Silage maize (*Zea mays* L) ripening behaviour affects nitrate leaching over following winter

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Abstract

For economical and environmental reasons nitrogen management is of major importance in growing silage maize (*Zea mays* L). However, studies to improve N management are often restricted to fertilization measures. Therefore we investigated management effects besides fertilization on nitrogen utilization in two field experiments over two years on an eutrophic sandy soil. Experiment 1 examined the effect of row distance (0.35 m and 0.70 m) and harvesting time (premature, mid September; common practice, beginning of October, late harvest, end of October) in a two-way factorial design. In experiment 2 five maize varieties, differing in habitus and characteristic of ripening, were grown using a one-way factorial design. Nitrate leaching over winter was determined by the suction cup method. The row distance showed no significant effect neither on the soil mineral nitrogen content (SMN) in autumn nor on the amount of nitrate leaching. However, SMN and nitrate leaching were affected by the harvest time with significantly lower values for the early harvest. In the second experiment significant differences among genotypes were found with nitrate leaching rates between 52 and 77 kg NO_3-N ha^{-1}. We conclude that the effects of harvesting time and variety on nitrate leaching were related to the stage of maturity of silage maize at harvest. Nitrate leaching during winter was lower when maize plants where prevented from sustained metabolic activity in autumn, either by premature harvest as shown in experiment 1 or by enhanced physiological ripening as in experiment 2.

Keywords: silage maize, nitrate leaching, soil mineral nitrogen (SMN), row distance, harvesting date

Introduction

As maize requires the bulk of nutrients relatively late in the season it is particularly suitable for the uptake of soil nitrogen which has been mineralised in early summer (Richards et al, 1999). Therefore, maize can use mineral and organic fertilizer nitrogen (N) quite effectively (Aufhammer et al, 1991; Lorenz and Steffens, 1997; Maidl et al, 1999). However, after the harvest of maize, large residual soil mineral nitrogen (SMN) contents have been regularly found (Engel and Mangstl, 1988; Sogbedji et al, 2000; Hege et al, 2001) indicating an increased risk of groundwater pollution with leached nitrate during the winter period (Benoît et al, 1995; Schäfer et al, 2002). Often, both quantity and timing of N fertilizer application are not well adjusted to the site-dependent N requirements of the maize crop and cause large residual soil mineral N (SMN) and N leaching, especially on coarse textured soils (Sticksel et al, 1994; 1999; Lütke Entrup et al, 1997; Lorenz and Steffens, 1997; Schroeder et al, 1998; Nevens and Reheul, 2005; Timmons and Baker, 1991). There are soils, however, particularly those with a high potential for N-mineralisation, common in some regions with a high livestock density, where even an adequate application of nitrogen fertilizer, is not sufficient to avoid high SMN values in autumn and nitrate leaching over winter (Kayser et al, 2011). Moreover, in a survey of silage maize fields in Northern Germany a nitrogen balance at the field scale could not explain high residual SMN values in late autumnn (Schiermann, 2004). Hence, other factors than fertilization and nitrogen balance at the field scale have to be considered in order to explain the considerably high nitrate leaching risk of maize. To date, the reasons for the apparent contradiction of maize being efficient in nitrogen uptake in summer, but frequently showing large residual SMN at the end of the season are not yet fully understood.

Among the management measures other than the amount of fertilizer nitrogen, the effects of timing of fertilizer application, the spacing of the plants, and grass as a undersown catch crop have been studied in several investigations. Tactical application of fertilizer nitrogen after assessing the actual SMN in spring has some potential to improve the nitrogen efficiency of the maize crop (Hugger, 1992; Richards et

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al, 1999; Schröder et al, 2000). Similarly, undersowing of a grass crop was shown to decrease the risk for nitrate leaching. There is considerable agreement about the possibilities and limitations of undersowing for reducing the leaching potential (Lütke-Entrup and Stemann, 1989; Müller, 1994; Aufhammer and Kübler, 1997; Jovanovic et al, 2000; Büchter et al, 2003). Apart from that, the effects of improved row spacing, e.g. double rows or narrow rows, are less clear and results are in part contridictory (Aufhammer and Kübler, 1997; Peyker, 2001; 2004; Rieckmann et al, 2003). It was argued that the spacing effect could interact with variety or site effects which would give varying results according to the variety and the conditions of the site (Peyker, 2001).

There is anecdotal evidence from a number of observations under practical farming conditions and from field experiments performed by local advisory services that the SMN content in autumn is affected by time of harvesting. In these investigations SMN contents increased with a delayed harvesting. This was especially observed on soils with a high potential for nitrogen mineralisation in combination with the cultivation of genotypes with delayed ripening – the so-called 'stay-green varieties'. This indicates the physiological state of maturity of the maize at harvesting as a possible cause for the variability of residual SMN in autumn. So far, there is no scientific evidence for this indication.

Maize breeders have been improving the N-efficiency of maize by breeding for some time (Wiesler, 1991; Presterl et al, 2000). Under low-input conditions the new genotypes were found to be superior to conventional varieties (Presterl and Thiemt, 1999). There is still a need to clarify as to how and to what extent the nitrogen-efficient maize genotypes affect the level of SMN after the harvest, particularly on the typically N-eutrophic soils of the main cultivation areas for maize in northern Europe.

This investigation analyses the effects of genotype, row distance and harvest time, as well as the interaction between row spacing and harvest time, on the N yield, the SMN accumulation in the soil and the nitrate leaching of silage maize.

Materials and Methods

The experimental site was located in northwest Germany Germany (52°56'44''N and 7°50'17''E) in an area with a high livestock density. The organic sandy soil has a considerably high N mineralization potential (TC, total carbon content 4%; TN, total nitrogen = 0.19%; C:N = 20.9). The soil is a sand-mix culture where a gleyic podzol with a top layer of degraded peat was mixed with the sandy subsoil. The field was sufficiently supplied with basic nutrients, (double lactate-soluble (DL) P = 148 and K = 83 mg kg^{-1}), and had also been planted with maize in the preceding six years.

The two experiments where adjacent to each other on the same site and both conducted over two years. The first experiment had a randomised, two-factorial design with six replications. The factor 1 'Row distance' was subdivided into the levels 1.1, row distance = 75 cm and 1.2, row distance = 35 cm. Factor 2 'Harvest time' consisted of the treatments 2.1, early harvest (Mid September), 2.2, common harvest time (Beginning of October), and 2.3, late harvest (End October). The variety 'Aldus' was cultivated with a density of 11 plants per m^2, irrespective of the row distance. The experimental plots had a size of 72 m^2 (6 * 12 m), giving 8 rows for a row distance of 75 cm and 17 rows for a row distance of 35 cm with row length of 12 m. Sowing was carried out on 3 May in the first year and on 24 April in the second year. Silage maize was harvested on 13 September, 5 October and 24 October in the first year; and on 18 September, 09. October and 29 October in the second year. These harvest dates were chosen to achieve a broad range of physiological stages of the plants at the time of harvest. The plots of both experiments were harvested by a chopper. After harvest the stubble was not incorporated into the soil to avoid additional mineralization processes.

The second experiment with the single factor 'Type of variety' was simultaneously set up in a block design with four replications. The different varieties and their characteristics are shown in Table 1. Maize was also sown with 11 plants per m^2. The harvest was carried out at the same time as the middle harvest date of the first experiment.

The plant protection measures followed local practice, where herbicides were applied in a mixture (active substances: Terbuthylazin, S-Metolachlor, Mesotrione and Nicosulfuron) and with no mechanical weeding. Because of detrimental weather effects, weed spread occurred in late summer in the first year, while in the second year, the maize plots were almost weed-free. Considering the known high mineraliza-

Table 1 - Description of the varieties in the second experiment.

Variety	FAO number	Breeder	Characteristics
Asket	S 260 / K 250	KWS	Middle-large low-input type
Prinval	S 260 / K 250	Asgrow	Large variety with regular ripening
Baltimore	S 240 / K 260	Nickerson	Large variety with early ripening
Mona	S 230 / K 250	Pioneer	Compact type, dry-down
Aldus	S 260 / K 260	Asgrow	Large variety, smooth ripening

Table 2 - Climatic data for the two years of the experiment and long term average.

	First year	Second year	Long term average
Daily temperature [°C]	8.9	9.9	8.7
Precipitation [mm]	673	834	783
Climatic water balance (Haude)	151	270	293
Amount of water leached [mm]	264	338	not recorded

tion rate on the site mineral N fertilizer application was limited to 60 kg/ha before seeding; no fertilizer N was applied later in the season. Due to the high phosphorus and the moderate potassium content of the soil no P and K fertilizers were applied.

A permanent vacuum-controlled suction cup system with three cups per plot at a depth of 75 cm was installed to take samples of drainage water. The suction pipes connecting the suction cups and sampling bottles were laid about 45 cm below ground and allowed unrestricted field management including ploughing. Water from suction cups was continuously collected and stored until sampling in 1 L brown bottles placed in closed crates below soil surface. Samples for laboratory analysis were collected for each cup weekly or fortnightly during the leaching period. Sampling in the first period ended on 23 April and on 11 March for the second period that was before sowing and fertilizing the new maize crop. The nitrate leaching losses were calculated as the product of the nitrate concentration and the amount of water percolating through the profile at a given time. It was assumed that after the soil water content had reached field capacity in autumn, daily drainage equaled precipitation minus potential evapotranspiration (Haude, 1954). Summing the nitrate leaching for all sample dates while percolation occurred gave a total loss over winter. Further target variables included dry matter yields, N yields at the time of the harvest, the SMN at different times in the growing period, and the nitrate concentration in the near-surface leaching water during the leaching period following the harvest. At the beginning of each leaching period in autumn and at the start of the growing season in spring, soil samples were taken from the layers 0-30 cm, 30-60 cm and 60-90 cm in order to determine the SMN content (sum of NO_3-N and NH_4-N).

The leachate samples and the soil samples for SMN (extracted with $CaCl_2$) were filtered with nitrogen-free filter paper, then examined with the automatic filter photometer EPOS-Analyzer 5060 (Eppendorf) for nitrate (NO_3) and ammonium (NH_4). Plant available potassium and phosphorus were extracted from air-dried soil samples following the DL-method (double lactate) (Anonymus, 1995). To determine the N yield, the biomass yields of the plots and their respective N contents were recorded. All plant materials were oven-dried at 60°C after sampling. The dried and ground material (<1 mm) was analysed for dry matter content (DM) at 105°C and for total N directly, using macro-N analysis according to Dumas.

The climatic data for the experimental site were obtained from a weather station approximately 5 km away. In both years, the average daily temperatures and the level of precipitation were higher than the long-term average. In particular, the second year was characterised by very high precipitation (Table 2).

The software package SAS (Version 8.1) was used for the statistical evaluation of the data. The test parameters were examined for significant treatment effects by analysis of variance (ANOVA). The data were tested for normality and homogeneity of variances (Webster, 2001). When necessary, a normal distribution and stabilization of the variances could be achieved by logarithmic or square-root transformation of the data. Where significant treatment effects were found by analysis of the transformed or original data, the Student-Newman-Keuls test was used to compare mean values. To make the interpretation

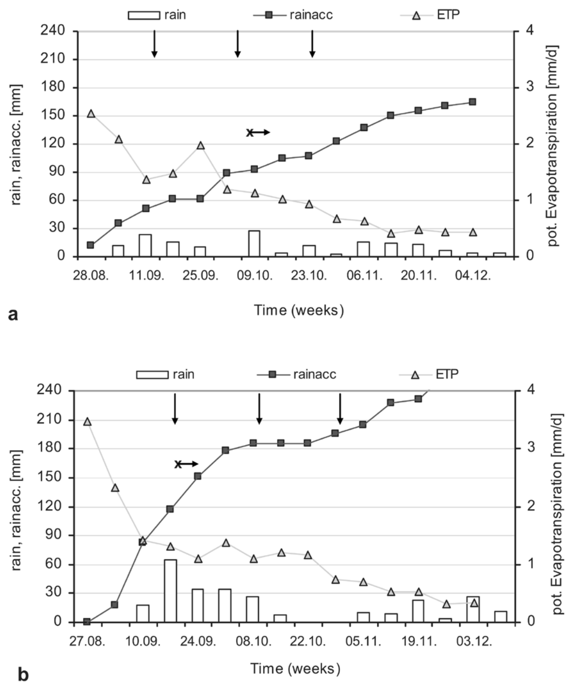

Figure 1 - The precipitation and evaporation from late summer to the end of autumn for the two experimental years; with time of harvesting (↓) and beginning of the leaching period (x→). Weekly values from 20 August of each experimental year, a = first year, b = second year; rain = precipitation [mm]; rainacc. = accumulated precipitation [mm]; ETP = pot. evapotranspiration [mm/d].

Table 3 - Results of the analysis of variance for DM yield, autumn soil mineral nitrogen, nitrate concentration in leaching water and nitrate leaching losses in the leaching period.

Effect	DM yield	Autumn SMN	NO_3-N-concentration	NO_3-N-leaching
	P value			
Year (Y)	0.4982 n.s.	0.0925 n.s.	0.0001 ***	0.0876 n.s.
Row space (R)	0.6951 n.s.	0.2121 n.s.	0.8384 n.s.	0.9515 n.s.
Harvest time (T)	0.0003 ***	0.0001 ***	0.0267 *	0.0233 *
Y*R	0.5097 n.s.	0.9642 n.s.	0.8596 n.s.	0.9066 n.s.
R*T	0.4996 n.s.	0.0866 n.s.	0.7400 n.s.	0.8327 n.s.
Y*T	0.9596 n.s.	0.8191 n.s.	0.8226 n.s.	0.8512 n.s.

of the data easier, arithmetic means of the untransformed data were used in tables and illustrations.

Results

The risk for nitrate leaching during winter seemed to have been also affected by the precipitation and evaporation rate from the time of harvest until leaching commenced. Respective conditions for both years are shown in Figure 1.

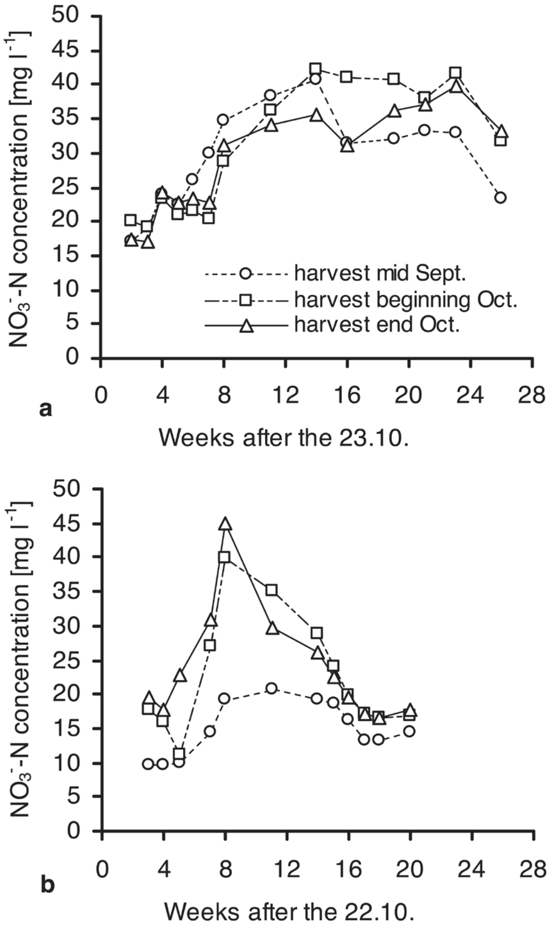

Figure 2 - NO_3-N-concentrations in leaching water after harvest of silage maize as an effect of time of harvest for the two experimental years. a: leaching period in the first year, b: in the second year.

Row distance and harvesting time (Experiment 1)

N concentrations in leachate

Row spacing had no effect on N concentration in leaching water in either year (Table 3). The plots that had been harvested very early showed lower nitrate concentrations during the middle of the first leaching period as well as during all of the leaching period in the second year (Figure 2). Nitrate concentrations during winter differed very little between plots that had been harvested at the common date (Beginning of October) and at the very late time (End of October).

N leaching losses

Row spacing showed no effect on the nitrate leachung losses over winter (Table 3). In contrast to the factor 'Row distance', the harvest time had a significant effect on the N leaching losses. In particular, a very early harvest time in the middle of September was followed by a reduced N leaching during winter (Figure 3). The interaction of the factors 'Row distance' and 'Harvest time' was not significant. This was also reflected in the corresponding soil mineral nitrogen contents in autumn for the different harvesting times (Table 4).

Maize variety (Experiment 2)

N leaching losses

The variety experiment was harvested at the beginning of October at the same time as the middle harvest date of the main experiment. Varieties showed significantly different N leaching, which made up to 30 kg N ha^{-1} during the following leaching period (Table 5).

N yield and N balance

With the exception of the somewhat declining variety "Prinval", DM yield proportions among the varieties were as expected. The tall-growing varieties, Aldus, Baltimore and Asket, showed the largest DM yield, and, due to the comparatively small variations in N content in *Zea mays*, this resulted in larger N offtake with harvested material (N yield). The traditional compact-variety "Mona" as well as "Prinval" had N yields that were about 13 kg N ha^{-1} smaller than that of the high yielding mass varieties. This was reflected in the N field balance (Table 5).

The N balance negatively correlated with the autumn SMN (Table 6). The autumn SMN, on the other hand, only accounted for 27% of the variation of the following N leaching losses during winter.

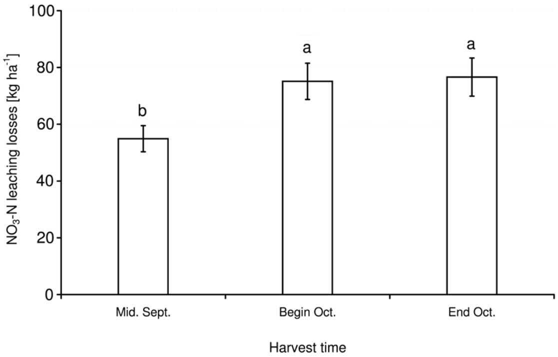

Figure 3 - N leaching losses for silage maize as an effect of the harvest time, averaged over both leaching periods. Error bars = standard error of the mean. Means with the same letter do not differ significantly.

Discussion

Effects of row distance

The results presented here have shown that narrower rows do not necessarily lead to smaller N leaching after harvest when maize plants are equally distributed per m^2. This is in agreement with findings of Barbieri et al (2000) but in contradiction with Aufhammer and Kübler (1997), Anonymus (1998), and Peyker (2001). The latter research, however, did not determine N leaching directly but inferred it from autumn SMN content. To date, research on the effect of row spacing on N leaching in maize cultivation that is based on suction cups or lysimeters is still scarce.

Under the experimental conditions presented here, a small advantage from a more even distribution of plants (narrower row spacing) was observed for SMN in early September, an effect, which, however, reversed as the autumn progressed. A similar result, a turn from lower SMN values under narrow row spacing compared to traditional row spacings of 0.75 m during the summer growing period to significantly higher SMN contents after harvesting, was also observed by Anonymus (1997) and Rieckmann et al (2003). Their experiments on row spacing in maize were also carried out in regions of intensive livestock production in Lower Saxony, Germany.

Obviously, nutrient-rich, deep soils with a high mineralisation potential favour the release of mineralised nitrogen in the soil after the maize harvest. It seems that experiments which indicated smaller nitrate leaching risk after maize with narrow row spacings took place either on relatively shallow soils or on soils with less potential for N mineralisation. Narrow row spacing as a possible means to reduce N leaching requires adapted sowing and harvesting technique. While narrow sowing machines even offer economical advantages and row independent harvest techniques for silage maize are available, there is still need to optimize corn harvest as well (Peyker et al, 2008).

Effect of harvest time

Until now, the effect of the harvest time on the nitrate leaching has not received much attention by research. Experiences by farmers and experimentation of extension services suggested that the ripening stage of maize at harvest could help to explain the wide range of residual SMN after maize harvest, especially on soils with a good mineralisation potential. This was confirmed by the results presented here. We found that nitrate leaching was smaller after an early harvest of a then still premature crop whereas a later harvest of a slowly ripening maize crop was followed by an increased nitrate leaching. Various aspects need to be considered to explain these findings.

The time of harvest is likely to affect the decomposition of maize residues. The release of mineral nitrogen from the rooting zone is generally expected to be higher at earlier harvest; however, this did not occur in our investigation. In contrast, a later harvest led to increased SMN values in the soil. Maize residues have been shown to have a relatively wide C:N ratio which makes a rapid decomposition after the harvest unlikely (Balesdent and Balabane, 1996). Likewise, John et al (2004) did not find any priming effect from maize residues which could explain larger SMN after late harvest. Thus, we might assume that the effects on SMN were not caused by dead roots and residues, but from the living, photosynthetically active maize plant, and that physiological processes contributed to increased mineral nitrogen contents in soil.

Weed infestation of the maize crop and after the harvest of maize could have affected SMN content in autumn as well. However, differences in plant N uptake caused by weed growth can be ruled out for an explanation of harvest time effects on SMN and N leaching losses. In fact, the early harvested plots did not indicate any particularly strong weed growth in both years after harvesting of the maize.

Table 4 - Autumn SMN content (0-90 cm soil depth) after silage maize harvest in both experimental years as an effect of harvest time (means and standard errors).

Harvest time	First year (1 Nov) SMN [kg ha^{-1}]		Second year (31 Oct) SMN [kg ha^{-1}]	
Mid September	69.9	(6.4)	64.4	(5.5)
Beginning of October	105.7	(11.6)	91.1	(6.0)
End of October	99.4	(7.7)	89.0	(5.3)

Table 5 - Dry matter yields, N yields and N balances as well as SMN in autumn and N leaching losses of different silage maize varieties as averaged over both experimental years (means with standard errors).

	DM yield† [dt ha-1]	N yield [kg N ha-1]	N balance‡ [kg N ha-1]	Autumn SMN [kg N ha-1]	N leaching losses [kg N ha-1]
Asket	125.3 (4.52) ba	144.8 (9.38)	8.8 (6.39)	77.7 (6.23)	60.0 (3.85) ba
Prinval	116.3 (7.38) ba	136.2 (10.85)	17.4 (8.40)	87.6 (15.05)	69.3 (9.02) ba
Baltimore	130.8 (5.93) a	149.8 (9.49)	3.7 (7.70)	72.3 (6.65)	58.6 (5.27) ba
Mona	107.1 (8.40) b	137.0 (14.45)	16.6 (11.04)	78.0 (5.00)	51.1 (7.43) b
Aldus	130.2 (4.89) a	150.6 (9.04)	3.0 (7.89)	89.5 (8.44)	76.9 (8.79) a

†different letters indicate significant differences at P<0.05 (SNK test)
‡simplified N field balance (spring SMN + fertilizer - N minus N yield)

The conditions for soil mineralization such as soil moisture, temperature, and aeration could have had a strong effect on the nitrogen release under the growing maize crop and after harvest. In our experiment, however, nothing indicated that these factors contributed significantly to treatment effects. One might assume that soil conditions under growing maize (late harvest) for the period between the first and last harvest, were more favourable for mineralization. However, this did not seem likely as firstly, there were no differences in the gravimetric soil moisture in the SMN samples between harvest dates, and secondly, as higher soil temperatures, that would actually promote mineralization, can not be assumed under the shading maize stands. Similarly, conditions affecting soil aeration were not necessarily favourable under late harvested crops. The effects of reduced SMN and leaching losses at earlier harvest stages seem to be too pronounced, especially as we are dealing with adequately loosened and biologically active topsoil, which was not greatly compressed or in any way structurally damaged.

Explanations which include an active involvement of the living maize plant are, therefore, more probable. Particularly high N leaching occurred when maize crops with only a small potential for increase in starch content remained in a living state until the harvest, i.e. without external signs of senescence. Such a combination of effects was particularly pronounced in the second experimental year, when already at the time of the second harvest, a total dry mass of 35% (previous year 24%) was reached. In comparison the early harvest time, with a dry weight content in the whole plant of 20% (first year) and 25% (second year), showed significantly lower amounts of residual SMN and N leaching losses. This explanation receives support from the results of the variety experiments, which showed that a long period of photosynthetic activity in the ripening phase, when no significant N uptake occurs, resulted in an increased autumn SMN content and potentially larger N leaching. Cultivation of varieties with early ripening of the residual plant, which is only partly reflected in the dry matter content of the whole plant due to differences in the cob proportion and corn ripening, resulted in smaller N leaching losses.

The details of the proposed interaction between maize plant and soil are still subject of further research. Our findings indicate that this is necessary and that attempts to explain the described effects only based on crop stand effects, while disregarding the active role of the maize plants, are less conclusive.

The release of easily available C sources in root exudations, as generally described by Grayston et al (1996), Kuzyakov and Domanski (2000), and Kuzyakov (2002) might contribute to differences in N mineralization. According to Qian et al (1997) it is quite likely that N turnover in soil is increased by C sources from maize roots. The amount and quality of this rhizodeposition has been shown to depend on photosynthetic activity of the maize plant (Melnitchouk et al, 2005).

Effects of different types of variety

The variety ‘Mona’ of the older breeding generation characterised by relatively fast ripening plants and early senescence showed the lowest N leaching losses. The next variety ’Baltimore’ has a higher yield potential and shows fast ripening. However, the highest N leaching losses were found for tall growing varieties of the stay-green-type, which were still physiologically active at harvest time. This indicates a relationship between the stage of physiological ripening, typical for the variety at harvest time, and N leaching. Leaching losses were smaller when ripening of the whole plant was advanced. To underpin this finding, further research should include a larger number of genotypes representing the phenotype groups.

To date, we do not know of other experiments which consider the influence of variety on N leaching. There are, however, a series of investigations by breeders aimed at improving the N utilisation of maize, which are confined to parameters of N efficiency related to yield building (Bertin and Gallais, 2000; Thiemt, 2002; Presterl et al, 2003).

It is confirmed that low-input varieties such as ‘Asket’ have an improved utilisation of soil N (Presterl and Thiemt, 1999). However, in the experiments presented here, this ability did not necessarily lead

Table 6 - Correlation coefficients for DM yield, N balance and SMN in autumn (r = correlation coefficient [Pearson], n = 44, data from both experimental years at plot level).

	N yield	Autumn SMN	N leaching losses
DM yield	+0.84***	.	.
N balance	.	-0.43***	-0.58***
Autumn SMN	.	.	+0.52***

to lower autumn SMN as well. Only when comparing with large-frame varieties of a similar phenotype ('Prinval' versus 'Aldus') there appears to be a tendency to smaller N leaching, although this cannot be statistically confirmed.

Muruli and Paulsen (1981), Bertin and Gallais (2000), and Presterl et al (2003) state that maize hybrids, selected under low-input conditions for N efficiency, do not always show a markedly improved N utilisation under conditions of excess N. Wang et al (2004) see the main reason for this in N-induced differences in root development. In the experiments presented here, however, the interaction of maize plants with the soil conditions, which was not considered in the above mentioned research, could well be responsible for the findings.

Contrary to the findings of Büchter et al (2003), the N field balance in our experiment could not adequately predict the amount of N leaching over winter. Prediction could not be improved by considering the spring SMN in the balance, or, as Büchter et al (2003) did, include an estimation of N deposition to the N input.

This implies that a simplified modelling of N flows at the field scale will not sufficiently picture the actual processes when the interactions with the soil N pool are not considered. This applies especially to the typically easily mineralized soils in northwest Germany in regions with a high livestock density. Consequently, simple field balances can lead to misjudgements about the potential risks of N leaching to the groundwater. The limitations of field balances are highlighted in the results of the variety experiment, in which the N offtake with harvested maize was even significantly negatively correlated with both, the autumn SMN and N leaching. This relationship is mainly due to the higher N uptake of the tall-growing, late-ripening varieties, and can therefore be better interpreted as a consequence of the phenotype effect – there is an increased risk of higher N leaching when there are longer periods of active photosynthesis of maize in autumn.

Interactions of soil and plant effects

The phenomenon that harvest time and the physiological state of the plant at harvesting contribute to varying N leaching has not been described until now, and the effects may well relate to an interaction of the maize plant with organic soil substances.

The combination of late-ripening, photosynthetically active maize plants with harvest times at which soil water content has already reached field capacity, seems to be particularly critical and might lead to larger residual SMN after harvesting and an increased risk of N leaching.

The interaction of row spacing effects and variety, as proposed by Peyker (2001) could not directly be confirmed in our experiments, as we included each factor in a separate experiment. However, considering the marked effects of variety, it appears that our results support Peykers (2001) statement after all. Further research into this is necessary and should include a range of locations and differing soil conditions, especially as some authors have not found any interaction between row spacing and the level of N supply, with respect to nitrogen utilization (Cox and Cherney, 2001; Ma et al, 2003). The aim is to optimize the effects of different row spacing on N leaching for different soils and varieties by examining in more detail the possible interactions.

Conclusions

The results of both experiments demonstrate that on soils with a high mineralization potential, management options besides fertilization, here the choice of harvest time and variety, can help to reduce N leaching losses after harvest of silage maize; reductions can be as high as 30 kg N ha^{-1}. Thus, the choice of harvest time and variety are useful to complement already established management measures in maize cultivation, which aim at reducing the risk of N leaching, such as under–sowing of catch crops and narrow row planting.

There is a need for further, more detailed investigations on the topic which should include different soils and sites. Possible interactions of the factors need to be explored and should include investigations on plant-soil processes. Particularly sites with a high mineralisation potential show increased SMN at the beginning of the winter leaching period. From an environmental point of view the suitability of maize on these sites, even when moderate N fertilizer levels are adapted, is questioned. This is especially the case in areas of high livestock density with a high proportion of maize cultivation that characterizes agricultural use in a broad belt in northwest Europe stretching from Denmark to the north of France.

There remains, therefore, an important task in order to reduce large N losses often coupled with maize cultivation, to explore fertilizer-independent options and to integrate these options into current cultivation practices.

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