Integrating maize and triticale in grass/clover based dairy systems: examining yields and autumn soil nitrate levels

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Abstract

To establish N-efficient crop rotations with perennial ryegrass/white clover, maize and triticale, a 9-year field experiment was executed on an organic experimental farm in the Netherlands. Crop rotations with different levels of slurry (dairy effluent from the free-stall barn, average dry matter content of 7%) application were tested for dry matter (DM) yield, N yield, soil mineral N in autumn, soil organic matter and soil organic N. Maize cropping and slurry application both increased annual DM yield. However, the second year of grass/clover following maize, maize itself and slurry applications each resulted in higher soil mineral N in autumn, increasing the risk of nitrate leaching losses. A rotation of 4 years of grass/clover, 2 years of maize and 1 year of triticale resulted in relatively high average annual DM production (12 t DM/ha/year) for Dutch conditions, with a higher potential N leaching loss in 2 out of 7 years.

Keywords: crop rotation, grass clover, maize, triticale, N efficiency, soil mineral N

Introduction

Urinary nitrogen (N) excretion is seen as the largest contributor to nitrate leaching in pastoral dairy farming (Di & Cameron 2002). Feeding supplements with a lower N content than grass/clover reduces nitrogen (N) intake by grazing dairy cows and reduces urinary N excretion, but growing these supplements in pastoral systems often increases N leaching per hectare compared to permanent pasture (Williams *et al*. 2007). When pasture is cultivated to establish a crop, the mineralising sward adds to the soil mineral N pool (Silgram & Shepherd 1999) which is prone to N leaching when drainage occurs. An example for sandy soils in northwest Germany is given by Kayser *et al.* (2008): permanent pasture + 160 kg N fertiliser/ha/year resulted on average in 26 kg mineral N/ha in autumn and 8 kg NO_3-N/ha leached. Spring cultivation of pasture that received 120 kg N/ha and was >15 years old and growing one season of an unfertilised maize crop, resulted in 113 kg mineral N/ha in autumn and 118 kg NO_3-N/ha leached.

To investigate the N efficiency and dry matter (DM) production of crop rotations involving grass/clover, maize and winter triticale, a 9-year field experiment was carried out in The Netherlands (De Boer *et al.* 2012). The effects of the number of years in grass/clover and 1 or 2 years of maize cropping were measured. Furthermore, different strategies for slurry application were examined. By limiting the N input to a maximum of 120 kg N/ha/year from slurry only (no grazing and no fertiliser N), considerable N fixation by clover could be expected. Soil organic matter, soil organic N and soil mineral N were monitored to establish if this N input was sufficient to maintain soil fertility.

Methods

A replicated (n=3) randomised block experiment was carried out from 2002 to 2010 at the organic experimental farm Aver Heino (Heino, The Netherlands). One replicate was situated on an elevated Plaggic Anthrosol, with an A-horizon of 80 to 100 cm (organic matter content at the start of the experiment of 6.0%). The other two replicates were situated on a humus rich, hydromorphic, sandy soil, with one replicate on a coarser sand than the other. The organic matter content of these soils was 4.7% at the start of the experiment. Other soil fertility parameters were similar for the three replicates, with with PAL (phosphate in ammonium lactate-acetic acid extracts of soils, a measure of plant available phosphate) on average 45 mg P_2O_5/100 g dry soil (i.e., more than sufficient, but not high), P-total 144 mg P_2O_5/100 g dry soil, and N-total 2.52 g/kg dry soil.

The treatments consisted of all combinations of six crop rotation schemes and four slurry application strategies (Table 1). Existing perennial ryegrass (*Lolium perenne*) /white clover (*Trifolium repens*) pasture was ploughed to establish the plots. Individual plots were 15 × 6 m. To reduce the likelihood of confounding the effects of crop rotation with weather conditions in any year, and to reduce the effects of the original pasture, the starting year selected for the first replication was year 4 of the crop rotation scheme, for the second replication year 5 and for the third replication year 6.

Maize was sown at 9–10 plants/m^2 following harvest and cultivation of grass/clover (first-year maize) or cultivation of a green manure crop (second-year maize). The first triticale plots were sown in autumn 2001 after cultivating and ploughing the existing grass/clover. From 2002 onwards, triticale was always sown after the maize harvest. Triticale was sown at 150 to 200 kg seed/ha.

No chemical weed or pest control was used during the experiment. Most of the weeds in pasture (mainly *Stellaria media* and *Taraxacum officinale*) were removed with the first harvest. Weeds in maize and triticale (notably *Echinochloa crus-galli*) were controlled with mechanical methods. Plots sown with maize experienced predation from pigeons on the seeds and seedlings, especially from 2005 onwards. Maize plants also suffered feeding damage caused by larvae of the click beetle (*Agriotes obscurus*). In both instances plants lost were re-sown where possible.

Slurry was sampled each year for analysis of chemical composition, and applied to the applicable plots at a rate of 120 kg N/ha (Table 1). The average composition of the slurry was 7.1% DM, organic matter 53 g/kg product, N-total 3.3 g /kg and P$_2$O$_5$ 1.2 g/kg. A sward injector was used on grass/clover and an injector on maize and triticale. On the grass/clover and triticale plots, slurry was applied as soon as the soils were dry enough to allow machinery on in early spring. First-year maize was grown following harvest and cultivation of grass/clover in spring; the slurry was applied on the grass/clover in early spring. For second-year maize, slurry was applied just before sowing, after cultivation of the green manure crop.

All treatments received P and K fertiliser in surplus of the annual P and K uptake by the crops, taking approximately 40 kg P$_2$O$_5$ and 180 kg K$_2$O/ha/year from slurry into account where this was applied. Soil pH-KCl was on average 4.7 in 2004 and 5.2 in 2008. Lime was applied to all plots in the autumns of 2005 (1400 kg/ha Dologran 15 (54% CaO), 2006 (1200 kg/ha) and 2009 (1400 kg/ha).

Every second year, starting from 2002, soil organic matter content and soil organic N content of each plot were assessed by taking six random soil cores per plot each spring and in autumn 2010 when the experiment was terminated. Each year, soil cores were taken from each plot in autumn (once maize was harvested) to determine soil mineral N (N-NH$_4$ and N-NO$_3$). Sampled soil layers were 0–30, 30–60 and 60–90 cm.

Maize and triticale were harvested at dough-stage (grains containing 30–35% DM) at 15 cm stubble height. Total N content of all harvested material was determined.

Data were log normal transformed and analysed using

Table 1. Treatments used in the nine-year experiment. All combinations of six crop rotation schemes (a) and four slurry treatments (b) were used, thus resulting in 24 plots per replicate. Treatments (crop rotation x slurry) were fully randomised.

a)   Crop rotation schemes, with Year 1 (Y1) being the first year of the rotation. G = grass/clover, being a mixture of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*); M = maize; T = winter triticale. To minimise confounding with weather conditions in any year, and effects of the original grass/clover sward, Replicate 1 started in 2002 with Y4 of all sequences, Replicate 2 with Y5 and Replicate 3 with Y6.
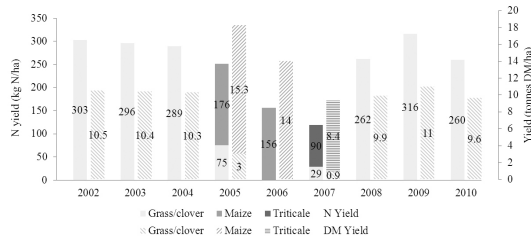
Crop rotation	*Year*								
	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9
G2M1	G	G	M	T	G	G	M	T	G
G2M2	G	G	M[1]	M	T	G	G	M	M
G3M1	G	G	G	M	T	G	G	G	M
G3M2	G	G	G	M[1]	M	T	G	G	G
G4M1	G	G	G	G	M	T	G	G	G
G4M2	G	G	G	G	M[1]	M	T	G	G

[1] First-year maize was sown following harvest and cultivation of grass/clover in spring; when maize was grown in two consecutive years, a green manure crop (either winter rye or a rye/Italian ryegrass mix) was sown after the first year maize.

b) Slurry application strategies and the amount of N applied (kg total N/ha/year).

Slurry application strategy	*Crop*	
	Grass/clover	Maize or triticale
S1	0	0
S2	0	120[1]
S3	120	0
S4	120	120[1]

[1] For the first-year maize crop, slurry was applied in early spring, before grass/clover was harvested and cultivated.

Figure 1   Annual DM yield (kg DM/ha) and N yield (kg N/ha) of grass/clover, maize and triticale in consecutive years in treatment G3M2S4, with 2002 being the first year of the crop rotation. Fitted values are given.

REML (Genstat 2012). The fixed model terms were *crop* (first-, second-, third- or fourth-year grass/clover, grass/clover before maize, first- or second-year maize, triticale, grass/clover after triticale); *slurry application*; *vyear* being the year as a variate to assess trends; for DM and N yield also *harvest number* of grass/clover (first to fifth cut); for soil properties also *soil layer*; and all interactions. Individual terms were sequentially dropped from the model when not significantly adding to variance accounted for. The resulting fixed models were used to calculate the fitted values reported. The random models consisted of replicate, calendar year, harvest number, plot number and their interactions.

Significant treatment effects ($P<0.05$) are reported on log normal scale, with the standard error (for variates) or standard error of the difference (for factors). To illustrate the effects, treatment means were calculated using the fixed models and back-transformed to enable reporting in the original units. Further details of the

treatments and statistical analysis are given in De Boer *et al.* (2012).

Results

Grass/clover as a main crop yielded between 6.6 and 10.8 tonnes DM/ha/year, maize yielded between 11.6 and 15.3 tonnes DM/ha/year and triticale between 5.8 and 8.4 tonnes DM/ha/year. When maize was grown after grass/clover, 2–3 tonnes DM/ha of grass/clover was harvested before maize was sown. Following triticale, grass/clover was sown and resulted in 0.6 to 0.9 tonnes DM/ha of grass/clover in the same season.

Yields, N-yields as well as soil mineral N levels in autumn declined significantly over time for all treatments (Table 2). This decline was least prominent when slurry was applied in each year (S4), and intermediate results were seen when slurry was applied to either grass/clover or to maize and triticale (S3 or S2; Table 2).

When grass/clover followed maize and triticale, the annual DM yield, N yield and soil mineral N were higher for the second year grass/clover than for the first year grass/clover. Annual DM yield and N yields for the third and fourth years were similar to that of the first year. Soil mineral N in autumn was still elevated in the third year (Table 3).

While maize yielded more DM, the N yield was lower than for grass/clover (Figure 1), reflecting the lower N content of maize compared to grass/clover.

Soil mineral N in autumn (0–90 cm) was relatively low following grass/clover (below 30 kg N/ha) and triticale, and significantly higher following maize (40–60 kg N/ha). While the soil mineral N levels for maize were lower in the deeper soil layers (30–60 and 60–90

Table 2   Trends in time (*vyear*) for annual DM yield (tonnes DM/ha), annual N yield (kg N/ha) and soil mineral N in autumn (0–90 cm; kg N/ha), and their interactions with slurry treatment. Effects are given on log normal scale. SE = standard error; SED = standard error of the differences.

	vyear	SE			
Total yield	-0.053	0.019			
Total N-yield	-0.070	0.021			
Soil mineral N	-0.084	0.027			
vyear.Slurry treatment	**S1**	**S2**	**S3**	**S4**	**SED**
Total yield	0	0.009	0.013	0.021	0.004
Total N-yield	0	0.012	0.010	0.022	0.005
Soil mineral N	0	0.014	0.015	0.022	0.007

Table 3   Effects of consecutive years of grass/clover on annual DM yield (tonnes DM/ha), annual N yield (kg N/ha) and soil mineral N in autumn (0–90 cm; kg N/ha). Effects are given on log normal scale. SE = standard error.

Grass/clover year	1st	2nd	SE	3rd	SE	4th	SE
Yield	0	0.110	0.039	-0.013	0.048	-0.118	0.066
N-yield	0	0.214	0.050	0.043	0.064	-0.137	0.087
Soil mineral N	0	0.252	0.081	0.214	0.102	0.100	0.142

cm), for triticale these were higher than for the top layer of 0–30 cm (Table 4).

There were no significant treatment effects on soil organic matter and soil organic N, nor were there significant changes over time.

Discussion

The treatments implemented in the experiment did not maintain the yields experienced in the first year of the experiment: both DM and N yields decreased over time, even when the crop rotation included 4 years of grass/clover and 120 kg N/ha/year as slurry. Indeed the trend in time (*vyear*) was negative for soil mineral N, and was not completely offset by slurry applications (Table 2), and no interaction between the trend in time and number of years of grass/clover was apparent. Treatment effects on soil organic matter and soil organic N were not significant, due to high variability seen in these parameters. Some factors may have inhibited growth or N fixation by clover, and, therefore, reduced total yield, e.g., a sub-optimal pH, molybdenum deficiency or soil-borne pathogens. Sub-optimal pH was corrected at several occasions with lime applications. Low molybdenum levels were measured in grass/clover in one replicate throughout 2002 (1.2 mg Mo/kg DM for S1 and 1.6 mg Mo/kg DM for S4). In 2009, paddocks adjacent to the experiment were sampled for nematodes, but no infestation was found.

In this experiment, grass/clover was cut and carried away from the plots. This is comparable to the management on a support block where grass/clover is mown to be ensiled and fed out elsewhere. In that case, it is likely that nutrients will need to be returned to maintain soil fertility by applying fertiliser, effluent from the milking platform or manure from wintering facilities. On a milking platform, where grass/clover is intensively grazed, N will be returned via excreta of the grazing animals, and in many cases also by applying effluent, resulting in a lower risk of depleting soil mineral N or organic N.

Maize yielded considerably more DM than grass/clover, increasing the total DM yield of a system including maize in the rotation. However, the residual soil mineral N content in autumn was higher than for grass/clover, increasing the risk of nitrate leaching in autumn and winter. Betteridge *et al*. (2007) indeed report much higher N leaching for maize than for pasture in New Zealand. In the current experiment, also in the absence of slurry application, it took two years of cropping before the soil mineral N levels in autumn were at or below the original level of the grass/clover that preceded the crop. Mineralised N from a cultivated grass/clover sward could sustain two years of maize crop in the current experiment, without the need for fertiliser or slurry N to maintain the maize DM yields. Johnstone *et al*. (2010) reported similar results for New Zealand conditions, and concluded that in many cases no fertiliser N would be required in 2 years of maize following grass/clover. Annual DM yield of maize in the current experiment was much lower than reported by Johnstone *et al*. (2010). This was mainly due to climatic differences between The Netherlands and New Zealand, but it was also lower than Dutch conventional farms can achieve (Van Schooten *et al*. 2012). With the organic management practices on Aver Heino, N applied would have been lower than for conventional systems; also seed was not treated against bird predation, and no chemical weed or pest control was used. Furthermore, soil pH was below optimum for maize, despite the liming.

Both triticale and maize have a lower N content than

Table 4 Effects of crop type and soil layer (a) and their interaction (b) on soil mineral N in autumn (0–90 cm; kg N/ha). Effects are given on log normal scale. SED = standard error of differences.

a) Main effects of soil layer and crop type

	Crop	Grass/clover	Maize	Triticale	SED
Soil layer	0-30 cm	0	1.062	0.074	0.113
	30-60 cm	-0.460			
	60-90 cm	-0.575			
	SED	0.185			

b) Interaction soil layer × crop type

	Crop	Grass/clover	Maize	Triticale	SED
Soil layer	0-30 cm	0	0	0	0
	30-60 cm	0	-0.220	0.533	0.129
	60-90 cm	0	-0.342	0.661	0.129

grass/clover (Figure 1) and will result in a lower N intake of animals than when grass/clover is consumed. A reduction in N intake may decrease urinary N excretion and therefore the risk of N leaching from urine patches (Mulligan *et al.* 2004).

To determine the optimal crop rotation for a dairy farm, the annual feed requirements need to be taken into account, as well as the area suitable for crop rotations. In the current experiment, maximal yields were achieved with G3M2S4 and G4M2S4. An additional year in grass/clover would extend the period of time with lower nitrate leaching risk and reduced the costs of cropping and pasture renewal. Hence, when supplements with relatively low N content are desirable and the farm is suitable for cropping, the G4M2 combination results in high yields, relatively low cost and an elevated risk of N leaching loss in only 2 out of 7 years.

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