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Nitrogen efficiency of Brussels sprouts under different organic N fertilization rates

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ABSTRACT

The identification of nitrogen efficient varieties is important to improve yielding abilities in organic farming systems which are usually N-limited. This holds true particularly for crops with a long growing period and high nitrogen demand such as Brussels sprouts.

Two field experiments with two different fertilizer levels were conducted on a hapludalf soil under the conditions of organic farming. Ten Brussels sprouts varieties with different growing periods were evaluated.

For N accumulation efficiency differences between cultivars were not consistent over both experimental years, but similar under different levels of nitrogen supply. An allometric relationship between bud dry matter and total plant nitrogen accumulation comprising all varieties in both years and both fertilizer levels explained 56% of the total variation. Additionally, nitrogen utilization efficiency (NUE) was influenced by bud nitrogen content and harvest index. We found different relationships between bud dry matter and bud nitrogen with contrasting bud nitrogen percentage between years. However, relating bud nitrogen to total aboveground N again gave a linear relationship unifying all factors. Harvest index was linearly related to NUE indicating that dry matter partitioning is a major determinant of NUE. Varietal differences in NUE differed between years. Within years, yields of individual cultivars grown under different nitrogen levels were linearly related. We conclude that nitrogen accumulation in buds is environmentally stable, whereas dry matter partitioning into the same organs is more variable. Apparently, varieties performing well under high nitrogen supply yield also high under limited nitrogen. Further investigations are needed since the large genotypic variation between years is not fully understood.

1. Introduction

Besides reduced pest and weed control options, limited nitrogen availability is a major yield constraint in organic farming (Doltra et al., 2011). Organic farmers have to ensure the availability of nitrogen by good cultivation management to reach adequate yields (Dawson et al., 2008). Particularly crops with a long growing period like Brussels sprouts (*Brassica oleracea L.* var. *gemmifera* DC) have a high nitrogen demand (Fink and Feller, 2001). Consequences of nitrogen limitations are fluctuating yields and quality defects (Hochmuth, 1992).

Strategies to match nitrogen availability and requirement have to be developed (Pang and Letey, 2000). The utilization of the available soil nitrogen is of foremost importance because nitrogen input into organic farming systems is restricted (EU, 2007). Thus, the identification of N-efficient varieties becomes an important tool to improve yield levels and yield stabilities.

Nitrogen efficiency is defined as the ability of a plant to produce high yields under low soil N conditions (Graham, 1984). According to the approach of Moll et al. (1982) nitrogen efficiency is the product of N accumulation efficiency and N-use efficiency (NUE). N accumulation efficiency means the efficiency in absorbing nutrients from the soil (total plant N uptake per available soil N), and N-use efficiency (yield per total plant N) is the effectiveness of the plants to use the nutrients for producing yields (Graham, 1984; Moll et al., 1982). Moll et al. (1982) replaced available N by fertilizer N and total plant N by aboveground plant N because available N and total plant N are difficult to measure in field experiments. In general, fertilizer N is not representative for available N because it is not the only source of plant available N (Dawson et al., 2008). N release from organic fertilizer and soil depends on soil properties concerning structure, temperature and water status. Huggins and Pan (1993) altered the formula of Moll et al. (1982) and defined plant available N accumulation efficiency as total aboveground plant N per plant available N (aboveground plant N at harvest + inorganic soil N at harvest), in order to take soil processes like volatilization and leaching into account.

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Differences in N accumulation efficiency were found for maize hybrids due to a greater root length density (Wiesler and Horst, 1992). In contrast, a study for cauliflower investigating the N accumulation efficiency of three F1 hybrids differing in yield performance at low N-supply, found no differences for N accumulation (Rather et al., 2000). The authors assume that yield differences are due to internal N-use efficiency rather than N accumulation efficiency as was also shown for white cabbage (Erley et al., 2010).

While root characteristics play an important role for N accumulation efficiency, partitioning of the nutrients within the plants and utilization on cellular levels determine the NUE of the plant (Sattelmacher et al., 1994). Nitrogen availability hardly affected partitioning of biomass or nitrogen in Brussels sprouts but final bud weight and bud nitrogen was related to the total biomass and nitrogen contents at the onset of bud growth (Booij et al., 1997). Varietal differences in bud initiation time are observed in cultivars differing in harvest time (Everaarts and Sukkel, 1999). Based on the relationship between yield dry matter and amount of intercepted radiation (Abuzeid and Wilcockson, 1989), which is reduced under N-limited conditions due to restricted leaf growth, varieties with an early onset of bud growth can be advantageous.

The objective of this study was to identify cultivars particularly suited for organic farming systems due to high nitrogen accumulation and nitrogen utilization efficiencies. We also tried to identify traits and physiological relationships explaining differences in nitrogen use of Brussels sprouts. We hypothesize that cultivars with an earlier and longer bud forming phase will have yield advantages due to a higher harvest index as a result of more bud in relation to leaf and stem growth.

2. Materials and methods

Two field experiments were conducted in 2005 and 2006 on the experimental station in Ruthe near Hannover, Germany, on a hapludalf soil derived from loess. Soil organic matter content amounted to 2%. Since 2003, the field was converted to organic farming management certificated by BIOLAND. Preceding crop included clover grass (Camena Samen, Lauenau, Germany) in both experimental years. Untreated, conventionally propagated seed from different breeding companies was used (Table 1). Plants were transplanted into the field at an average dry weight of 4.1 g/plant at a density of 3.5 plants/m^2. Weed control was done using a hoeing machine at early growth stages and by hand thereafter. The field trials were laid out as two-factorial split plot design with three replications. The main factor was N fertilization and the subfactor was variety. Organic fertilizers were pellets of ground pig hairs (Beckmann & Brehm GmbH, Beckeln, Germany) which consisted of 13% N, 1% P_2O_5, 0.2% K_2O and 0.2% MgO. 33% Net N mineralization of grounded pig hairs was estimated by Dierend et al. (2006) derived from a two year covered fallow plot. In 2005, the amounts of applied N were 220 kg N/ha and 110 kg N/ha. The total N supply calculated as the sum of plant N and soil mineral N at the end of the growing season was almost the same in both treatments (Table 2). In 2006, the amounts of applied fertilizer were 240 and 40 kg N/ha, resulting in a difference in total N supply between the fertilizer levels of 82 kg N/ha.

Table 1
Varieties, breeding companies and harvest period indicated by breeding companies.

Variety	Supplier	Harvest period
Maximus F1	S&G	September–October
Cyrus F1	S&G	October–November
Diablo F1	Bejo	October–November
Topline F1	Agri	Mid October–December
Philemon F1	S&G	Mid November–December
Igor F1	Hild	Mid November–Beginning January
Revenge F1	Bejo	December
Silverline F1	Agri	Mid December–Mid January
Genius F1	S&G	December–February
Esperal F1	Seminis	January–March

Soil samples were taken on 4 spots within each plot from each soil layer at 0–30 cm, 30–60 cm, and 60–90 cm depth prior to planting and at each harvest date. Soil mineral N was extracted by addition of 0.1 N KCI solution. Nitrate-N was analyzed using the UV method according to Hoffmann (1991) and ammonium-N was determined using DIN 38406/5.

Weather data were taken from a weather station at the experimental station in Ruthe. Mean air temperature during the growth period was 14.8 °C in 2005 and 15.5 °C in 2006, respectively. Temperature sum was calculated using a base temperature of 0 °C (Table 2).

Harvest of the late varieties was 252 days after planting (DAP) in 2005 compared to 196 DAP in 2006, but temperature sums were almost the same in both years. The early varieties Maximus F1 and Cyrus F1 were harvested 169 DAP in 2005 and 196 DAP in 2006.

At harvests, four adjacent plants per plot were sampled. Green leaves, senescent leaves, stems and buds were separated. To obtain dry weights, samples were oven dried at a temperature of 70 °C. Total N content was determined using the Kjehldahl method.

Statistical calculations were performed using SAS (SAS Institute Inc., Cary, NC, USA). The procedure GLM was used for the analysis of variance. Means were evaluated by LSD test ($\alpha = 0.05$). Linear regressions were carried out on natural logarithm transformed data of bud dry matter and N accumulation for each fertilizer level. The slopes were subjected to *F*-test using GLM.

Table 2
Environmental conditions and average N supply in 2005 and 2006.

Date	DAP	Temperature sum [°C]	Cum. global radiation [kWh/m^2]	Average N supply[a] [kg N/ha]		Average plant N concentration [%]	
				110[b]	220[b]	110[b]	220[b]
02.05.2005	0	0	0				
18.10.2005	169	2559	689	277	295	2.4	2.5
09.01.2006	252	3000	732	–	–	2.1	2.1
				40[b]	240[b]	40[b]	240[b]
15.05.2006	0	0	0				
26.06.2006	42	609	165	180	328	3.2	3.4
14.08.2006	91	1604	404	174	261	2.2	1.8
25.09.2006	133	2322	524	170	276	2.7	2.2
27.11.2006	196	3051	600	197	279	2.2	2.4
09.01.2007	239	3338	621	–	–	2.1	2.4

[a] Calculated as the sum of soil mineral nitrogen and nitrogen recovered in the plant.
[b] Fertilizer level.