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Research article

Timing of harvest of *Phragmites australis* (CAV.) Trin. ex Steudel affects subsequent canopy structure and nutritive value of roughage in subtropical highland

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ABSTRACT

In recent decades, constructed wetlands dominated by common reeds [*Phragmites australis* (CAV.) Trin. ex Steudel] have been utilized for treating nitrogen-rich wastewaters. Although plant harvest is a vegetation management in constructed wetlands for the purpose of improving nutrient removal, harvested biomass has become a problem in many places. The reed has attracted increasing interest for its potential as high-quality roughage for ruminants. Therefore, it is crucial to understand the effect of reed harvest timing on subsequent regrowth, reconstruction of canopy structure, and nutritive value of regrown biomass for roughage when defining an appropriate vegetation management in constructed wetlands. The shoots of common reeds were harvested in January (winter), March (spring), and May (early summer) in a free-water surface constructed wetland in southwest China. Harvesting in winter enhanced the shoot regrowth and concentrations of total digestible nutrients (TDN), probably due to vigorous translocations of nonstructural carbohydrates from rhizomes. Harvesting in spring and early summer decreased aboveground biomass, nitrogen (N) standing stock, and concentrations of TDN. From fifty to 110 days after harvest, the TDN had sharply declined to values similar to non-harvested stands. Thus, to obtain high-quality roughage, it is recommended that regrown shoots be harvested again within a year in the early growing stage after the first harvest in winter.

1. Introduction

Common reed [*Phragmites australis* (CAV.) Trin. ex Steudel] is a cosmopolitan perennial emergent macrophyte species mainly distributing in lakesides, along rivers and in marshes. The reed has a high ability of biomass production and dominating of aquatic habitats, whose introduction and rapid expansion can threaten natural ecosystems (Saltonstall et al., 2010). On the other hands, the reed is the most frequently used plant species worldwide in constructed wetlands (CWs) for wastewater treatment because of its high biomass production and nutrient uptake. CWs provide high filtration of pollutants from wastewater arising from sewage, domestic discharge, and agricultural drainage with low investment and operation costs. Currently, CWs vegetated with reed is an attractive technology for removal of metal (Gikas et al., 2013) and BTEX (Ranieri et al., 2013a,b) as well as practice for removing nutrients.

Harvesting aboveground biomass is a recommended practice for control and/or managing the growth (Asaeda et al., 2006) and improving nitrogen (N) removal of CWs in productive areas (Álvarez and Bécares, 2008; Koottatep and Polpraset, 1997). On the other hand, biomass waste produced by CWs has become a problem in many places (Kadlec and Wallace, 2009; Liu et al., 2012). As a consequence of difficulties of capital cost of harvesting, plant harvest is not favored for nitrogen removal (Crites and Tchobanoglous, 1998). It is necessary to find uses for harvested biomass, as well as new sources of income for local communities, when macrophyte cultivation is applied for ecological restoration (Köbbing et al., 2013).

Increases in the demand for livestock products have been driven largely by human population growth, income growth and urbanization (Thornton, 2010). Thus, human population growth throughout developing countries increases demand for feed all over the world. Encouraging bioenergy production could directly

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compete with forage-livestock production (Sanderson and Adler, 2008). Moreover, unstable production of feed has been caused by recent abnormal weather. Therefore, exploitation of alternative feed resources is necessary to meet the increasing demand. In recent years, the reed has attracted increasing interest for its potential as high-quality roughage because of its high N content, neutral detergent fiber (NDF), potassium, and magnesium (Baran et al., 2002; Kadi et al., 2012). From the viewpoint of potential large areas of reed bed (Guo et al., 2013) and the increasing number of CWs for wastewater treatment (Kadlec and Wallace, 2009), the reed could be a valuable source of roughage.

Efforts are required to manage the growth of *P. australis* and the nutrient values for roughage. The timing of the harvest of aboveground biomass of reed is one possible strategy, since it affects the annual rhizome resource allocation and aboveground regrowth (Asaeda et al., 2006). It has the potential to reduce subsequent regrowth because rhizome reserves are reallocated from the aboveground biomass (Karunaratne and Asaeda, 2004; Kühl et al., 1997). Several studies have reported that winter harvest promotes subsequent aboveground regrowth (Granéli, 1989; Hansson and Granéli, 1984). On the other hand, contradictory reports have found that winter harvest does not affect aboveground biomass (Bjorndahl, 1985). Karunaratne and Asaeda (2004) reported that early summer harvest negatively affected regrowth, whereas Güsewell (2003) showed early summer harvest had no effect on biomass production. Furthermore, Fogli et al. (2014) reported that winter and summer harvesting only slightly decreased aboveground biomass in the riparian community, did nothing in the intermediate community, but significantly diminished biomass in fen meadows. Thus, the quantity of aboveground biomass production affected by the timing of harvest varies with locations and conditions.

To determine the most efficient vegetation management for sustainable utilization of reed bed, it is essential to understand the effect of harvest timing on aboveground biomass production. In addition, standing reed litter can have a direct detrimental effect on the reed itself, probably due to the creation of shade (Granéli, 1989). Thus, harvesting may influence canopy structure and morphology. It is also important to make clear the effect of harvesting on development of canopy structure for a better understanding of subsequent biomass production. The canopy structure has been investigated by several researchers, which just sampled once for the growing season (Hirose and Werger, 1995; Hirtreiter and Potts, 2012). Currently, little is known about seasonal changes of canopy structure.

As noted above, the timing of harvest is well known to affect subsequent biomass production. However, it remains unclear how the timing of harvesting affects the nutritive values of reed, total digestible nutrients (TDN), crude protein (CP), etc. We hypothesized different timings of harvest would affect the seasonal dynamic of nonstructural carbohydrate between shoots and rhizomes, and subsequently affect the nutritive values of roughage.

The present study aimed to explore the effective timing of harvest for managing the growth, and for using the regrown biomass as roughage for ruminants. To investigate the management implications of the different harvest times, we reaped reed shoot biomass in winter (January), spring (March), and early summer (May). Our final goal was to contribute to the establishment of vegetation management strategies able to improve both sustainable utilization of reed bed and nutritive values of roughage.

2. Materials and methods

2.1. Study site

Because of recent economic and population growth, Lake Dianchi has become the largest eutrophic lake in the Yunnan province of China, and has been listed in China's 'Three Important Lakes Restoration Act'. According to monitoring data from 2005 to 2012, annual concentrations of total N ranged from 1.82 to 3.01 mg L^{-1}, and those of total phosphorus ranged from 0.13 to 0.20 mg L^{-1} in the main water body of Lake Dianchi (Zhang et al., 2013). To resolve the eutrophication of the lake, a large number of CWs were established along the lakeside. Samples were obtained from a free-water system CW of Lake Dianchi in Jinning, Kunming, China (24° 46′ N, 102° 44′ E) with a surface area of 0.23 km^2 (Fig. 1). Effluent from the Nanchong River is discharged into the lake. Agriculture in this area is a major contributor of wastewater, which contains a high concentration of nitrate N (>10 mg N L^{-1}) and flows into the lake during the rainy season (Tanaka et al., 2013). The predominant vegetation is *P. australis*, cattail (*Typha* sp.), and manchurian wild rice [*Zizania latifolia* (Griseb.) Turcz. ex Stapf]. The water depth was 0 m, but the ground remained wet from February to May. The water depth increased from late June, reached a maximum of 0.6 m in August, and then decreased again from October onward. The water depth thus changed seasonally from 0 to 0.6 m at *P. australis* communities.

Lake Dianchi lies at an altitude 1880 m above see level, with subtropical highland climate in Köppen's classification. Hourly precipitation and air temperature data were obtained from the weather station (WeatherHawk Station, Campbell Scientific, USA) located in Xiaozhai village (E24° 41′ N, 102° 43′ E). Monthly cumulative rainfall and mean daily temperatures are shown in Fig. 2. The rainy season occurs from May to October, and annual rainfall was 654 mm in 2013. The mean annual temperature was 16.3 °C, and the mean daily temperature reached a maximum of 23.6 °C on 26 June and a minimum of 0.3 °C on 16 December. Mean daily temperature was relatively high from May to July.

2.2. Plant harvest, sampling, and canopy structure analyses

The scheme for harvesting and sampling is shown in Fig. 3. In this study, harvest just represents the mowing treatment, and it does not mean sampling. Plots of *P. australis* 5.0 × 5.0-m in size were mapped and subsequently harvested on January 26 (Jan-harvest), March 30 (Mar-harvest), and May 31 (May-harvest) 2013, while an additional non-harvested plot (non-harvest) was retained. Jan-, Mar-, and May-harvests represent winter, spring, and early summer harvesting, respectively. We assumed that practical harvest management was applied at a height of 40 cm for roughage use. Thus, plants were cut at a height of 40 cm above the ground.

Three replicate samples of the aboveground standing biomass within a 0.5 m^2 (1.0 × 0.5 m) frame were taken in the non-harvest plot on 26 January and in each experimental plot on 3–4 November 2013. Samples were always taken from previously unsampled new quadrats by cutting with a sickle at ground within a visually homogeneous pure stand with uniform shoot density.

Canopy structure and light distribution within a canopy were determined on 20–21 March, 22–24 May, 22–23 July, and 19–20 September 2013 by applying the stratified clipping method described by Monsi and Saeki (1953). Two 1.0 × 0.5-m quadrats were marked in reed stands of each experimental plot (Jan, Mar, May, and non-harvest). The relative light intensity was measured using a LUX/FC Light Meter (TM-201, TENMARS, Taiwan). After measurement of light intensity, all the plants within the quadrat were cut with a sickle at ground level. Plants were cut into 0.4-m segments along the stem, keeping plant and leaf inclinations as natural as possible. The plant segments were placed into polyethylene bags for transport to the laboratory, where cut segments were sorted as stems, leaves, inflorescences, ears and weeds. As for samples gathered 50 days after harvest (DAH), the stems were classified into old and new stems by appearance. The old stems