BIOMASS AND BIOENERGY 51 (2013) 145–153

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Yield comparison of four lignocellulosic perennial energy crop species

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ARTICLE INFO

Article history:
Received 7 December 2012
Received in revised form
13 January 2013
Accepted 18 January 2013
Available online 14 February 2013

Keywords:
Virginia fanpetals
Biomass yield
The number of shoots
Moisture of biomass
Plant density
Giant Miscanthus

ABSTRACT

From 2006 to 2009, block template experiments were conducted to evaluate the biomass yield of four crop species—Amur silvergrass, Giant Miscanthus, Virginia fanpetals, and two Basket willow clones—at the University of Life Science, Lublin, Poland. The dry matter (d m) yields and number of shoots were determined each November, while biomass moisture levels were determined every November and March. The averages of the 4-year research datasets indicated that Giant Miscanthus produced the greatest biomass (16.5 t ha^{-1} d m), while the two Basket willow clones (8.8–10.2) t ha^{-1} d m, and Amur silvergrass (6.2 t ha^{-1} d m) produced the lowest biomass. The mean yield of Virginia fanpetals was 13.0 t ha^{-1} d m. The largest number of shoots per one m^2 were produced by *Miscanthus* species (55 units), with Basket willow and Virginia fanpetals producing half this amount (24–28 units). Similar moisture levels were obtained for Basket willow biomass harvested in autumn (49.5–54.6)% and winter (48.4–49.7)%. The biomass moisture levels of the other species in March was approximately two times lower (14–29)% than that in November (27–70)%.

In a second experiment, the effect of varying plant density (10 000 and 30 000 plants per ha) on the yield of Giant Miscanthus was investigated. Double the biomass yield was obtained in crops with a density of 30 000 plants per hectare compared to 10 thousand. The higher yields were accompanied by larger, heavier, taller, but thinner shoots.

1. Introduction

It is imperative to reduce greenhouse-gas emissions; therefore, the international community is continuously developing different strategies to protect the environment. Such actions aim to slow the pace of climate change. European Strategies [1,2] require a 20% reduction in carbon emissions by 2020, in addition, to suggesting the need for 20% of energy to be produced from renewable sources. The European Bioeconomy in 2030 envisions production and conversion of biomass playing a leading role [3]. Furthermore, many groups are calling for the total decarbonization of the economy by 2050. However, the realization of these ambitious scenarios is threatened in the biomass sector of Europe, because of the early and complete elimination of subsidies for the establishment of perennial dedicated energy crop plantations (non-food, second generation crops). These actions have certainly contributed toward reducing the surface area of these crops in Europe, which resulted in a rapid increase of import of pellets. For instance, according to an analysis by Wood Resources International, more than 2 million tons of wood pellets were shipped from the U.S. and Canada to Europe in 2011, which was a 300% increase from 2008 [4]. In simulations of the appropriate use of

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0961-9534/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biombioe.2013.01.017

low-carbon sources (i.e., solar radiation, wind energy, water, geothermal, etc.), or with the closed carbon circuit (biomass), it has been assumed that this trend of positive reaction to renewable energy sources (RES) should continuously grow until 2050, despite the ongoing financial crisis [5,6]. As a partial replacement for traditional energy materials (such as coal and petroleum), the use of bioenergy in the production of second- and third-generation biofuels [7], including biomass, will contribute toward slowing the rise in temperature on our planet. This in turn, will reduce the risks to the ecosystem, particularly due to the certified sustainability of biofuels [8]. The U.S. analysts expect greenhouse-gas emissions to decline by 19% in transport, and 6% in total in the U.S. economy by 2050 [9]. However, another study has indicated the potential negative effects of replacing minerals with biofuels. Examples include the negative effects of the costly (and for many people unethical) production of ethanol from corn, unprofitable cellulosic ethanol technologies, and unnecessary sugarcane-ethanol import from Brazil [10]. Other work has highlighted the benefits of using of non-food plants (perennial energy crops) on land unsuitable for food production [11,12]; however, the drawbacks of such solutions have also been noted [13,14]. Meanwhile, the global bio-economy invested 260 billion $ in 2011, which was an increase from the 211 billion $ invested in 2010 [15]. Further side effects that constitute tremendously beneficial consequences of these investments include the significant growth in employment in the new green economy. From an optimistic perspective, by 2050, the number of jobs in this industry is expected to exceed several million [16].

In various parts of the world, bioenergy resources are considered as primary energy sources. In agricultural areas that have large areas of unused land, the main source of renewable energy should be biomass [17,18] derived from field crops. In northern China, the extent of such set-aside areas is estimated to be 100 million hectare [19]. In the “25 × 25” program of the U.S., the establishment of plantations of energy crops covering an area of more than 40 million hectares is scheduled for 2025 [20]. The authors of the “Billion Tons Update Report” have predicted the scale of biomass production and space required for the cultivation of energy crops by 2030 in U.S.A. In the area of interest (perennials) with respect to the current study, depending of farm gate prices, a foundation of 9.3–21.5 million hectares of dedicated crops is required [21]. The implementation of these plans is based on the results of the Biomass Crop Assistance Program (BCAP), with an expected return of 75% of costs through establishing plantations. However, despite this support, much lower levels of interest should be expected, because of the unfavorable price offered to farmers for harvested biomass. The offered prices of dry biomass per ton are too low (24–27) $ compared to that expected (75–133) $ by farmers [22].

The potential of biomass production is enormous, since it is of importance for bioenergy, as well as the future of nonfuel by-products of biorefineries [6]. At present, calculations of available energy contained in biomass are subject to variation, ranging from 130 to 270 EJ/year around the world, by 2050 [23]. The simplest example is straw, which is the by-product of cereal grains production. At a local scale, straw delivers approximately 60 GJ of heat energy from 1 ha per year. In comparison, significantly greater amounts of biomass (and energy) may be obtained from dedicated perennial plantations of lignocellulosic crop species that grow in fields.

Among the known plants that are grown at larger or smaller scales in many countries are Giant Miscanthus, Reed canary grass, Basket willow, and poplar [24–26]. Among the species with high potential yield (10–25) t ha^{-1} d m under the climatic conditions of Europe and the U.S.A., many authors have suggested Giant Miscanthus, Switchgrass, and willow (Common osier), mainly basket [11,27–29]. High dry matter yield at 10–20 t ha^{-1} may be obtained from the cultivation of new crop called Virginia fanpetals (*Sida hermaphrodita* L. Rusby), which is a species that is little known outside of Poland [30]. We provided a brief description of *Sida* in our previous publication [31]. Furthermore, the biomass yield of Amur silvergrass is rarely matched by the above-mentioned species [19].

Plant species cultivated for energy purposes often do not have very high soil quality requirements. For instance, such plants may be grown in poor nutrient soils, sites threatened by erosion, rehabilitation-need sites, or on sites unsuitable for the cultivation of consumption crops. However, the meteorological requirements of such species are quite varied. For instance, *Miscanthus* × *giganteus*, which is a spontaneous sterile triploid discovered in Japan [32], combines the features of two species from Asia (*M. sinensis* and *Miscanthus sacchariflorus*), with better yields occurring during warm, humid summers. The young plants of this species do not tolerate low temperatures or water shortages, which could reduce establishment rates. Although Giant Miscanthus is a crop that is highly effective in its use of water [33], exceptionally high decreases in yield are sometimes experienced [34]. Willow, in contrast, requires a significant amount of water [27]. In comparison, Virginia fanpetals have both moderate temperature and precipitation requirements [30,31]. Further, low water requirements are characteristic of Amur silvergrass and other grass species [35], which may indicate yield stability regardless of the amount of precipitation during the growing season.

A particularly important characteristic of biomass for energy purposes is the moisture content of crops at harvest time. In this regard, there are significant differences between species. In autumn, the biomass water content may oscillate by approximately 50%. Herbaceous biomass harvested in winter (*Sida*, *Miscanthus*) has much lower moisture content, often less than 20% [30,36]. In the case of woody plants, such as willow or poplar, the timing of harvest has little effect on this trait [25]. Half the fresh mass content yield of these species is water. Such characteristics result in these crops requiring costly drying processes prior to storage and the formation of fuels (e.g. briquettes, pellets). Therefore, the results of comparative tests of energy crop species should assist in the selection of plants, the cultivation of which could result in economic success, while minimizing the impact of cultivation on the environment.

This paper presents the biomass yield results of several energy crop species grown under identical agroecological conditions.

During the research period, the weather conditions were subject to considerable variation. The data presented in Table 1 shows that the average annual temperature during the study