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Biomass yield and energy balance of three perennial crops for energy use in the semi-arid Mediterranean environment

M. Mantineo [a,*], G.M. D'Agosta [a], V. Copani [a], C. Patanè [b], S.L. Cosentino [a]

[a] *Dipartimento di Scienze Agronomiche, Agrochimiche e delle Produzioni Animali, Sezione Scienze Agronomiche (DACPA), Via Valdisavoia, 5 - 95123 Catania, Italy*
[b] *CNR-ISAFOM, Unità organizzativa di supporto di Catania, str.le V.Lancia, Zona Industriale, Blocco Palma I, 95121 Catania, Italy*

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A B S T R A C T

Three different lignocellulosic energy crops (a local clone of *Arundo donax* L., *Miscanthus x giganteus* Greef et Deu. and *Cynara cardunculus* L. var. *altilis* D.C. cv. "Cardo gigante inerme") were compared over 5 years (2002–2007) for crop yield, net energy yield and energy ratio. In a hilly interior area of Sicily (Italy), two different irrigation treatments (75 and 25% of ETm restoration) and two nitrogen fertilization levels (100 and 50 kg ha^{-1}) were evaluated in a split-plot experiment. In the fourth and fifth years of the field experiment (2005–2007) no fertilizer or irrigation was used.

From crop establishment to the third year, above ground dry matter yield increased over all studied factors, in *A. donax* from 6.1 to 38.8 t ha^{-1} and in *M. x giganteus* from 2.5 to 26.9 t ha^{-1}. Fifteen months after sowing, *C. cardunculus* yielded 24.7 t ha^{-1} of d.m. decreasing to 8.0 t ha^{-1} in the third year. In the fourth and fifth years, above ground dry matter yields of all crops decreased, but *A. donax* and *M. x giganteus* still maintained high productivity levels in both years. By contrast the yield of *C. cardunculus* yield fell to less than 1 t ha^{-1} of d.m. by the fourth year.

Energy inputs of *A. donax* and *M. x giganteus* were higher in the year of establishment than that of *C. cardunculus* (34 GJ ha^{-1} for *A. donax* and *M. x giganteus* and 12 GJ ha^{-1} for *C. cardunculus*), mainly due to irrigation.

Net energy yield showed low or negative values in the establishment year in *A. donax* and *M. x giganteus*. In the second and third year, net energy yield of *A. donax* was exceptionally high (487.2 and 611.5 GJ ha^{-1}, respectively), whilst *M x giganteus* had lower values (232.2 and 425.9 GJ ha^{-1}, respectively). *M x giganteus* attained its highest net energy yield in the fourth year (447.2 GJ ha^{-1}). Net energy yield of *C. cardunculus* reflected energy output of the crop, being high in the first compared to subsequent years (364.7, 277.0 and 119.2 GJ ha^{-1}, respectively for the first, second and third years).

A significant effect of the different irrigation treatments was noted on all the studied parameters in all species. Conversely, only *A. donax* was affected by nitrogen fertilization.

1. Introduction

Increasing biomass use is one of the key tools proposed by the European Community to reduce its dependence on imported oil and oil products, thus improving the security of energy supply in the medium and long term (European Biofuels Technology Platform, 2008). Moreover, biomass use on a global scale could contribute to improving the environment, given that biomass sources are 'carbon neutral' since the carbon they emitted into the atmosphere when burned is offset by the carbon that plants absorb from the atmosphere whilst growing (Royal Society, 2008).

Several biomass feedstocks for energy can readily be produced in the EU, such as those from arable crops currently grown for food: sugar, starch and oil crops, forestry or domestic waste and marine biomass. However, it is also possible to increase the production of dedicated crops, the 'energy crops', "*that are bred or selected to produce biomass with specific traits that favour their use as an energy vector*" (European Biofuels Technology Platform, 2008).

One of the most promising sources of biomass are lignocellulosic crops that can be used for the production of heat and electricity by means of direct combustion or the production of biofuel and biogas from pyrolysis and gasification these are already mature technologies. The production of so called 'second generation' biofuels, like BTL-biomass to liquid, SNG-gas-synthetic gas, bio hydrogen, and in particular 2nd generation bioethanol which can be derived from a feedstock rich in cellulose and hemicelluloses, could open up new frontiers for lignocellulosic crops (Yang and Wyman, 2008).

Research carried out in recent years in the Mediterranean environment, where the constraints are low water availability and

* Corresponding author. Tel.: +39 095 234480; fax: +39 095 234449.
E-mail address: md.mantineo@unict.it (M. Mantineo).

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high temperatures during summer, have indicated giant reed, *Miscanthus* spp. and cardoon are among the most promising species for energy and cellulose production (Lunnan, 1997; Foti and Cosentino, 2001; Anatoly and Pereira, 2002; Cosentino et al., 2005, 2007, 2008; Christian and Haase, 2001; FAIR3 CT96-2028, 2000; Jones and Walsh, 2001; Lewandowski et al., 2000). These unimproved perennial species produce considerable amounts of lignocellulosic biomass; they are either native to the Mediterranean area (cardoon), naturalised in these environments (giant reed) or again have good adaptation capacity (*Miscanthus*).

As a first consideration, the use of energy crops presupposes a close scrutiny of the energy accumulated and used in their production because according to Lewandowski and Schmidt (2006) "*only crops that yield significantly more energy than is required to grow them are suitable energy crops*".

Energy balance was a much-debated topic in the early 1970s during the first world energy crisis (Pimentel et al., 1973). It has also been widely discussed recently mainly due to environmental emergencies and the high prices of fossil fuels.

Indeed, there is growing interest in considering the energy balance of crop production, since energy parameters may be used as indicators of environmental effects and the sustainability of plant production (Girardin et al., 2000; Hülsbergen et al., 2001). Energy balance is an adequate instrument to identify an efficient energy crop (Boehmel et al., 2008); it has been performed on different energy crops, but a direct comparison of these results is very difficult because of the various methodologies used. Therefore, the aim of this study is to evaluate the yield and the energy balance of three species under the Mediterranean climate, using consistent methods so that the amount of energy used for irrigation and nitrogen application may be compared.

2. Materials and methods

2.1. Agronomic techniques

The field experiment was carried out in a 5-year period from 2002 to 2007 at Enna (Sicily, 550 m a.s.l., 37°23′N Lat, 14°21′E Long) in a typical Xerorthents sandy soil (USDA, 1975). The 1.20 m deep soil had the following properties: field capacity of 20.9% of dry weight at −0.03 MPa and wilting point of 10.6% of dry weight at −1.5 MPa, and apparent volumetric mass 1.2 kg m^{-3}.

Three different perennial lignocellulosic species were compared: *Arundo donax* L. (local clone Fondachello, Cosentino et al., 2006), *Miscanthus x giganteus* Greef et Deu. (provided by Piccoplant (Oldenburg, Germany) and *Cynara cardunculus* L. var. *altilis* D.C. cv. "Cardo gigante inerme"). *A. donax* L. and *M. x giganteus* were each transplanted on April 10th 2002 at 2 plants m^{-2}, whilst *C. cardunculus* was sown on May 30th 2002 at 1 plant m^{-2}.

The following factors were studied in a split-plot experimental design with three replicates: two levels of the water restoration in the soil of maximum evapotranspiration (ETm) (75 and 25%); two levels of nitrogen fertilization: 100 and 50 kg ha^{-1}, considering water restoration as main plot (48 m^2) and nitrogen fertilizing level as sub-plot (24 m^2).

Weed control was performed by manual hoeing only during the establishment year. No evident crop diseases were detected.

In *A. donax* and *M. x giganteus*, half the nitrogen fertilization was applied in spring, as ammonium sulphate, and half at the beginning of stem elongation, as ammonium nitrate. In the first year of the trial, *C. cardunculus* received one third of the nitrogen fertilizer at sowing as ammonium sulphate and two thirds at the leaf rosette phase using ammonium nitrate. In the following years half was applied at plant sprouting in September and half at stalk elongation in April–May as ammonium nitrate. The water was distributed by means of a drip irrigation system according to Cosentino et al. (2007). The crops have different thermal requirements; *Arundo* and *Miscanthus* grow in spring–summer, whilst *Cynara* grows in winter. *Arundo* and *Miscanthus*, being warm season crops, were irrigated throughout the summer season with the same amount of water and same schedule, whilst *Cynara*, since it dries off in summer, was irrigated during summer in the establishment year after sowing and again in September in the second and third years with just light waterings in order to activate sprouting. The amount of available water in the first 80 cm of the soil was 98.6 mm.

In the fourth and fifth years (2005–2007) all the plots were left without external inputs (fertilization, irrigation); no evident crop diseases were detected.

Air temperature, rainfall and class "A" pan evaporation were recorded, using a data logger and probe sensors (CR 10, Campbell Scientific, USA) located 100 m from the experimental field.

At harvest, in February–March for *Arundo* and *Miscanthus* and in August–September for *Cynara*, above ground biomass and its partitioning (stems or stalks, leaves and panicles or heads) were determined. Crops were harvested taking into consideration two factors: lowest humidity content and non-disturbance of the sprouting of the buds in spring.

Moisture content of each plant part was calculated by drying samples at 60° in a thermo-ventilated oven until constant weight was achieved. Moisture content was calculated as % oven dry weight. Homogeneous dried samples of the different parts of each plant were milled in a rotor mill prior to chemical analysis.

2.2. Crop water use (CWU), water use efficiency (WUE) and energy water use efficiency (EWUE)

For each water treatment, crop water use (CWU) and crop water use efficiency (WUE), were determined according to Cosentino et al. (2007). Crop water use (CWU) was determined with a water balance calculation in the period between sprouting and harvest by adopting the following formula: CWU = I + P where CWU = crop water use (mm); I = water supplied by means of irrigation (mm); P = precipitation (mm). Crop water use efficiency (WUE), expressed as the ratio of aboveground dry biomass production at final harvest to water used by the crop (CWU), was calculated.

Furthermore, at harvest the efficiency of water used by the crop was calculated on energy input (EWUE).

2.3. Chemical analysis and determination of N supply

Nitrogen content in samples of each plant part was determined by the Kjeldahl method (AOAC, 1990). The amount of protein was calculated as the following: protein (% of dry matter) = N% × 6.25 in order to calculate the energy output of aboveground biomass.

Ash content (dry weight basis) was measured after 15 h in a muffle furnace at 550 °C until constant weight.

2.4. Nitrogen use efficiency (NUE) and energy nitrogen use efficiency (ENUE)

Nitrogen use efficiency (NUE), which indicates the total biomass produced per unit of N uptake, expressed as the ratio of dry matter production to nitrogen content (g g^{-1}), was calculated according to Beale and Long (1997). Energy nitrogen use efficiency (ENUE), which indicates the energy output per unit of N uptake, is calculated as the ratio of energy output to nitrogen content.

2.5. Energy balance

In order to analyse energy inputs, dates of execution, technical means and materials used, and execution time of farming