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Research article

Effect of *Phragmites japonicus* harvest frequency and timing on dry matter yield and nutritive value

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ABSTRACT

Phragmites is a cosmopolitan perennial emergent macrophyte that is distributed worldwide. In recent years, *Phragmites* has attracted attention for its potential use as roughage. Given the increasing demand for feed and the number of constructed wetlands (CWs) vegetated with *Phragmites*, *Phragmites* is expected to play an important role in roughage production. Thus, it is vital to understand the effects of harvest timing and frequency on dry matter yield, nutritive value, and nitrogen (N) removal to establish appropriate vegetation management. In two CWs in Southwest China, four treatments with different harvesting frequencies were evaluated in monospecific areas of *P. japonicus*. The four treatments included no harvest, single harvest at 6 months, two harvests at 2 and 4 months, and three harvests at 2, 4, and 6 months. A sharp decline in the total digestible nutrients (TDN) concentration and the rate of increase in dry matter (DM) yield was associated with the heading timings, and the seasonal variations in TDN were likely influenced by carbohydrate accumulation in the stems. The three harvest treatment contributed to substantially improve the N and DM yields without decreasing the nutritive value but negatively affected the growth in the following year. Therefore, not only the combinations of harvest timing and frequency but also other management practices, including partial harvesting, may be needed to optimize CW performance and roughage production.

1. Introduction

Recent economic and human population growth has increased the demand for livestock products (Thornton, 2010). Meanwhile, serious issues concerning animal feed production have arisen. The bioenergy sector could directly compete with forage-livestock production (Sanderson and Adler, 2008). Forage production systems cannot be widely adapted due to competition for land with food crop production (Mcintire and Debrah, 1986), and an overall slowdown in the expansion of agricultural land, including pasture, is expected (Bruinsma, 2003). Consequently, human population growth throughout developing countries is increasing the demand for feed all over the world; consequently, the exploitation of alternative feed resources is a matter of great urgency.

Phragmites is a cosmopolitan clonal plant found throughout the world. Within the genus, *P. australis* (CAV.), Trin. ex Steudel has attracted attention for its potential use as roughage because of its high contents of crude protein (CP), neutral detergent fiber (NDF), and total digestible nutrients (TDN) (Baran et al., 2002; Kadi et al., 2012; Asano et al., 2015; Tanaka et al., 2016). Furthermore, *Phragmites* species have been used as important vegetation for constructed wetlands (CWs) to treat nutrient-rich wastewater. Since the first full-scale CW systems were put into operation during the late 1960s, there are currently more than 50,000 CWs in Europe and more than 8000 CWs in North America (Vymazal, 2005, 2011). CWs are also gaining popularity for cost-effective wastewater management in developing countries, and the number of CWs has increased in Southern and Central Africa and Asia (Kadlec and Wallace, 2009). Conversely, anthropogenic influences, including nutrient enrichment, have often fueled the increasing expansion of

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P. australis, which has become a serious issue in many regions (Findlay et al., 2003; Güsewell, 2003; Kettenring et al., 2011). Given the increasing habitat area of *Phragmites*, it could be a valuable source of roughage. Although harvesting aboveground biomass is a recommended practice for improving nitrogen (N) removal in productive areas (Álvarez and Bécares, 2008; Koottatep and Polpraset, 1997), the capital costs have interfered with plant harvest (Crites and Tchobanoglous, 1998). Thus, roughage production by harvesting *Phragmites* is expected to play an important role in not only supplying feed but also recovering the harvesting costs.

Multiple harvest of reed is more effective than single harvest in removing N and P (phosphorus) (Hernández-Crespo et al., 2016; Suzuki et al., 1989). Tanaka et al. (2016) suggested that high nutrient removal efficiency and high-quality roughage production could be compatible when considering the frequency and timing of harvest. The harvest timing could negatively affect subsequent regrowth because it hinders the annual rhizome reserves allocation from the aboveground biomass (Asaeda et al., 2006; Fogli et al., 2014; Karunaratne and Asaeda, 2004; Kühl et al., 1997); therefore, continuous harvesting could reduce the efficiency of nutrient removal in CWs from a long-term perspective. Furthermore, insufficient reloading of reserve carbohydrates in the rhizome could result from harvesting during the growing season and could subsequently reduce the nutritive value of shoots due to the minimal translocation of reserve carbohydrates from the rhizome (Tanaka et al., 2016). However, little is known about the effect of harvest frequency on dry matter yield, nutrient value, and N removal efficiency.

An appropriate management strategy, including a combination of timing and frequency of harvesting, should be established for sustainable roughage production and high-efficiency N removal in CWs. Therefore, we first aimed to explore the effect of harvest timing on the yield and nutritive value; second, we estimated the effect of harvest frequency on the yield, nutritive value, and N removal; and finally, we considered the implications for better CW management. In the present study, we annually reaped *P. japonicus* Steudel from one to three times and investigated the yield and nutritive value of the harvest.

2. Materials and methods

2.1. Study site

Lake Dianchi is the largest freshwater lake in the Yunnan Province of China and has had a serious water eutrophication problem since the 1970s. According to monitoring data from 2005 to 2012, the annual concentrations of total N ranged from 1.82 to 3.01 mg L^{-1}, and those of total P ranged from 0.13 to 0.20 mg L^{-1} in the main water body of Lake Dianchi (Zhang et al., 2013). To mitigate the eutrophication of the lake, a large number of CWs were established along the lakeside. Samples were obtained from the following two different free-water system CWs: from the east side (E) and west side (W) of Lake Dianchi (Fig. 1). Site E (24° 52′ N, 102° 47′ E) was situated at a distance from the lakeshore, where the maximum water depth did not exceed 10 cm. Site W (24° 52′ N, 102° 39′ E) was located near the lakeshore, where the water was relatively deeper than at Site E, and the water depth reached a maximum of 38 cm in winter. Agriculture is a major land use at both sites. The predominant vegetation in the coastal areas of Lake Dianchi is *P. japonicus,* cattail (*Typha sp.*), and manchurian wild rice [*Zizania latifolia* (Griseb.) Turcz. ex Stapf]. *Phragmites japonicus* is morphologically similar to *P. australis*, but it has a unique ability to generate epigeal stolones and is distributed over a wide range in Asia.

Hourly precipitation and air temperature data were obtained from the weather station (WeatherHawk Station, Campbell Scientific, USA) in Kele village (E24° 52′ N, 102° 47′ E). The distance from weather station to site E and W was 0.7 and 13.5 km, respectively. The mean daily temperatures and precipitation are shown in Fig. 2. The rainy season occurs from May to October, and annual rainfall was 980 mm in 2015. The mean annual temperature was 17.5 °C, and the mean daily temperature reached a maximum of 24.7 °C on May 31 and a minimum of 2.7 °C on January 10.

2.2. Harvest management

Four treatments with different harvesting frequencies were carried out in monospecific stands of *P. japonicus*. Each plot area was 64 m^2 (8 m × 8 m). The harvesting schedule is shown in Table 1. In this study, harvest just represents the mowing treatment, and it does not mean sampling.

The four harvesting frequencies included a single harvest at 6 months (HF1), two harvests at 2 and 4 months (HF2), three harvests at 2, 4, and 6 months (HF3), and no harvest as the control (HF0). Dead aboveground biomass has a great effect on shading, and may cause a serious internal competition for light resources (Tanaka et al., 2016). The quality of harvested roughage may also be degraded by dead aboveground biomass. Thus, dead aboveground biomass was removed from all treatments at sites W and E on February 3 and 5 of 2015, respectively. Furthermore, the dead aboveground biomass was removed on January 29 and February 1 of 2016 at sites E and W, respectively. We assumed that practical harvest management was implemented at a specified height above the surface water level. Thus, the plants were harvested or removed at a height of 10 and 40 cm above the ground at sites E and W, respectively.

2.3. Plant sampling and analysis

Three replicate samples of aboveground standing biomass within a 0.25 m^2 (0.5 × 0.5 m) frame were cut with a sickle at ground level and sampled monthly from March to August of 2015. Immediately before the removal of dead biomass on January 29 and February 1 of 2016 (Table 1), the samples of aboveground biomass were also collected. To investigate the effects of harvest frequency on aboveground growth in the following year, the aboveground biomass was collected in April and June of 2016. Sampling was always performed within visually homogeneous stands with uniform shoot density. The plant samples were placed into polyethylene bags for transport to the laboratory.

The samples of shoots were divided into two parts at the cutting height of 10 and 40 cm from the base at site E and W, respectively, and then upper part was sorted as harvested or removed biomass. Harvested biomass was regarded as roughage sample collected from March to August of 2015, and was then classified as dead or live tissues and then being sorted as stems, leaves, and ears. Removed biomass represents dead biomass assumed to remove in January 29 and February 1 of 2016 at sites E and W, respectively. The dry weight was determined after oven drying at 80 °C to a constant weight. The dried plant materials were ground until they were fine enough to pass through a 2-mm sieve.

The plant samples of harvested biomass (stems and leaves) were analyzed for NDF, acid detergent fiber (ADF), acid detergent lignin (ADL), CP, neutral detergent insoluble crude protein (NDICP), acid detergent insoluble crude protein (ADICP), ether extract (EE), and crude ash. The NDF and ADF contents were expressed exclusive of residual ash (Van Soest et al., 1991) using α-amylase for the NDF analysis. The ADL, CP, EE, and crude ash content were determined according to the Association of Official Analytical Chemists (AOAC, 1990). The contents of NDICP and ADICP were analyzed in neutral