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# Above- and belowground nitrogen uptake of winter catch crops sown after silage maize as affected by sowing date

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Regions in north-western Europe characterized by high density of livestock/biogas plants and extensive silage maize production are facing major environmental challenges due to excessive residual soil mineral nitrogen (N) in autumn and hence nitrate leaching. Winter catch crops (CC) have potential to accumulate residual N; however, the N uptake potential after maize harvest in autumn and spring remains unclear. Therefore, a two-year field trial (April 2012–April 2014) was conducted at three sites, to quantify the combined effects of four consecutive CC sowing dates (10 Sep; 20 Sep; 30 Sep and 15 Oct) and two CC species (rye, *Secale cereale*. L. and Italian ryegrass, *Lolium multiflorum* Lam.) on DM accumulation and N uptake of CC above- and belowground in autumn and spring, and to derive functional relationships. The results clearly showed that rye was more effective in accumulating biomass and nitrogen than Italian ryegrass. The better performance of rye was related to increased growth intensity of roots and shoot, a different allocation pattern and higher N uptake efficiency. An exponential function of temperature sum (Tsum) produced a reliable prediction of above- and belowground biomass and N. To achieve an agronomically relevant N uptake of 20 kg N $ha^{-1}$, rye required 278 °Cd Tsum, which corresponds to a sowing date latest in the second decade of September. Under favourable growing conditions, a biomass accumulation of up to 5 Mg DM $ha^{-1}$, corresponding to 83 kg N $ha^{-1}$ above- and belowground, seems achievable under the given environmental conditions. In continuous maize grown under the environmental conditions of Northern Germany, however, catch crops will not reach a relevant N uptake on the long-term average.

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## 1. Introduction

In many areas of Europe silage maize is major source of feed for intensive livestock and also an important feedstock for the bioenergy sector, and these increased demands explain the increased maize acreage over the past years (Möller et al., 2011). In Schleswig-Holstein, the northernmost federal state of Germany, for instance, silage maize production accounts for 26% of the arable land area (Statistics north Hamburg and Schleswig-Holstein, 2014), with the principle area of production in the Geest region, characterized by a high density of dairy farms (Lesschen et al., 2011) and biogas plants with maize that is often grown continuously. In this region, coarse-textured soils with low water-retention capacity prevail and surplus winter precipitation can frequently cause substantial nitrate ($NO_3$) leaching to the groundwater (MELUR, 2012; LLUR, 2014; Velthof et al., 2014). Silage maize production is associated with long-term application of organic fertilizers, frequently applied in excess (Schröder et al., 1998), leading to the risk of surplus residual soil mineral nitrogen (N) in autumn (Ten Berge et al., 2007). This risk increases with the increasing contribution of silage maize in the crop rotation (Herrmann, 2013). High N losses are likely to occur especially if the N release from slurry or soil organic matter is underestimated (Schröder et al., 1998). In addition to the adoption of optimal fertilization practices (e.g. timing, amount, technique and placement), the introduction of catch crops (CC) constitutes another option to reduce negative environmental impact (Moreau et al., 2012).

Catch crops, sometimes also referred to as cover crops, are sown in the phase between two cash crops, when the surface might otherwise be bare ground, and they can provide a wide range of ecosystem services (Thorup-Kristensen et al., 2003; Blanco-Canqui et al., 2015). Frequently reported effects are yield increases of the following crop (Thilakarathna et al., 2015), the suppression of weeds (Uchino et al., 2009; Brust et al., 2014), the provision of

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valuable forage (Franzluebbers and Stuedeman, 2014) and reduction of erosion (Laloy and Bielders, 2010). Additionally, the critical issue of soil organic carbon depletion that occurs under maize production is alleviated by the introduction of CC (Poeplau and Don, 2015). Accumulation of N in the above- and belowground biomass, which otherwise is at risk of being leached to the groundwater (Kaspar et al., 2012), is a major feature. The ability to absorb, accumulate and retain reasonable amounts of N reduces $NO_3$ leaching losses, as shown for non-leguminous CC species (Tonitto et al., 2006; Constantin et al., 2010; Malone et al., 2014). Reports on the N uptake of rye (*Secale cereale* L.) and Italian ryegrass (*Lolium multiflorum* Lam.) grown as CC, for the period until the end of the growing season, range between 10 and 123 kg N $ha^{-1}$ in the above- and belowground biomass (Schröder et al., 1996; Thorup-Kristensen, 2001). Most studies, however, have investigated only the N uptake of non-leguminous species before ploughing in spring, and shown average values of ca. 40 kg N $ha^{-1}$ accumulated (Shipley et al., 1992; Schröder et al., 1996; Vos and van der Putten, 1997; Kramberger et al., 2009; Constantin et al., 2010 and Kramberger et al., 2014), while there is a lack of knowledge on N uptake in the period before winter (Ketterings et al., 2015). The N uptake potential of CC grown after maize is critical, because under the climatic conditions of northern Germany the maize harvest usually occurs at the end of September/beginning of October, with a low temperature sum (Tsum) remaining until the end of the growing season (Feyereisen et al., 2006; Van Dam, 2006). Nitrogen uptake of CC was found to be highly correlated with their rooting depth and intensity in deep soil layers (Thorup-Kristensen, 2001; Kristensen and Thorup-Kristensen, 2004). Furthermore, rooting depth of various species is reported to be linearly dependent on Tsum (Thorup-Kristensen, 2001; Smit and Groenwold, 2005). To deplete soil Nmin, CC thus require a vegetation period of sufficient duration for the development of a large and deep root system (Thorup-Kristensen, 2001). Rye and Italian ryegrass seem suitable CC species for such conditions (Wagger et al., 1998; Fowler et al., 2014; Cougnon et al., 2015; Malcolm et al., 2015), but delayed sowing of CC, due to late harvesting of the maize crop, will inevitably reduce N uptake (Van Dam, 2006) and hence increase the risk of N losses, as reported by Hashemi et al. (2013). To face the challenge of N losses, farmers in Schleswig-Holstein are financially supported for the introduction of CC after silage maize sown latest until 10 October by a new agri-environmental measure 'winter greening' (MELUR, 2015). There are, however, hardly any studies that have investigated the effect of CC sowing date on yield, N flows and environmental impact throughout the whole maize-CC system (Shipley et al., 1992; Schröder et al., 1996). The objectives of the current study, therefore, were to quantify the impact of CC sowing date and CC species on the above- and belowground DM and N accumulation in late autumn and spring, and to derive functional relationships. The study is based on a two-year field experiment conducted at three sites in northern Germany. Companion papers will address the nutrient carry-over from CC to maize and related environmental effects.

## 2. Material and methods

### 2.1. Experimental sites and weather conditions

The present study is based on a field experiment conducted between April 2012 and April 2014 at three sites, representing two major landscapes of the federal state of Schleswig-Holstein, northern Germany. There was one site at the experimental farm 'Ostenfeld' (OF) located in the Eastern Upland (54°19′N, 9°48′20 E, 14 m above sea-level). The dominant soil type is a transition between a Haplic Luvisol and Cambic Podzol and has a silty-sandy texture. Details of soil characteristics are given in Table 1. The climate is humid-temperate with an average annual precipitation of 847 mm and a mean annual temperature of 8.9 °C. A crop of winter wheat (*Triticum aestivum* L.) was grown on the site before the experiment was established. The other two sites were at the experimental station 'Schuby' (54°31′20N, 9°26′40E, 20 m above sea-level), which represents the Geest region. The soil is classified as a Carbic Podzol of sandy structure. The humid-temperate climate is characterized by a mean annual precipitation of 885 mm and an average annual temperature of 8.6 °C. Two environments were provided for Schuby: (i) a site with irrigation (SI) where forage grasses were grown the year before the onset of the field trial and (ii) a rainfed site (SN) with a history of continuous maize managed with applications of cattle slurry or biogas digestate.

**Table 1**
Soil characteristics of the experimental sites Ostenfeld (OF), Schuby without irrigation (SN) and Schuby irrigated (SI), with $N_{tot}$: soil total N content, $C_{org}$: soil organic carbon content, C/N: carbon to nitrogen ratio and dB: soil bulk density, determined gravimetrically.

| Sites | Depth [cm] | Sand | Silt | Clay[%] | $N_{tot}$ | $C_{org}$ | C/N | $pH_{CaCl2}$ | dB [g $cm^{-3}$] |
|---|---|---|---|---|---|---|---|---|---|
| OF | 0–30 | 63 | 31 | 6 | 0.14 | 1.49 | 10.7 | 5.8 | 1.56 |
| | 30–60 | 62 | 35 | 3 | 0.05 | 0.52 | 11.3 | 5.9 | 1.47 |
| | 60–90 | 49 | 43 | 8 | 0.02 | 0.20 | 10.9 | 5.9 | 1.57 |
| SN | 0–30 | 85 | 6 | 9 | 0.15 | 2.82 | 18.9 | 5.4 | 1.53 |
| | 30–60 | 88 | 9 | 3 | 0.12 | 2.32 | 19.4 | 5.6 | 1.40 |
| | 60–90 | 90 | 10 | 0 | 0.04 | 1.14 | 31.3 | 5.5 | 1.50 |
| SI | 0–30 | 86 | 7 | 7 | 0.23 | 3.46 | 15.2 | 5.4 | 1.47 |
| | 30–60 | 89 | 7 | 4 | 0.05 | 0.98 | 21.3 | 5.3 | 1.40 |
| | 60–90 | 92 | 8 | 0 | 0.02 | 0.37 | 20.8 | 5.1 | 1.50 |

Weather conditions in the two experimental periods (2012/2013, 2013/2014) differed substantially and showed considerable deviation from the long-term average. While the first period (2012/2013) was characterized by low temperatures from December to April, temperatures were mild in November and from January to April of the second period (Fig. 1). Mean daily temperatures of below 0 °C occurred on 40 (Ostenfeld) and on 68 days (Schuby) in the winter of 2012/2013, but on only 14 (Ostenfeld) and 15 days (Schuby) in 2013/2014. The annual sum of precipitation was substantially lower than the long-term average in 2012/2013, whereas it was higher in 2013/2014.

### 2.2. Experimental setup, treatments and field operations

At each site the experimental plots were laid out as a four-factorial randomized block design (experimental period, site, sowing date, CC species) with three replications and a plot size of 51–72 $m^2$. For the second experimental period, plots were established in another area of the experimental site, but in close proximity to the area used in previous period in order to minimize the possible effects of local differences in soil conditions. Treatments comprised three sites (OF, SI and SN), four CC sowing dates (sd) (10 Sep, 20 Sep, 30 Sep, 15 Oct (sd1-sd4)), and two CC species treatments, rye (*Secale cereale* L.) and Italian ryegrass (*Lolium multiflorum* Lam.) which is subsequently referred to as LM. The preceding crop of maize (*Zea maize* L.) was established in late April/beginning of May at a plant density of 10 plants $m^{-2}$ in rows 75 cm apart. Fertilizers were applied before sowing: 250 kg $ha^{-1}$ $K_2O$, 124–140 kg $ha^{-1}$ $P_2O_5$ (30% as banded starter), and 30 kg $ha^{-1}$ MgO as top dressing. Calcium-ammonium nitrate was applied as top dressing shortly after sowing at 180 kg N $ha^{-1}$ less the N value of the spring soil mineral N. Herbicides were applied according to good agricultural practice. At SI, maize plots were irrigated following the recommendation by the German weather service, i.e. only 20 mm on 30 May 2012, but in 2013 a total of 128 mm was applied, with applications on five occasions from 5

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