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Comparison of *Arundo donax* L. and *Miscanthus x giganteus* in a long-term field experiment in Central Italy: Analysis of productive characteristics and energy balance

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ARTICLE INFO

Article history:
Received 6 March 2007
Received in revised form
1 September 2008
Accepted 24 October 2008
Published online 30 November 2008

Key words:
Arundo donax L.
Miscanthus x giganteus
Energy crops
Dry matter production
Long-term evaluation
Energy balance

ABSTRACT

Miscanthus x giganteus (miscanthus) and *Arundo donax* L. (giant reed) are two perennial crops which have been received particular attention during the last decade as bioenergy crops. The main aim of the present study was to compare the above-ground biomass production and the energy balance of these perennial rhizomatous grasses in a long-term field experiment. The crops were cultivated from 1992 to 2003 in the temperate climate of Central Italy with 20,000 plants ha^{-1}, 100–100–100 kg N, P_2O_5, K_2O per hectare, and without irrigation supply. For each year of trial, biomass was harvested in autumn to estimate biometric characteristics and productive parameters. Besides, energy analysis of biomass production was carried out determining energy output, energy input, energy efficiency (output/input) and net energy yield (output–input). Results showed high above-ground biomass yields over a period of 10 years for both species, with better productive performances in giant reed than in miscanthus (37.7 t DM ha^{-1} $year^{-1}$ *vs* 28.7 t DM ha^{-1} $year^{-1}$ averaged from 2 to 12 years of growth). Such high yields resulted positively correlated to number of stalks (miscanthus), plant height and stalk diameter (giant reed). Moreover, these perennial species are characterised by a favourable energy balance with a net energy yield of 467 and 637 GJ ha^{-1} (1–12 year mean) for miscanthus and giant reed respectively. With such characteristics, both grasses could be proposed as biomass energy crops in Southern Europe with a significant and environmentally compatible contribution to energy needs.

1. Introduction

Perennial rhizomatous grasses, as miscanthus (*Miscanthus x giganteus*) and giant reed (*Arundo donax* L.) are generating much interest in Europe, as new sources of biomass for energy production.

There are many benefits expected from the production and use of these perennial grasses. They can give an important contribution to reduce anthropogenic CO_2 emissions because the quantity of CO_2 released by combusting biomass is does not exceed the amount that has been fixed previously by photosynthesis while the plants were growing [1–3]. In the other hand, the situation of agricultural sector in UE, characterised by food surplus, can be improved introducing alternative non-food crops as energy crops that can represent a new opportunity for the population of rural areas [4].

Furthermore these perennial grasses show some ecological advantages in comparison with annual crops. In fact

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0961-9534/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biombioe.2008.10.005

miscanthus and giant reed need to have a limited soil management (planting and related tillage), reducing risk of soil erosion [5] and determining a likely increase in soil carbon content and in biodiversity [6]. Moreover, due to the recycling of nutrients by their rhizome systems, perennial grasses have a low demand for nutrient inputs and since they have few natural pests, they may also be produced without pesticide use [7].

Giant reed native from East Asia is widely diffused in Mediterranean environment where it is frequently found in riparian habitats. Usually it does not set fruit because the pollen results unfruitful; consequently, the better propagation method, for this species, is the use of rhizomes [8].

Throughout the United States, from northern California to Maryland *A. donax* is an invasive weed [9], growing in water and is classified as an emergent aquatic plant [10]. Currently, in Europe this species has been indicated like one of the most promising for energy production for the Southern areas of Europe [11,12]. Its high biomass productivity has been observed also reducing crop inputs, such as fertilisation and plant density [13,14] and this high yield is furthermore stable in the long-term [15,16]. Giant reed has a C3 photosynthetic cycle, but it has high rates of photosynthesis and productivity similar to those of C4 species [17].

Miscanthus was a perennial C4 grass endemic to East Asia, introduced in Europe as ornamental plant about 50 years ago [18]. Therefore it is adapted to warmer climates [19] and in addition it has shown a good adaptation to the climatic conditions of Central and South Italy.

European research has focused on one single clone *M. x giganteus*, which is a sterile, triploid interspecific hybrid [20]. Its sterility necessitates vegetative propagation by rhizome division or in vitro cultures [21]. Yield above 30 t ha^{-1} $year^{-1}$ (dry matter) are reported for locations in southern Europe with high annual incident global radiation and high average temperatures but only with irrigation. In central and northern Europe where global radiation and average temperatures are lower, yields without irrigation are more typically 10–25 t ha^{-1} $year^{-1}$ (dry matter). Yield variation depends on the different rainfall amount and distribution and confirmed that water availability is an essential yield-determining-factor [22].

Miscanthus and giant reed were characterised by favourable energy balance and total input decreased from the establishment to following years of growth [22–24,7,15,16]. For miscanthus the input ratio is between 14:1 and 20:1 and nitrogen, energy and land use efficiencies were simultaneously highest with low nitrogen supply level [6].

The aim of this study is to carry out a 12-year long-term comparison of giant reed and miscanthus, in order to investigate the productive characteristics and the energy balance of these perennial grasses and to estimate their potentialities as energy crops under the climatic conditions of Central Italy.

2. Materials and methods

2.1. *Crop culture*

Two experimental fields were carried out in 1992, one with miscanthus (*M. x giganteus*) and one with giant reed (*A. donax* L.) at the experimental centre of Rottaia Pisa (43°40′N latitude, 10°19′E longitude; 2 m altitude).

The soil was a typical Xerofluvent, representative of the lower Arno River plan and it was characterised by a superficial water table, 120 cm deep in driest conditions (Table 1). The previous crop was barley. Tillage was conducted in the autumn of 1991 and consisted of medium-depth ploughing (30–40 cm). Seedbed preparation was conducted in the spring, immediately before planting, by a pass with a double-disk harrowing and a pass with a field cultivator. For miscanthus and giant reed planting rhizomes with a couple of buds weighing 500 g taken from plants were used. The rhizomes were planted at 10–20 cm of soil depth.

Pre-plant fertiliser was distributed at a rate of 100 kg P_2O_5 ha^{-1} (triple super phosphate), 100 kg K_2O ha^{-1} (potassium sulphate) and 100 kg N ha^{-1} (urea). Nitrogen fertiliser was applied in the establishment year (1992) as 50% pre-plant and 50% side dressing when plants were 0.30–0.40 m tall. In the following years, P_2O_5 and K_2O fertilisers were applied during the winter (approximately at the end of January) while N was applied entirely at the start of growth in the spring (approximately during March). Plots were kept weed-free by hoeing. No crop diseases were detected during the experimental period and irrigation treatment was never necessary during the different field experiments.

The experimental design was a randomised block with four replications (plots 10 m × 10 m each). Miscanthus and giant reed were grown in 0.50 and 0.50 m wide rows at a population of 20,000 plants ha^{-1}. From the establishment year onward, harvests were carried out in autumn at the end of each growing season.

The border plants in the outer rows were not included in the harvested area. Plants in a 10 m^2 area were harvested by cutting 5 cm above-ground level and weighed to determine fresh weight. Height, stem diameter and shoot number were also determined on a small sub-sample (plants on 2 m^2 area). The sub-samples were placed in a forced-draft oven at 75 °C for 72 h and ground after determination of the dry weight.

Daily changes in air temperature and daily rainfall were recorded along the growing cycle at nearby whether station. The mean thermal time in growing degree days (GDD) was

Table 1 – Soil physical and chemical characteristics in *Arundo donax* and *Miscanthus x giganteus* field trials.

	Arundo donax	*Miscanthus x giganteus*
Sand (2–0.05 mm) (%)	44.3	41.9
Silt (0.05–0.002 mm) (%)	42.3	44.5
Clay (<0.002 mm) (%)	13.4	13.6
pH	8.3	7.9
Organic matter (%)	1.63	1.81
Total nitrogen (Kjeldahl Method) (g kg^{-1})	1.35	1.17
Available phosphorus (Olsen) (mg kg^{-1})	8.8	10.7
Exchangeable potassium (Dirks and Scheffer) (mg kg^{-1})	106.2	108.2
Field capacity (wt %)	21.0	25.0
Permanent wilting point (wt %)	9.2	9.6

Soil horizon 0–0.30 m sampled on February 1992 before planting.