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Research paper

The effects of maize (*Zea mays* L.) hybrid and harvest date on above- and belowground biomass dynamics, forage yield and quality – A trade-off for carbon inputs?

Martin Komainda*, Friedhelm Taube, Christof Kluß, Antje Herrmann

Institute of Crop Science and Plant Breeding, Grass and Forage Science/Organic Agriculture, Kiel University, Hermann-Rodewald-Str. 9, D-24118 Kiel, Germany

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ABSTRACT

There are two major environmental constraints of silage maize (*Zea mays* L.) production: loss of soil organic carbon (SOC) and nitrogen (N) leaching to groundwater. Winter catch crops (CC) increase carbon inputs and can accumulate residual N, but only if the preceding maize is harvested timely to allow high above- and belowground biomass and N accumulation. To quantify the combined effects of hybrid maize variety and harvest date on forage yield and quality, as well as on root dynamics, root turnover and carbon input, a two-year field experiment (April 2012–October 2013) was conducted in northern Germany. Early maturing Suleyka was harvested at 10 (hd1) and 20 (hd2) September and mid-early Ronaldinio at 30 September (hd3) and 15 October (hd4). Maize hybrids showed no consistent differences of aboveground dry matter (DM) and N accumulation dynamics. Only the very early harvest (hd1) resulted in 11–13% lower DM yields. Sufficiently high DM and starch contents, however, were not achieved at harvest dates prior to hd_3 (30 September). Similar to shoot yield, the final accumulated root biomass, carbon (C) and N were not affected by hybrid/harvest date, and on average amounted 2.48 t DM, 1.2 t C and 52.9 kg N ha^{-1} in the upper soil depth of 30 cm, which represented between 77 and 75% of the DM, C and N accumulation to 60 cm soil depth. Root turnover during the growing season reached up to 65, 75 and 69% of root DM, N and C. Stubble DM and C left on the field, however, was 31% lower at early harvest (hd1) compared to later harvests, resulting in a trade-off to total C inputs compared to delayed harvest. The quantified C inputs are discussed by two C balance approaches, which indicate that silage maize cultivation is not necessarily associated with SOC degradation, especially if winter catch crops are introduced.

1. Introduction

Soil organic carbon (SOC) influences several soil functions and thus plays an important role in the sustainable productivity of cropping systems (Reeves, 1997). Levels of SOC are determined by the balance between losses, caused by soil erosion and decomposition by microorganisms, and by inputs of carbon (C) from crop residues and organic fertilization. Differences in the quantities and chemical composition of crop residues, and the effects of soil tillage may explain the impact of crop species on SOC dynamics (Wright et al., 2007). Crops that provide high amounts of annual C input are generally regarded as beneficial for enhancing C sequestration and soil functioning. According to the German C balance approach, silage maize production is associated with a net C demand, i.e. SOC losses (Vdlufa, 2014). The total amount and retention of plant residues in SOC can differ between above- and belowground plant parts. Retention coefficients of root-derived C range between 17 and 39%, but for aboveground residues they are only 12.2–17% (Bolinder et al., 1999; Clapp et al., 2000; Kätterer et al., 2011; Menichetti et al., 2015). Consequently, knowledge on the belowground biomass accumulation of maize is essential for simulations of SOC dynamics in the context of land use change. Quantification of belowground C inputs in the field, however, may be challenging and rhizodeposition is especially difficult to quantify (Nguyen, 2003; Amos and Walters, 2006). The net accumulated belowground biomass of maize is frequently determined by spontaneous sampling at variable depths, either at silking or at harvest (Buyanovsky and Wagner, 1986; Crozier and King, 1993; Bolinder et al., 1999; Costa et al., 2002; Zhang et al., 2012; Ning et al., 2014; Dietzel et al., 2015; Yu et al., 2015). Other approaches aim to quantify roots sequentially (Anderson, 1988; Peng et al., 2010) or by estimation applying allometric functions (Wiesmeier et al., 2014), all of which underestimate gross root production due to root turnover during the growing season. The ingrowth core technique is one method that allows the quantification of gross root accumulation (Steingrobe et al., 2000, 2001).

* Corresponding author.
E-mail addresses: mkomainda@gfo.uni-kiel.de (M. Komainda), ftaube@gfo.uni-kiel.de (F. Taube), ckluss@gfo.uni-kiel.de (C. Kluß), aherrmann@gfo.uni-kiel.de (A. Herrmann).

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A negative C balance of silage maize may be compensated, at least partly by organic fertilization and by sowing adapted catch crops which require timely establishment after early maize harvest (Van Dam, 2006; Komainda et al., 2016). Under the climatic conditions of northern Germany, maturity of the maize crop for ensilage, i.e. a dry matter (DM) content of at least 30%, is usually not reached before end of September/beginning of October (Herrmann et al., 2013). An earlier maize harvest, however, is required for achieving an adequate N uptake by catch crops in autumn, which is necessary for reduction of leachate nitrate concentration to within the non-critical range (Komainda et al., 2016). This earlier harvest is commonly associated with a reduced DM content at maize harvest (Darby and Lauer, 2002), unless the grower switches to a variety in an earlier maturity group. In addition, the full yield potential will not be exploited, and the maximum root biomass will be reached shortly after the onset of anthesis (Amos and Walters, 2006). Choosing an earlier hybrid, in contrast, may result in lower amounts of shoot biomass and residue. Menichetti et al. (2015) for instance, reported a positive correlation between yields and maize-derived C inputs in a long-term field trial in Sweden. Consequently, maize-catch crop systems aligned to ground water protection may lead to a trade-off between catch crop N uptake before winter and maize C input. There are, however, hardly any studies available so far which have systematically explored the impact of maize maturity-group and harvest date on above- and belowground biomass accumulation.

This study represents the second of a series dealing with management options for improving the N flows in continuous maize-catch crop systems. Companion papers focussed on the impact of catch crop sowing date and species on shoot and root DM and N accumulation in late autumn and spring (Komainda et al., 2016) as well as N losses (N leaching and N_2O emission) and the N use efficiency of subsequently grown maize (Komainda et al., 2017). The objective of the present work was to investigate the effect of silage maize hybrid and harvesting date on (i) the dynamics of above- and belowground biomass and N accumulation, (i) yield and forage quality, (iii) root turnover during the growing season and estimate the corresponding yield-related C input to quantify any trade-offs between silage maize productivity and carbon inputs, which may provide quantitative data for simulations of SOC dynamics. Hypotheses addressed were:

i) Early harvest of an early maturing silage maize hybrid does not allow to exploit the site yield potential and results in lower forage quality.
ii) Early maize harvest will reduce C inputs to the soil due to lower root production, which may be compensated by catch crops.
iii) Spontaneous root sampling underestimates the total root production due to root turnover during the growing season.

2. Material and methods

2.1. Experimental site and weather conditions

The present study was conducted between April 2012 and October 2013 at the research farm 'Ostenfeld' (OF), located in the Eastern Upland, of the federal state of Schleswig-Holstein, northern Germany (54°19′N, 9°48′20 E; 14 m above sea-level). The dominant soil type is a transition between Haplic Luvisol and Cambic Podzol of silty-sandy texture with details given in Komainda et al. (2016).

The experimental site is characterized by a humid-temperate climate with an average annual precipitation of 847 mm, of which 502 mm occur during April-October, the growing season for maize. The mean annual temperature is 8.9 °C and the growing season mean temperature is 13.2 °C. Weather conditions during the experimental periods are summarized in Fig. 1. Conditions were somewhat cooler and wetter in 2012 (12.8 °C, 552 mm), while in 2013 precipitation was only slightly lower (495 mm) and temperature was slightly above average (13.4 °C). There were lower than average temperatures in April and July of both years, and also in June and August of 2012. Temperatures were higher than average in September of both years and in August of 2013. Rainfall was substantially below long-term average in August of both years, in May and September to October of 2012, and in April and July of 2013. Rainfall was substantially above average in April and July of 2012 and in May–June of 2013.

2.2. Experimental setup, treatments and field operations

The field experiment was established in April 2012 as a three-factorial (year, N fertilization, hybrid/harvest date) randomized block design with three replications and a plot size between 51 m^2 resulting in a total experimental area of 2754 m^2. Each block included four replicates, designated for studying the impact of catch crops (4 levels) after maize harvest, see also Komainda et al. (2016). Before establishment of the experiment, the field was grown with a minerally-fertilized maize-winter wheat (*Triticum aestivum* L.) rotation for ten years. Treatments of the current study comprised two years (2012 and 2013), two N fertilizer levels (N0 and N180), and four consecutive maize harvest dates, i.e. 10, 20, 30 September and, 15 October (respectively, hd1–hd4). For harvest dates hd1 and hd2, the early maturing hybrid maize cv. Suleyka was used, while for harvest dates hd3 and hd4, the mid-early hybrid maize cv. Ronaldinio was sown. The maturation behaviour of Suleyka is characterized by an earlier senescence of stover rather than ear; i.e., Suleyka can be classified as dry-down type, while Ronaldinio has a synchronous maturation of stover and ear. Explicit harvest dates are given in Table 1. The unfertilized controls were machine-harvested on hd1 (Suleyka) and hd3 (Ronaldinio). In the second year the experiment was moved to a new field in close proximity to the area used in the previous year. Sowing was carried out during the last decade of April (2012: 20 April; 2013: 25 April), using a pneumatic seed drill to establish a plant density of 10 plants m^{-2} in rows 75 cm apart following soil tillage (mould-board plough) and seedbed preparation (rotary harrow). Before sowing, all plots received basal dressings of 124 kg ha^{-1} P_2O_5 (30% as banded starter), 250 kg K_2O ha^{-1} and 30 kg MgO ha^{-1}. Nitrogen fertilizer was applied as calcium-ammonium nitrate (CAN) as a top dressing shortly after sowing. Total N fertilization (less spring soil mineral nitrogen) amounted to 149 kg N ha^{-1} as calcium-ammonium nitrate. Herbicides were applied following standard farm practices.

2.3. Sampling of above- and belowground biomass

Aboveground DM yield was quantified by machine harvesting of two inner rows on consecutive harvest dates (hd1–hd4), as indicated in Table 1, using a plot harvester (J. Haldrup s/a, Løgstør, Denmark) in a total of four replications per block. Stubble DM was quantified manually by cutting 10 of the remaining stubbles to soil surface at hd1 and hd3. After fresh weight determination, stubbles were hand-chopped and dried (58 °C) to constant weight. In addition to machine harvest dates, the dynamics of aboveground DM and N accumulation (AGB and AGN) as well as belowground DM and N accumulation (BGB and BGN) were quantified by five/four manual harvests (d1-d5) during the growing season, i.e. at silking and two samplings each before and after, with the last sampling (d5) being identical with machine harvest hd1 for Suleyka and hd3 for Ronaldinio; see Table 1. On each sampling date, 5 consecutive plants (10 plants at first sampling) randomly assigned to a row bordered by unharvested rows, were cut manually near the soil surface, weighed and crushed in a garden chopper (AB-4110SE, Viking, Kufstein, Germany). On the last two sampling dates, the ear fraction of the total aboveground dry matter was determined by sampling five additional plants after fractionation between ear (plus husk) and stover. A representative subsample was subsequently dried in a forced-air oven until constant weight (58 °C) for DM determination.

For forage quality analysis, samples containing stalks, ears and stubbles were ground in a two-step procedure: first passing a 5-mm