasslands ranges from 127 to 400 kg N ha^{-1}. The wide range is due to differences in experimental conditions (soil type, soil organic matter, N management, sward age and management) and the method of estimation of N mineralisation (N balance, models, N uptake, and *in-situ* or laboratory incubations). More experimental data are needed in order to derive accurate estimates of N mineralisation, N supply to the subsequent crop and N losses after ploughing grasslands.

- Crops with an N demand higher than 250 kg N ha^{-1} are blanched celery, broccoli, Brussels sprouts, cauliflower, Italian ryegrass, kale, leek, perennial ryegrass, pickling cucumber, potato, red cabbage, savoy cabbage, silage maize, spinach, winter wheat and white cabbage.
- Italian ryegrass, winter rye and fodder radish can be grown as winter crops and have an N uptake of about 40 kg ha^{-1} when the main crop is harvested on 21 September.
- In The Netherlands, grass, silage maize and potatoes are the most common crops after temporary grassland. Perennial and Italian ryegrass and potato have an N demand of more than 300 kg N ha^{-1}. Silage maize has a demand of 254 kg N ha^{-1}. Potato and silage maize can be followed by a winter crop.

Table 4. Mean N yield (kg N ha⁻¹) in marketable products and crop residues, N use efficiency (= total N yield/N supply) and N demand (total N supply required to obtain the N yield) of different crops in The Netherlands (derived from: Smit & van der Werf, 1992; and unpublished information, Plant Research International).
N supply under average conditions in the Netherlands = 50 kg soil N_{min} ha^{-1} in spring + 50 kg N ha^{-1} from mineralisation and atmospheric deposition during crop growth + the recommended N rate (that depends on the actual amount of soil N_{min} in spring).

Crop	N in products	N in crop residues[1)]	Total N yield	N use efficiency	N demand
Asparagus	20	23	43	0.29	148
Beetroot (red beet)	135	90	225	0.92	245
Blanched celery	165	0	165	0.63	262
Broccoli	20	155	175	0.50	350
Brussels sprouts	97	135	232	0.80	290
Bunched carrots	95	0	95	0.73	130
Carrot	100	30	130	0.87	149
Cauliflower	80	120	200	0.57	351
Chinese cabbage	60	65	125	0.60	208
Dwarf French bean	45	95	140	0.70	200
Endive	115	45	160	0.73	219
Fennel	70	110	180	0.90	200
Green pea	37	188	225		
Headed lettuce	75	20	95	0.43	221
Iceberg lettuce	64	70	134	0.61	220
Italian ryegrass [2)]	280	30	310	0.92	337
(curly) kale	80	75	155	0.62	250
Kohlrabi	73	42	115	0.50	230
Leek	85	34	139	0.43	323
Onion	120	5	125	0.54	231
Parsley	65	0	65	0.30	217
Perennial ryegrass [2)]	265	45	310	0.92	337
Pickling cucumber	104	81	185	0.69	268
Potato	180	20	200	0.61	328
Radish	50	0	50	0.28	179
Red cabbage	185	175	360	1.03	350
Savoy cabbage	160	140	300	0.86	349
Scorzonera	75	42	117	0.62	189
Silage maize	180	0	180	0.71	254
Spinach	70	35	105	0.39	269
Strawberry	15	16	31	0.14	221
Sugar beet	90	120	210	0.93	226
Swede	98	52	150	0.65	231
Turnip-rooted celery	73	75	148	0.62	239
White radish	120	0	120	0.67	179
Winter wheat	200	45	245	0.98	250
Witloof chicory	71	44	115	1.05	110
White cabbage	200	115	315	0.79	399

[1)] N in stubbles and roots not included; [2)] sown late March

Table 5. Classification of crops according to N demand.

N demand, kg N ha^{-1} yr^{-1}	Crops
< 200	Asparagus, Bunched carrots, Carrot, Witloof chicory, Radish, Scorzonera, White radish
200-250	Headed lettuce, Iceberg lettuce, Kohlrabi, Onion, Parsley, Endive, Sugar beet, Chinese cabbage, Beetroot (red beet), Strawberry, Swede, Turnip-rooted celery, Dwarf French bean, Fennel
250-300	Blanched celery, Pickling cucumber, Silage maize, Brussels sprouts, Spinach, Winter wheat, (curly) kale
>300	Broccoli, Cauliflower, Italian ryegrass, Leek, Perennial ryegrass, Potato, Red cabbage, Savoy cabbage

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