Nitrogen fertilization and utilization of sorghum as an extra forage crop on dairy farms

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Abstract

Sorghum may have potential as an extra forage crop on dairy farms. It can be an addition to the crop rotation with maize and grass-clover leys, in order to prevent disadvantages of continuous maize cropping. However, concerning the cultivation of sorghum, questions arise around fertilization and nitrate leaching caused by residual mineral nitrogen (N) after harvest. Therefore, in 2018 and 2019, we performed experiments to quantify N utilization of sorghum and to estimate optimal N fertilization, including the risk of nitrate leaching. Two types of sorghum (a type high in starch (ST) with a potential for high starch content and type high in fibre (FT) with high cell wall content) and maize (reference) were compared, each with three levels of N fertilization (0, 70, 140 kg N ha^{-1}). In both years, dry matter (DM) and N yield were highest in maize (P<0.001; up to 6 t ha^{-1} more DM yield for maize than for ST or FT). The two sorghum types differed in N response: FT showed an N response, whereas ST did not. The type high in fibre had the lowest residual N in the soil after harvest (P<0.001; up to 40 kg ha^{-1} less residual N on FT plots), indicating a possible reduction of nitrate leaching. Optimal level of fertilization was expected to be lower for sorghum than for maize. A relatively high yield of ST under N limitation indicates that sorghum cultivation is possible on relatively poor soils. In conclusion, because of the low required N inputs and the potentially reduced risk on nitrate leaching, sorghum is a promising crop to extend crops rotations on dairy farms.

Keywords: sorghum, mineral nitrogen, fertilization, yield, nitrate leaching

Introduction

Sorghum, a crop originating from the African continent, may have potential as an extra forage crop in dairy farming in temperate regions of western Europe. It can be added in crop rotations with maize and grass clover leys and in that way prevent the disadvantages of continuous maize cultivation, such as a decrease of organic matter in soils, soil compaction, plant-related diseases and high water and nutrient inputs. Sorghum has been shown to be more tolerant to water shortages (Lemaire *et al.*, 2006), has a high nitrogen (N) usage efficiency (Thievierge *et al.*, 2015) and it may positively affect organic matter accumulation in soils (as compared to maize) (Schittenhelm and Schroetter, 2014). For dairy farming, two types of sorghum are available, a type with potential for high starch content (ST); *Sorghum bicolor*), and a type rich in fibre (FT), with high cell wall content; *Sorghum sudanense*). The type with high starch content has a plant height of 100-140 cm and a relatively high grain yield, whereas FT has a plant height of 200-300 cm and a lower grain yield. From nutritional point of view, sorghum silage can (partly) replace maize silage in the diet of ruminants.

Even though the cultivation, harvest and ensiling of sorghum have similarities with the cultivation of maize, many questions remain concerning fertilization and nutrient leaching of sorghum cultivated in the temperate regions of western Europe. Therefore, in 2018 and 2019 we performed experiments to quantify the nitrogen (N) utilization of sorghum and to estimate the optimal N fertilization, including the risk of nitrate leaching. Results were analysed with a two-way ANOVA with the statistical package R.

Material and methods

A field experiment was implemented in Moergestel on a field with a sandy soil and a history of long-term arable land use. Two types of sorghum were compared with maize: ST (cultivar C7) and FT (cultivar NutriHoney in 2018 and cultivar Suzy in 2019). Three levels of N fertilization (0, 70 and 140 kg N ha^{-1}, applied as calcium ammonium nitrate, CAN) were tested in four randomised replicates, adding up to 36 experimental field plots. Each of the 36 experimental plots was 3.5 m wide and 5 m long and had 7 rows of sorghum or maize with a distance of 50 cm between the rows. In both years, plants were sown in May. Plant density was 110,000 plants ha^{-1} for maize and 225,000 plants ha^{-1} for sorghum.

In both years the crops were harvested in September. On every plot, 3 rows of 3 metres were harvested. Subsamples of the biomass yield of each plot were sent to a laboratory (Eurofins) to analyse dry matter (ISO 6496), ash content (ISO 5984), nitrogen (Kjeldahl method, ISO 5983), sugars (Luff-Schoorl method, NEN3571: 1947nl), starch (amyloglucosidase method, ISO 15914) and digestibility of organic matter (based on Tilley and Terry, 1963). Furthermore, directly after harvest, soil samples (0-90 cm) were taken to analyse residual mineral N as an indication of potential nitrate leaching.

Results and discussion

In both years, dry matter and N yield was highest in the fertilized maize plots. Without fertilization, in 2018 ST had the highest N-yield (Table 1). The two sorghum types differed in N response: ST did not, or hardly, result in extra yield with higher N fertilization, but FT did show an N response (Table 1). Maize and FT both had a higher N yield with higher N fertilization, but for ST this response was observed only in 2018. As a result, residual N after harvest was higher in ST, especially in 2019 (Table 1). The fibre type had the lowest values for residual mineral N in the soil after harvest, despite a lower N yield.

Digestibility of organic matter and starch concentration were highest in maize and lowest in FT (Table 2). Sugar concentration was highest in the FT, and in 2018 the N concentration was higher in the ST (Table 2). In 2019 no differences in N concentrations were observed. Differences between years might have been caused by weather conditions. For FT, different varieties were used in 2018 and in 2019, which may also have caused differences, for example in starch content.

Table 1. Yield, N-mineral in the soil and N yield with different fertilization levels in 2018 and 2019.

Crop	**Maize**			**Sorghum C7 (ST)**			**Sorghum Nutrihoney / Suzy (FT)**			***P*-values**		
N application (kg ha^{-1})	**0**	**70**	**140**	**0**	**70**	**140**	**0**	**70**	**140**	**Crop**	**N appl.**	**Crop×N**
2018												
Yield (t DM ha^{-1})	13.4	19.0	21.1	12.4	13.2	14.6	10.8	15.7	15.3	<0.001	<0.001	0.1
Residual N (kg N ha^{-1})	19	21	31	18	26	59	10	12	29	<0.001	<0.001	0.018
AEN[1] (kg DM kg N^{-1})	n.a.	80	29	n.a.	11	20	n.a.	69	0	n.a.	n.a.	n.a.
N yield (kg N ha^{-1})	114	184	239	126	151	194	92	159	192	0.015	<0.001	ns
2019												
N application (kg ha^{-1})	0	60	120	0	60	120	0	60	120	Crop	N appl.	Crop×N
Yield (t DM ha^{-1})	14.6	17.7	16.9	10.8	9.8	10.2	10.7	11.3	13.7	<0.001	<0.03	<0.03
Residual N (kg N ha^{-1})	34	47	53	32	56	76	27	38	34	<0.001	<0.001	<0.01
AEN[1] (kg DM kg N^{-1})	n.a.	52	0	n.a.	0	0	n.a.	10	40	n.a.	n.a.	n.a.
N yield (kg N ha^{-1})	147	251	196	118	97	101	80	97	167	<0.01	<0.001	ns

[1] AEN = agromic efficiency of applied nitrogen; DM = dry matter.

Table 2. Nutritional value with different fertilization levels in 2018 and 2019.[1]

	Maize			Sorghum C7 (ST)			Sorghum Nutrihoney / Suzy (FT)			*P*-values		
2018												
N application (kg ha^{-1})	0	70	140	0	70	140	0	70	140	Crop	N-appl.	Crop×N
Digestibility OM (%)	81	80	80	71	71	70	65	65	65	<0.001	ns	ns
Starch (g kg ds^{-1})	339	369	388	326	311	313	198	268	242	<0.001	ns	ns
Sugars (g kg DM^{-1})	97	74	77	51	60	68	119	85	77	<0.001	ns	0.037
N (g kg DM^{-1})	8	10	11	10	11	13	8	10	13	<0.001	<0.001	ns
2019												
N application (kg ha^{-1})	0	60	120	0	60	120	0	60	120	Crop	N-appl.	Crop×N
Digestibility OM (%)	77	77	77	66	68	68	60	58	60	<0.001	ns	ns
Starch (g kg ds^{-1})	432	457	449	296	310	317	133	98	145	<0.001	ns	ns
Sugars (g kg dm^{-1})	35	27	33	56	56	56	71	81	68	<0.001	ns	ns
N (g kg dm^{-1})	10	14	12	11	10	10	8	9	12	ns	ns	ns

[1] OM = organic matter; DM = dry matter.

The optimal level of N-fertilization was found to be lower for sorghum than for maize. The lower residual N in the soil after harvest on the FT plots indicates a possible reduction of nitrate leaching. The lack of response to N fertilization of ST coincided with a relatively high yield under N limitation, leading to the conclusion that sorghum cultivation is possible on relatively poor soils. The nutritional value of sorghum may be lower than the nutritional value of maize, but thanks to the low N inputs and low residual mineral N in the soil, sorghum has potential as an extra crop in dairy farming.

Conclusions

This study has shown that the N requirements of sorghum differ from the N requirements of maize, and that N fertilization of sorghum should thus be lower than of maize. The lack of response to N fertilization coincided with a relatively high yield under N limitation, leading to the conclusion that sorghum cultivation is possible on relatively poor soils. In conclusion, because of the low required N inputs and the reduced risk on nitrate leaching, sorghum is a promising crop to extend crops rotations.

Acknowledgements

This research was funded by the province of North Brabant.

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Volume 28
Grassland Science in Europe