ELSEVIER

Journal of Environmental Management 85 (2007) 672–679

Journal of Environmental Management

www.elsevier.com/locate/jenvman

Biomass production and carbon sequestration potential in poplar plantations with different management patterns

S. Fang*, J. Xue, L. Tang

College of Forest Resources and Environment, Nanjing Forestry University, Nanjing 210037, PR China

Received 2 March 2005; received in revised form 24 July 2006; accepted 27 September 2006
Available online 15 November 2006

Abstract

Biomass production and carbon storage in short-rotation poplar plantations over 10 years were evaluated at the Hanyuan Forestry Farm, Baoying County, China. Experimental treatments applied in a split-plot design included four planting densities (1111, 833, 625 and 500 stems ha^{-1}) and three poplar clones (NL-80351, I-69 and I-72). Based on the model of total biomass production developed, total plantation biomass production was significantly different in the plantations. The ranking of the plantation biomass production by planting density was $1111>833\geqslant 625>500$ stems ha^{-1}, and by components was stem > root ⩾ branch > leaf for all plantations. At 10 years, the highest total biomass in the plantation of 1111 stems ha^{-1} reached about 146 t ha^{-1}, which was 5.3%, 11.6% and 24.2% higher than the plantations of 833, 625 and 500 stems ha^{-1}, respectively. The annual increment of biomass production over10 years differed significantly among initial planting densities and stand ages ($p<0.01$), but no significant difference was observed from age 7 to 10. Mean carbon concentration among all biomass components ranged from 42–50%, with the highest carbon concentrations in stems and the lowest in leaves. Over the study period, the dynamic pattern of total plantation carbon storage by planting density was similar to that of total biomass production. At age 10, the highest total plantation carbon storage in the plantation of 1111 stems ha^{-1} reached about 72.0 t ha^{-1}, which was 5.4%, 11.9% and 24.8% higher than in the plantations of 833, 625 and 500 stems ha^{-1}, respectively. The annual carbon storage increment over 10 years differed significantly among initial planting densities and stand ages ($p<0.01$), and it showed a pattern similar to the annual biomass production increment of the plantations. The results suggest that biomass production and carbon storage potential were highest for planting densities of 1111 and 833 stems ha^{-1} grown over 5- and 6-year cutting cycles, respectively. If 3- or 4-year cutting cycles are used, the planting density should be higher than 1111 stems ha^{-1} (e.g., 1667 or 2500 stems ha^{-1}). Based on the mean annual carbon storage for the plantation of 625 stems ha^{-1}, as an estimation, the mean carbon storage in the biomass of poplar plantations (excluding leaves) amounts to 3.75×10^{7} t ha^{-1} yr^{-1} in China.

Keywords: Poplar plantation; Planting density; Cutting cycle; Biomass production; Carbon storage

1. Introduction

Today's urgent need for substantive CO_2 emission reductions could be satisfied more cheaply through available sequestration technologies than by an immediate transition to nuclear, wind or solar energy (Lackner, 2003). Regarding the observed increase in the atmospheric concentration of CO_2 and the global climate question, forests offer two main options. First, the volume of atmospheric CO_2 may be reduced by increasing forest biomass. This may be achieved through an expansion of forests—either by planting currently unforested land, or by allowing the existing forests to accumulate higher biomass. The second main approach is to utilize forest directly as a source of raw materials for energy production, usually referred to as bioenergy, which is considered a carbon—neutral energy source. Use of bioenergy represents a positive contribution towards the CO_2 concentration problem if it replaces fossil fuels (van Kooten, 2000). Since trees are a terrestrial carbon sink (Houghton et al., 1998), managed forests in theory can sequester carbon both in situ (biomass and soil) and ex-situ (products).

*Corresponding author. Tel.: +86 25 85427345; fax: +86 25 85428682.
E-mail address: fangsz@njfu.edu.cn (S. Fang).

0301-4797/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2006.09.014

According to FAO (2000) estimates, forest plantations cover 187 million ha worldwide, a significant increase from the 1995 estimate of 124 million ha. The reported new annual planting rate is 4.5 million ha globally, with Asia and South America accounting for 89%. However, there is strong variation in the carbon sequestration potential among different plantation species, regions and management. Variations in environmental conditions can affect carbon sequestration potential even within a relatively small geographic area. In addition, management practices (e.g., fertilization) can easily increase carbon sequestration of species such as eucalypts (Koskela et al., 2000; Montagnini and Nair, 2004). Different estimates are available on carbon (C) sequestration rates of common plantation species of varying rotation ages (FAO, 2003).

When compared to other forest species, poplars have many characteristics that make them suitable for plantation culture which enable the production of large quantities of wood in short periods of time. These include fast growth, adaptability to different environmental conditions, and suitability for diverse silvicultural systems. Poplars and their hybrids have displayed the capacity for rapid biomass accretion (Anderson et al., 1983; Pallardy et al., 2003), and poplar wood is of increasing interest for use in long-term storage products such as lumber and oriented strand board. Hence an effective role may be envisioned for poplar plantations in CO_2 sequestration schemes, with perhaps even greater impact by using short-rotation poplar as a replacement for fossil fuels in energy production (Vitousek, 1991).

Since the introduction of some clones in the 1970s, poplars have been incorporated into many managed systems for production of timber and fiber throughout the south temperate central China which includes all or portions of Jiangsu, Anhui, Zhejiang, Hubei, Henan, Shandong and Shanxi provinces, an area of roughly 600 000 km^2 (Fang et al., 1999). Despite genetic variation in many traits within species and among hybrids of poplars (Dickmann et al., 2001; Fang and Yang, 2003), and their culture techniques are well documented (Dickmann et al., 2001; Fang et al., 2004), there has been little systematic study of the role of poplar plantations in CO_2 sequestration. Further, there has been no comprehensive study of how the management practices and poplar genotypes affect the CO_2 sequestration. The objectives of this research were to test different management patterns in short-rotation plantations for biomass production and carbon sequestration capacity on floodplain sites.

2. Materials and methods

2.1. Study area

The study area was located at Hanyuan Forestry Farm, Baoying County, Jiangsu Province, China (33°08′N, 119°19′E). The area has a warm temperate climate with a mean annual precipitation of 964 mm. The annual frost-free period is about 229 days long, and the average radiant intensity is 494.04 kJ cm^{-2}. Mean annual air temperature is 14.3 °C, with average temperatures of 0.4 °C in January and 27.6 °C in July. The clay loam soil has moderate fertility with organic matter content of about 0.84%, a pH value of 7.8, a total nitrogen content of 0.064%, available P and K contents of 1.76 and 67.57 mg kg^{-1} respectively, and Ca and Mg contents of 0.29% and 0.06% respectively. The water table is about 1.0 m and the bulk density of soil to 1.0 m is 1.35 g cm^{-3}.

2.2. Plantation design and establishment

The poplar plantation trial was established in 1992 with 1-year-old seedlings over an area of about 27.0 ha. A split-plot randomised block design was used to establish four planting densities in three blocks and three poplar clones in split-plots. The four planting densities were 1111 stems ha^{-1} (spacing: 3.0×3.0 m), 833 stems ha^{-1} (spacing: 3.0×4.0 m), 625 stems ha^{-1} (spacing: 4.0×4.0 m) and 500 stems ha^{-1} (spacing: 4.0×5.0 m). The three poplar clones were clone I-69 (*Populus deltoides* Bartr. cv. 'Lux', clone I-72 (*P. xeuramericana* (Dode) Guinier cv. 'San Martino' and clone NL-80351 which is a hybrid of clone I-69 × clone I-63 (*P. deltoides* Bartr. cv. 'Havard').

2.3. Sampling procedures

The mean-tree technique was used to assess the above-ground biomass, root biomass and carbon content of the poplar plantations. This technique involves destructive sampling of trees that best represent the mean size of a plantation and uses the number of trees in the plantation to expand mean-tree values to an area basis.

2.3.1. Sample tree selection

The selection of sample trees was based on multiple characteristics, i.e. the average DBH of the plantation and on the averages of total height and crown dimensions. Diameters at 1.3 m height of all trees on each plot were measured annually. Total height, crown width and crown height were measured for all trees within 15% of the mean DBH for each plot. The single tree closest to the means of DBH, height and crown features of each plot and with good form and vigour was selected for destructive sampling.

2.3.2. Destructive sampling

A total of 44 sample trees were cut at ground level in August or September: 4 trees in 1994 (one tree for each planting density), 36 trees from 1995 to 1997 (12 sample trees each year) and 4 trees in 2000 (one tree for each planting density). Each sample tree was divided into three components—stem, branches and foliage. The stem was cut into 2.0 m bolts, and stem samples were obtained from disks cut from the center of each bolt. The branches were divided into older branches, branches of intermediate age, current branches and dead branches. Green weights of all