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Influence of harvest time and frequency on light interception and biomass yield of festulolium and tall fescue cultivated on a peatland

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ABSTRACT

In this study, we report efficiencies of light capture and biomass yield of festulolium and tall fescue cultivated on a riparian fen in Denmark under different harvesting managements. Green biomass targeted for biogas production was harvested either as two cuts (2C) or three cuts (3C) in a year. Three different timings of the first cut in the 2C systems were included as early (2C-early), middle (2C-mid) and late (2C-late) cuts corresponding to pre-heading, inflorescence emergence and flowering stages, respectively. The fraction of intercepted photosynthetically active radiation (f_{PAR}) was derived from the canopy reflectance measured on 61 dates throughout a year, and cumulative interception of PAR (IPAR) and radiation use efficiency (RUE) was calculated. The dynamics of f_{PAR} and biomass accumulations was similar for both crops before the first cuts in all managements. Festulolium f_{PAR} in 2C-early and 2C-mid managements declined faster than in 2C-late and 3C managements in the second growth period and thus growing period IPAR of 2C-early and 2C-mid declined by 8% as compared to 3C management where IPAR was 925 MJ m^{-2}. Annual festulolium dry matter (DM) yield in 2C-early and 2C-mid managements (average 14.1 Mg DM ha^{-1}) decreased by 22% compared to 3C management (18.2 Mg DM ha^{-1}). The highest and the lowest RUE of festulolium were observed in 3C and 2C-mid managements as 1.97 and 1.59 g MJ^{-1}, respectively. For tall fescue f_{PAR} declined rather slowly in the second growing period in all 2C managements, which contributed to similar IPAR (908–919 MJ m^{-2}), total biomass yield (16.4–18.8 Mg DM ha^{-1} yr^{-1}) and RUE (1.80–2.07 g MJ^{-1}) for all managements. Whereas both crops were highly productive under both 3C management and 2C management with first harvest after flowering (i.e., 2C-late), the 2C-late strategy is recommended as the least intensive of the two management systems.

1. Introduction

Drained peatlands are vulnerable to gaseous carbon (C) losses as carbon dioxide (CO_2) due to aerobic biological oxidation of peat upon lowering of the water table (Frolking et al., 2011; Waddington et al., 2015). Also, fluvial C and nutrient losses may result and potentially leading eutrophication of aquatic bodies notably in riparian peatlands (Hoffmann et al., 2011). The losses to the environment are aggravated by intensive agricultural managements such as annual cropping systems with tillage and application of mineral fertilizers and manure. Traditional agriculture in peatlands in northern Europe is further challenged by continuing peat subsidence which calls for a change of cropping systems to flooding tolerant crops. Adjusting land use practice by cultivation of flooding tolerant perennial biomass crops could be a win–win land use option as these crops do not require annual ploughing and sowing, and thus could reduce the tillage induced CO_2 losses (Liu et al., 2006; Chatskikh and Olesen, 2007). Perennial biomass crops could also increase the sequestering of atmospheric CO_2 as they can intercept more radiation for longer growth periods than annual crops (Cadoux et al., 2014; Dohleman and Long, 2009; Kandel et al., 2013a). Finally, high-yielding perennial biomass crops could possibly mitigate nutrient losses owing to sustained nutrient uptake and export from the ecosystem (Christen and Dalgaard, 2013).

In recent years, reed canary grass (RCG; *Phalaris arundinacea* L.) has been tested as a candidate biomass crop for drained and rewetted peat soils in northern Europe (Shurpali et al., 2010; Palmborg, 2012; Kandel et al., 2013a; Järveoja et al., 2016; Karki et al., 2016). Finland has pioneered RCG cultivation in northern peatlands with a cultivated area of up to 19,000 ha, but currently the expansion is stagnating due to poor feedstock quality for combustion (Lind et al., 2016). In Denmark, however, RCG and other perennial grasses

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cultivated in peatlands are currently targeted primarily for biogas production as crude biomass (Kandel et al., 2013c), or after extraction of components for value-added chemicals (Parajuli et al., 2015). In a Danish study, yields of RCG (cv. Bamse) green biomass were as high as 16 Mg ha^{-1} yr^{-1} which was obtained under intensive cutting and fertilization managements (Kandel et al., 2013b). However, the yields declined after the third year of establishment due to deteriorating RCG stands, and the cultivar could not compete with other meadow grasses both under drained and rewetted peat soil conditions (Karki et al., 2016). Also, RCG could not stay green after the first winter frost and thus wintertime photosynthesis was negligible compared to other meadow grasses, which grew spontaneously in spring barley plots after autumn harvest and stayed green throughout the winter (Kandel et al., 2013a). Therefore, it is attractive to test other perennial biomass crops that have better stay-green traits in winter than RCG (Clifton-Brown et al., 2002; Thomas and Ougham, 2014). To be suitable for cultivation in lowland areas, however, the crops must be able to survive at shallow ground water table and during periodic waterlogging, which is a recurrent phenomenon in poorly drained northern peatlands, especially in the period between late autumn and early spring.

Festulolium (×*Festulolium*) and tall fescue (*Festuca arundinacea* Schreb.) are suitable perennial grasses as feedstocks for biogas production (Seppälä et al., 2009; Ambye-Jensen et al., 2013). Festulolium is a hybrid or a hybrid derivative between species of fescue (*Festuca*) and ryegrass (*Lolium*) designed for their combined complementary characters (Ghesquière et al., 2010; Østrem et al., 2013). Festulolium and tall fescue are native of northern Europe and are known for quick establishment, aggressive growth and weed suppression, excellent regrowth capacity, winter survival, and high yields (Ghesquière et al., 2010; Østrem et al., 2013; Jiao et al., 2016). Spring growth of festulolium in particular is earlier than for perennial ryegrass (*L. perenne*) – a grass commonly cultivated in northern Europe for fodder production – and therefore the first cut of festulolium can normally be done earlier (Helgadóttir et al., 2014). *Festuca* species are known for their superior ability to grow in harsh environments (Thomas and Humphreys, 1991) and some festulolium varieties have maintained these traits (Touno et al., 2011) making them suitable for cultivation in potentially waterlogged peat soils.

As yet, festulolium and tall fescue are relatively unproven biomass crops on peatlands, and it is important to develop best harvest management practices to optimize the biomass production. Harvest management of perennial grasses is largely planned according to the end use of the biomass (Parajuli et al., 2015). Biomass crops aimed for thermochemical conversion are normally harvested once a year at senescence when moisture and nutrient concentrations are low, which are preferred biomass traits for combustion (Jørgensen and Sander, 1997; Pahkala and Pihala, 2000). In contrast, crops cultivated for biogas production (anaerobic digestion) are normally harvested frequently in a growing period to obtain less lignified biomass with higher nutrient contents, which are the preferred traits for anaerobic digestion (Kandel et al., 2013c,d; Wahid et al., 2015). Frequent cutting, however, may increase the environmental impact due to increased fertilizer demand to support regrowth after cutting (Kandel et al., 2013b). Thus, caution in fertilizer application should be maintained in riparian peat soils as unused plant nutrients may reach aquatic bodies more easily from these ecosystems (Wohlfart et al., 2012). Therefore, a perennial grass, which can produce higher biomass yields of appropriate quality with low cutting frequency, would be an ideal crop as it may reduce the environmental footprints and cost of cultivation.

Frequent harvesting rejuvenate the greenness of perennial grasses potentially increasing cumulative canopy photosynthesis and biomass yield (Kandel et al., 2013b), but biomass cutting also creates a transitory fallow condition with decreased radiation interception at the start of the regrowth period. In the present study, we aimed to evaluate the balance of light interception and biomass yield in festulolium and tall fescue cultivated in a poorly drained peatland with different harvest managements.

2. Materials and methods

2.1. Study site and soil properties

The study was conducted on a cultivated fen peatland located in the area of the Nørreå river valley in Denmark (56°27′28″N, 9°40′33″E). Long-term (1985–2015) annual mean air temperature in the area is 7.9 °C, annual precipitation is 650 mm and global radiation is 3540 MJ m^{-2}. The natural fen was a minerotrophic wetland, which received nutrients from surrounding moraine landscapes through drainage and surface runoff (Knadel et al., 2011; Walpersdorf et al., 2013). The fen was drained in the beginning of the 20th century for agricultural use with establishment of open ditches. Later, subsurface drainage systems (tiles) were also introduced. In recent times (1985–2009), spring barley and ley-grass were cropped in rotation. In 2009, the site was rented for field experiments and cultivated with spring barley and RCG until 2013 (Kandel et al., 2013a). In August 2013, the field was ploughed and cultivated with festulolium (cv. Hykor) and tall fescue (cv. Kora).

Details of soil properties at the study site were presented in previous studies (Kandel et al., 2013a,b). In brief, peat depth was >1 m and bulk density in the top soil (0–20 cm depth) was 0.29 g cm^{-3}. The density decreased with depth as the peat in deeper layers was less decomposed. The peat soil had an average total organic carbon content of 36.3%, total nitrogen content of 3.0%, total phosphorous of 0.25%, total potassium of 0.79% and a pH (KCl) of 6.6 at 0–20 cm depth.

2.2. Experimental design and harvest managements

The study site had nine blocks (18 × 24 m) arranged in a Latin square design (Fig. 1). Six of these blocks were cultivated with festulolium and tall fescue, whereas three blocks (not included in this study) were cultivated with short rotation willow (*Salix viminalis* L.). Festulolium and tall fescue were each sown in three blocks in August 2013 and fertilized (80–11–38 kg N–P–K ha^{-1}) in the following spring (13 May 2014) with standard mineral fertilizers (Fig. 2). The grasses were harvested on 15 June and 25 August 2014. After the first harvest, the blocks were fertilized again at the same rate as in spring. After the second harvest, no further management operations were done in 2014.

The present harvesting management study was conducted in the second full year of biomass stand from March 2015. All blocks were fertilized with the same rate of standard mineral fertilizer (80–16–60 kg N–P–K ha^{-1}) in spring. Hereafter, each block was divided into four plots (18 × 6 m) to impose four different harvest managements as a split-block design (Fig. 1). The harvest treatments included a three-cut system (3C) with first harvest on 18 May, second harvest on 17 July and third (final) harvest on 30 September 2015. Further, three two-cut systems (2C) were included which differed by the timing of the first cut: early (2C-early), middle (2C-mid) and late (2C-late) first cut. The first cuts in the 2C-early, 2C-mid and 2C-late treatments were done on 18 May, 01 June and 15 June, respectively, representing phenological stages of pre-heading, inflorescence emergence and flowering. After each harvest (except after the final harvest), the harvested area was fertilized again with standard mineral fertilizer at rates of 80–0–100 kg N–P–K ha^{-1} in all managements (Fig. 2). The second (final) 2C harvesting was done on 30 September from all plots. At