EVALUATION OF SHORT-ROTATION WOODY CROPS TO STABILIZE A DECOMISSIONED SWINE LAGOON

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ABSTRACT

Fast growing tree stands represent an environmentally friendly, less expensive method for stabilization of decommissioned animal production lagoons than traditional lagoon closure. We tested the feasibility of using short-rotation woody crops (SRWCs) in central Oklahoma to close a decommissioned swine lagoon by evaluating the growth performance and nutrient uptake of two SRWCs. After backfilling a de-watered swine lagoon with soil, we planted sycamore (*Platanus occidentalis*) in 2008 and cottonwood (*Populus deltoides*) in 2009 at 2240 trees ha^{-1}. After three growing years, sycamore averaged 4.5 m and 4 cm in height and diameter respectively, whereas the two-year-old cottonwood averaged 5.8 m and 4.8 cm in height and diameter respectively. Cottonwood produced 16 Mg/ha of dry biomass and contained 193 kg/ha of Nitrogen (N) and 31 kg/ha of Phosphorous (P). Sycamore produced 8.5 Mg/ha of dry biomass and contained 72 kg/ha of N and 14 kg/ha of P.

INTRODUCTION

Livestock production has been one of the major agribusiness activities in the United States. Larger operations of swine, poultry, and cattle are being increasingly established over the past two decades (Thorne 2007). Liquid manure from the operations is stored in the lagoons. The lagoons contain the two most important nutrients in excess, Nitrogen (N) and Phosphorous (P), but also can be a source of pollution during run-off and/or leaching to the nearby water sources (Bicudo and others 1999) and may cause serious damages like hypoxia or anoxia to the aquatic life, for example, the dead zone of Gulf of Mexico (Rabalais and others 2002). Therefore, lagoon decommissioning has been a subject of great concern (Leffert and others 2008, Thorne 2007). Plants can be the best option for stabilizing the decommissioned lagoons since plants can prevent or at least reduce pollution and remove, degrade, or contain chemical pollutants, located in the soil and water (Chappell 1997, Doty and others 2007, Eapen and D'Souza 2005, Oyang and others 2002, Rockwood and others 2004, Schnoor and others 1995). Plants offer a lower cost and environmentally friendly technology with the benefit of woody biomass production (Eapen and D'Souza 2005, Leffert and others 2008, Paulson and others 2003, Rockwood and others 2004). Plants with fast growth, deep roots, and high water usage are very effective in the process (Nyer and Gatliff 1996). Short-rotation woody crops (SRWCs) can be an excellent option because these crops have the benefits of fast growth and high biomass production. SRWCs, for example, loblolly pine has relatively high ability to take-up, metabolize, and sequester nutrients (Will and others 2006). Similarly, SRWCs also have high transpiration, e.g., more than 38 cm of water per month per unit of ground surface area (Samuelson and others 2007). Sycamore (*Platanus occidentalis*) is one of the model species of SRWCs (Tuskan 1998) and can tolerate metal contaminated sites (Pulford and Watson, 2003). Cottonwood (*Populus deltoides*) also is an excellent candidate species due to its rapid growth rate and high nutrient requirement (Gochis and Cuenca 2000). *Populus* spp. growth responds positively to water from animal waste lagoons (Leffert and others 2008, Robinson and others 2000, Vose and others 2000). Thus, sycamore and cottonwood are suitable candidates for the dual purpose of lagoon stabilization and biomass production. The goal of this study was to test the feasibility of using SRWCs in central Oklahoma to close a decommissioned swine lagoon by evaluating the growth performance and the rate of nutrient removal by sycamore and cottonwood.

METHODS

STUDY AREA

The study area is located in Stillwater, OK, and owned by Oklahoma State University. Average annual rainfall in this area is 93 cm and average annual temperature is approximately 16^{o}C. Average growing season ranges from 225-230 days.

The 2-acre decommissioned lagoon that had been in operation for more than 50 years was prepared for planting by pumping the liquid out from the lagoon in November 2007. Once the sludge was exposed, the berm of the lagoon was mixed with the sludge material to create a level surface. A cap of mineral soil (10-30 cm deep) was placed over the sludge soil mixture compacted. In spring 2008, and unimproved bare-root sycamore seedlings (George O. White nursery, Licking, MO) were planted, whereas a mix of 25

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different 50-cm cottonwood cuttings from OK/TX selections from the same nursery were planted in spring 2009. Each species was planted in 4 separate randomly assigned plots at a1.8 m X 2.4 m spacing to achieve a planting density of 2240 trees per hectare. Immediately after planting, oxyfluorofen (Goal, DowAgroScienes) was sprayed to reduce competition. Directed sprays of glyphosphate were initiated in June to further reduce competition from weeds. Drip irrigation was provided as needed during the growing season.

DATA COLLECTION

Tree sampling—During October and November 2010, when the leaves were still on the trees (following two growing seasons for cottonwood and three growing seasons for sycamore), eight trees of each species were selected for harvest to ensure adequate representation of all tree sizes. Branches, leaves and stem (including bark) were separated and oven dried at 66^{o}C until constant weight. Different allometric equations were developed for separate biomass components for each species. However, bark biomass was estimated based on the total stem biomass. We assumed 20 percent of the total stem biomass was bark for cottonwood (Guidi and others 2008) and 10 percent of the total stem biomass was bark for sycamore (Cobb and others 2009). To account for leaf abscission before harvest, we estimated the proportion of leaf drop at time of harvest using data from five litter traps per plot. Litterfall was collected each month and the proportion of total litter that fell before harvest was calculated. Based on that estimate, we multiplied the standing foliage biomass of sycamore and cottonwood by 1.42 and 1.41 respectively.

The product of diameter at breast height (d) squared and height (h) was the best predictor for aboveground biomass based upon R^2 value. Hence, we measured d and h of all the remaining trees in December 2010 to estimate the dry biomass of the remaining trees.

Nitrogen and phosphorous uptake—Leaf, stem wood, stem bark and branch wood samples of air dried biomass components were collected for nutrient analysis at the time of harvest. Leaf samples were randomly selected from a minimum of 5 trees per plot. Wood samples and bark samples were taken from the top, middle and bottom portion of the harvested tree stems. No nutrient analysis on branch bark was carried out. The samples were sent to the SWFAL (Soil, Water and Forage Analytical Laboratory, Oklahoma State University) to determine N and P concentration. N and P contents were calculated by multiplying the biomass of each component by the concentration.

RESULTS AND DISCUSSIONS

ALLOMETRIC EQUATIONS

Ninety-seven percent of the sycamore and 90 percent of the cottonwood survived through the 2010 growing season. Allometric equations developed for both species are shown in Figure 1. The percent of variation explained by d^2h varied between 67 and 98 percent for the various biomass components. Similarly, studies have found d^2h to be the best predictor of aboveground biomass (e.g. Cole and Ewel 2006, Senelwa and Sims 1998, Verwust 1991)

ABOVEGROUND BIOMASS

Both species grew rapidly. Cottonwood trees were larger and taller than sycamore even though the sycamore trees were a year older. Wittmer and Immel (1978) also found faster growth for cottonwood. Fast growth in cottonwood has been attributed to its higher photosynthesis rate (Nelson 1984). Table 1 summarizes the average height, diameter and biomass partitioning of both species. The 3-year old sycamore attained the maximum height of 6.45 m and maximum diameter of 8.5 cm, whereas, average sycamore height and diameter were 4.47 m and 4.05 cm respectively, greater than the average reported by most other studies (e.g. Brinks and others 2011, Wittmer and Immel 1978). However, Davis and Trettin (2006) reported height of 5.45 m and diameter of 5.9 cm after the third growing season in a sycamore plantation. Our study showed that cottonwood attained the maximum height of 8.6 m and maximum diameter of 10.9 cm, whereas average height and diameter were 5.85 m and 4.85 cm respectively. A study done in 2-year-old cottonwoods in Missouri River floodplains showed that the average height and diameter reached 4.37 m and 3.8 cm respectively (Pallardy and others 2003). Higher yields in our study probably reflected the abundance of nutrients in the decommissioned swine lagoon and perhaps the advantage of better clonal stock.

On average, cottonwood had 16 Mg/ha of aboveground biomass, almost double that of sycamore, which produced 8.5 Mg/ha. SRWCs can produce more than 20 Mg of dry wood/ha/yr (Stolarski and others 2008, Szczukowski and others 2005). We expect the growth rates of our stands to increase during the next several years, the stands are now fully occupied and perhaps approach the 20 Mg/ha/yr growth rate. Pallardy and others (2003) reported the maximum of 16.1 Mg/ha of dry matter with an average being 11.7 Mg/ha in a two-year old cottonwood planted in the Missouri River floodplains. Heilman and Stettler (1985) reported 16.7 Mg/ha in two-year cottonwood stands. On the other hand, biomass for 3-year old sycamore was lower than what Wood and others (1976) reported. There are two possibilities for this: two of the sycamore plots had water logged conditions during some part of the growing seasons which may have reduced the growth and Wood and others (1976) study included fertilization and spacing treatments. The higher biomass for cottonwood than sycamore in our study was because of higher growth rate despite the younger age and lower survival. Moreover, most of the cottonwoods had multiple stems growing from the cuttings which led to the higher biomass. Also, the cottonwood clones had been selected for fast growth while the sycamore seedlings were unimproved.

Sycamore partitioned 44 percent of its aboveground biomass to stem-wood, 5 percent to bark, 22 percent to foliage and 29 percent to branch. Wood and others (1976) also reported that foliage biomass made up about 20 percent and that branch biomass accounted for 25 percent of the total yield in three-year old stands. Cobb and others (2008) reported a range of 64 to 78 percent stem biomass in 6-year-old sycamore stands with different treatments. Similarly, bark biomass was 6 percent, branch biomass content was about 15 percent of the total, whereas foliage biomass ranged from 8 to 21 percent and depended upon irrigation and fertilization. Compared to Cobb and others (2008), lower stem biomass partitioning in our study is due in part to the younger age of our stands; younger trees allocate more carbohydrate towards leaf area development and have not had time to accumulate large amounts of woody biomass.

Cottonwood biomass comprised 38 percent stem biomass, 9 percent bark biomass, 24 percent foliage biomass and 29 percent branch biomass. Our findings were similar to those of Coleman and others (2004) except that stem biomass was higher than ours because stem biomass included bark biomass in their results. A study by Baker and Blackmon (1976) in a 1-year old cottonwood also showed a similar trend of branch biomass, but foliage biomass was higher than our study implying that younger stands allocate their biomass towards leaf production. Similarly stem biomass (34 percent) (bark biomass not separated) was also lower because of age. Foliage biomass represents the current year growth only whereas stem biomass growth is the accumulation of woody biomass over time.

NUTRIENTS CONTENT

Each biomass component except stem-wood had higher N concentration (Harner and Stanford, 2003) in cottonwood than sycamore (Table 2). This higher concentration can probably contribute to the rapid growth of poplar trees (O'Neill and Gordon 1994). Foliar N concentration was highest of all biomass components, 2.5 percent in cottonwood and 1.9 percent in sycamore. Total N content in cottonwood was 193 kg/ha whereas P uptake was 31 kg/ha. Sycamore stands contained 72 kg/ha of N and 14 kg/ha of P. Our estimates of total N and P uptake do not include foliage uptake during previous growing seasons. To estimate total uptake from the site, the current values should be adjusted upwards based on estimated foliage production of previous years. Our study shows higher N content in the plant components on a per hectare basis when compared with most other studies of similar aged stands implying the abundance of N and fast growth at our site. N-uptake rate increases with increased available N (Coleman and others 2004). A study by van Miegroet and others (1994) found a range of 112-197 kg N/ha in three-year old sycamore, but this study included the direct use of N fertilizers at different amounts.

Once harvested, all aboveground woody biomass components and the nutrients in them are taken out from the lagoon. The foliage biomass was slightly below one-quarter of the total in both species and had a high N and P content; nutrients in the foliage can be removed by raking or blowing leaf litter off the site.

CONCLUSION

Our study illustrates that SRWCs can take up large quantities of N and P from the decommissioned lagoons and thus possibly reduce loss due to runoff and leaching. SRWCs planted in a decommissioned swine lagoon performed better than most other studies in terms of biomass and nutrient (N and P) uptake. Two-year cottonwood outperformed 3-year-old sycamore producing 16 Mg/hectare biomass. Similarly, 3-year-old sycamore also performed well, although exhibiting only half the production of cottonwood biomass. In addition, nutrient uptake was higher in cottonwood than sycamore due to both higher nutrient concentrations and greater biomass production. Growth rate and nutrient uptake should continue to increase in the coming years.

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Table 1—Average tree size and biomass for three-year-old sycamore and two-year-old cottonwood trees growing on a decommissioned swine lagoon in central Oklahoma. Values in the parenthesis represent the standard deviation.

			Biomass (kg)/tree			
Species	Height (m)	Diameter (cm)	Stem-wood	Bark	Leaf	Branch
Sycamore	4.47 (0.76)	4.05 (1.25)	1.89 (0.66)	0.19 (0.07)	0.87 (0.57)	1.12 (0.4)
Cottonwood	5.85 (1.21)	4.85 (1.78)	2.89 (1.79)	0.72 (0.45)	1.87 (0.93)	2.29 (1.84)

Table 2—Nitrogen (N) and Phosphorous (P) percentages in the aboveground biomass components of the species.

	Stem-wood		Bark		Leaf		Branch	
	N	P	N	P	N	P	N	P
Sycamore	0.49	0.16	0.79	0.13	1.86	0.2	0.57	0.14
Cottonwood	0.34	0.11	1.08	0.18	2.50	0.29	1.29	0.23

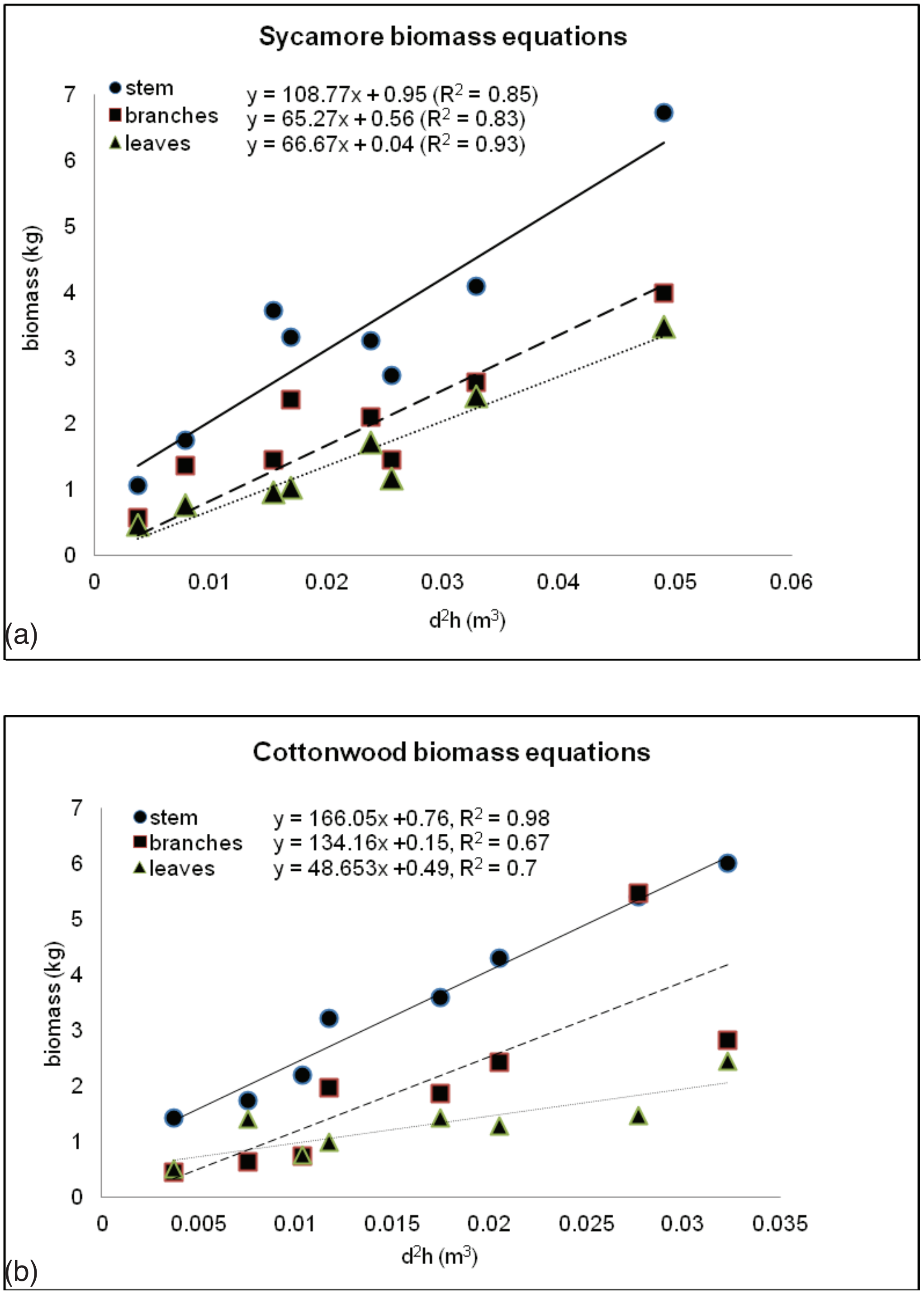

Figure 1—Allometric equations for each aboveground biomass components of (a) three-year-old sycamore and (b) two-year-old cottonwood trees growing on a decommissioned swine lagoon in central Oklahoma. Stem biomass includes both the stem-wood and bark biomass.