Ecological Engineering 109 (2017) 1–9

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Influence of harvest managements of festulolium and tall fescue on biomass nutrient concentrations and export from a nutrient-rich peatland

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ARTICLE INFO

Keywords:
Biomass
Nutrient concentration
Nutrient removal
Harvest managements
Nitrogen
Phosphorus

ABSTRACT

This study was designed to show the effects of harvest time and frequency on biomass nutrient concentrations (total ash, N, P, K, Ca, Mg, Fe, Mn, Cu and Zn) as well as total nutrient removal potential by festulolium and tall fescue cultivated on a nutrient-rich fen peatland. The harvest managements included a three-cut (3C) and three two-cut (2C) systems which differed by two-week delays of first cut as: 2C-early, 2C-mid and 2C-late, representing phenological stages of pre-heading, inflorescence emergence, and flowering, respectively. In the study year, the grasses received 80-16–60 kg N-P-K ha^{-1} in spring and 80-0–100 kg N-P-K ha^{-1} after each harvest (except final). Nutrient concentrations and total ash content in the biomass dropped sharply during spring-summer growth. Concentrations of Ca, Mg and Mn were significantly higher in tall fescue biomass during spring-summer growth, but for other nutrients, there were no consistent differences between the two grasses. Total ash in the biomass from 3C managements (1.1 Mg ha^{-1}) was ~28% higher than in the biomass removed by 2C managements (0.8 Mg ha^{-1}). Similarly, mean annual N removal by 3C (315 kg N ha^{-1}) was 31% higher than by 2C (240 kg N ha^{-1}) managements, but net removals (removed minus applied N) from both managements were similar (75–80 kg ha^{-1}). Net P-removal by 3C (37 kg P ha^{-1}) was higher than by 2C (26 kg P ha^{-1}) managements, whereas total K removals in all managements were close to the applied K amount (i.e., net removals were close to zero). Whereas all crop/management combinations extracted more N and P than applied, the 2C-late approach is recommended since the biomass yield was higher than for the other 2C approaches, and it required less fertilizer and management inputs than the 3C approach.

1. Introduction

The cultivation of perennial grasses for biomass and bioenergy on abandoned peatlands can be an economically viable and environmentally suitable option as such grasses require minimal management and fertilizer inputs, stay green for long periods, and can reduce nutrient loading to aquatic systems (Christen and Dalgaard, 2013; Kandel et al., 2013a; Giannini et al., 2015). Biomasses for combustion purposes are often produced with an attempt to minimize concentrations of nutrients in the biomass (Jørgensen, 1997; Kering et al., 2012; Masters et al., 2016). However, from an environmental perspective, nutrient removal (export) from nutrient-rich peatlands may be desired to reduce, e.g., nitrogen (N) and phosphorous (P) leaching to aquatic bodies (O'Driscoll et al., 2014; Giannini et al., 2015) and nitrous oxide emissions to the atmosphere (Maljanen et al., 2007; Huth et al., 2012). Therefore, crop managements on cultivated nutrient-rich peat soils should target to optimize both biomass yield and net nutrient export. Yet, this may require some addition of mineral fertilizers as complete cessation of fertilization may severely affect crop growth and yield, and thus biomass nutrient removal (Kandel et al., 2013b; Nielsen et al., 2013).

Festulolium (×*Festulolium*) and tall fescue (*Festuca arundinacea* Schreb.) are perennial grasses native to northern Europe and can be suitable species to cultivate in peatlands for biomass production. Festulolium is a hybrid or a hybrid derivative between *Festuca* (fescue) and *Lolium* (ryegrass) species, designed for their combined complementary characters (Østrem and Larsen, 2010). Festulolium and tall fescue have excellent capacities of quick establishment, aggressive growth, weed suppression, winter survival, flooding tolerance, tolerance to frequent harvesting, long growing period, and high yield (Razmjoo et al., 1997Razmjoo et al., 1997; Østrem and Larsen,2010).

Biomass traits of perennial grasses, such as proportion of stem, leaf and panicles, as well as nutrient concentrations in the plant parts, are influenced by harvest management (Høgh-Jensen and Søegaard, 2012; Ambye-Jensen et al., 2013; Kandel et al., 2013c; Butkutė et al., 2014; Wahid et al., 2015). Hence, harvest time and harvest frequency of

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http://dx.doi.org/10.1016/j.ecoleng.2017.09.006
Received 9 February 2017; Received in revised form 6 September 2017; Accepted 9 September 2017
Available online 14 September 2017

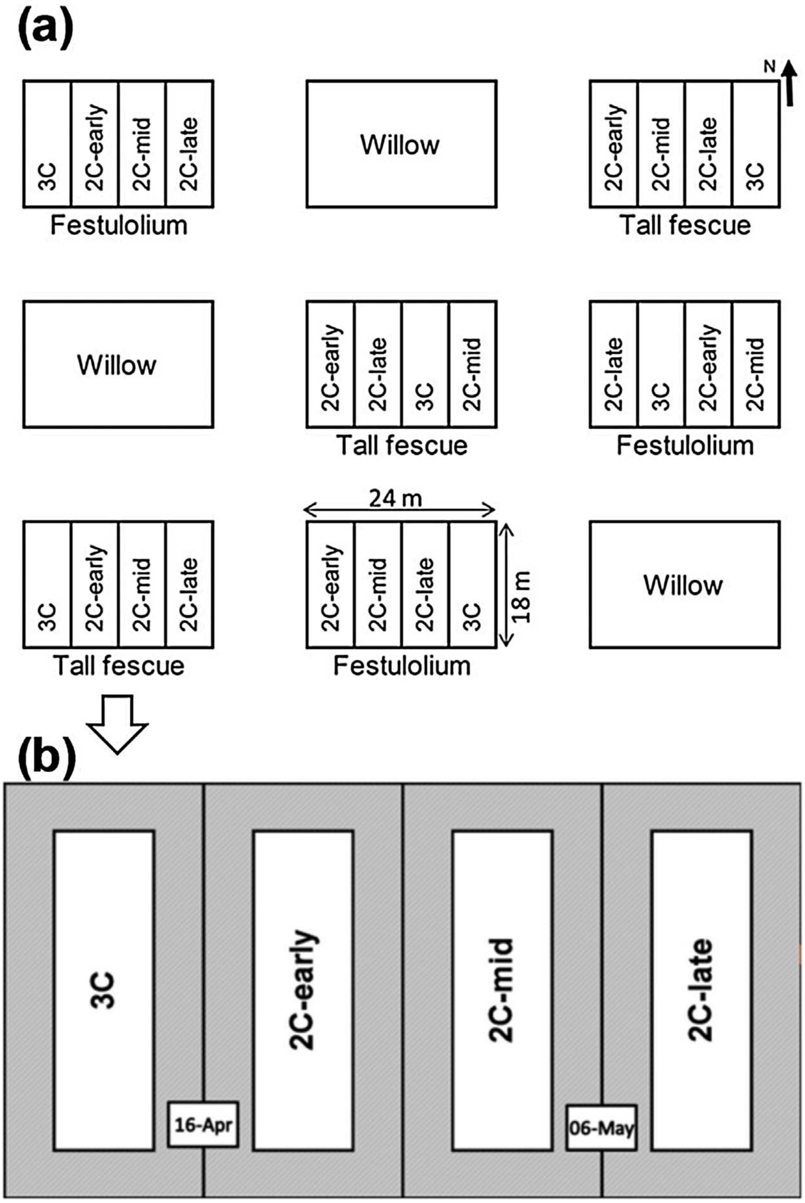

Fig. 1. (a) Layout of the field experiment with nine blocks (18 × 24 m) cultivated with festulolium, tall fescue and willow (only festulolium and tall fescue blocks were used in this study). Each block of festulolium and tall fescue were divided into four plots (6 × 18 m) to impose four different harvest managements as a split-block design. (b) A detail layout of an individual block with border (grey areas), net plots (white areas) and areas in borders (2 × 1 m) where biomass was harvested on 16 April and 06 May 2015 to monitor the dynamics of biomass nutrient concentration and uptake during spring growth. Abbreviations for managements: 3C − three cuts in a year; 2C-early, 2C-mid and 2C-late denote timing of first cut as early, mid or late cuts in two-cut (2C) managements representing phenological stages of pre-heading, inflorescence emergence and flowering, respectively.

perennial grasses are important management tools to optimize biomass yield and quality for bioenergy production (Kandel et al., 2013b, 2013c; Wahid et al., 2015; Dragoni et al., 2016). Biomass for thermochemical conversion is generally harvested once a year during winter or spring as the dry senesced biomass has relatively low nutrient concentrations which are preferred traits to minimize problems with corrosion and fouling of combustion plants (Jørgensen, 1997; Wichtmann et al., 2014; Dupont et al., 2016). However, biomass for hydrothermal or biochemical conversions, such as anaerobic digestion (AD), fermentation or protein extraction, may preferably be supplied from frequent harvest of less lignified biomass during the growing season (Kandel et al., 2013c, 2013d; Parajuli et al., 2015; Sari et al., 2015). Such frequent harvesting may also increase nutrient removal from environmentally sensitive cropping areas as the concentrations of phloem-mobile nutrients (e.g., N, P, and potassium, K) are higher in the green biomass before reallocation to belowground parts during senescent stages (Hill, 1980). Further advantages of frequent harvest are related to reduced losses of aboveground biomass parts (especially leaf and panicles which are rich in nutrients) that are potentially lost by shattering after senescence thereby reducing harvestable biomass and nutrient export (Larsen et al., 2014; Christensen et al., 2016).

A number of studies have evaluated festulolium and tall fescue biomass yields in response to crop maturity and harvesting frequency on mineral soils (Razmjoo et al., 1997Razmjoo et al., 1997; Høgh-Jensen and Søegaard, 2012; Ambye-Jensen et al., 2013; Lindström et al., 2013; Butkutė et al.,2014). Yet, research on biomass yields, nutrient concentrations, and nutrient export from organic peat soils remains limited. We recently reported on the cultivation of festulolium and tall fescue on a poorly drained nutrient-rich fen peatland, focussing on the influence of harvest management on light interception (Kandel et al., 2016), annual carbon (C) fluxes (Kandel et al., 2017a) and biogas yield (Kandel et al., 2017b). The specific objectives of the present study were to examine the effects of harvest time and frequency on biomass nutrient (elemental) concentrations as well as total nutrient export by festulolium and tall fescue when cultivated on a nutrient-rich fen peatland.

2. Materials and methods

2.1. Study site, cropping history and climate conditions

The study site was a cultivated peatland in the Nørreå river valley