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Assessing the efficiency of switchgrass different cultural practices for pellet production

Kyriakos D. Giannoulis[a,*], George Vlontzos[b], Theodore Karyotis[c], Dimitris Bartzialis[a], Nicholaos G. Danalatos[a]

[a] University of Thessaly, Department of Agriculture, Crop Production & Rural Environment, Laboratory of Agronomy and Applied Crop Physiology, Fytokou Str., 38446 Volos, Greece
[b] University of Thessaly, Department of Agriculture, Crop Production & Rural Environment, Fytokou Str., 38446 Volos, Greece
[c] Institute for Soil Mapping and Classification, Larissa, Greece

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ABSTRACT

Switchgrass is a perennial crop producing high amounts of biomass for good quality pellet production. The objective of this study is to examine the efficiency of different cultural practices of switchgrass for pellet production under field conditions for four different N-fertilization (0, 80, 160 and 240 kg ha^{-1}) and two different irrigation levels (0 and 250 mm), in two soils in central Greece with rather different moisture status over the period 2009–2012. Moreover, comparison between three harvest methods (two different types of bales and silage) was made. The results derived from this study revealed that the bale at 22 kg is the harvesting practice with the highest costs while there was reduction of efficiency scores when nitrogen levels increased. At both environments the efficiency scores followed the same trend, confirming that low levels of nitrogen fertilization enhance the economic competitiveness of switchgrass production. Palamas site is the area where switchgrass for pellet production had positive income ranging from 400 to 1600 € ha^{-1}, while Velestino site had always negative. Therefore, places like Velestino with non-aquic soil should be avoided for switchgrass. These data suggest that growing switchgrass for solid biofuel production as energy crop is a worthwhile decision only in areas with a moderately shallow groundwater table (aquic soil) or maybe in high precipitation regions.

Introduction

During the past two decades the major objectives of world energy policy were the reduction of carbon emissions, the environmental protection and the sustainable energy. Currently, many countries establish goals for biofuel production. Today, biofuel production, in most countries, is far below of their goals. Therefore, many countries will try to achieve their targets through imports (Zah and Ruddy, 2009).

The Common Agricultural Policy (CAP), especially after the implementation of the Agenda 2000, has set a series of environmental preconditions which should be satisfied by the farmers, in order to be eligible for receiving both the decoupled and coupled subsidies. The new CAP framework for the 2014–2020 programming period reinforces the environmental conservation agenda, aiming to increase the efficiency of inputs being used during the agricultural production procedure.

One of the major objectives of the EU economic policy and development strategy is to become a low-carbon and resource-efficient economy. According to this goal by the year 2020 the EU should have increased by 20% the efficiency of energy use, decrease by 20% the CO_2 emissions and 20% of the overall energy being consumed should be produced by renewable energy resources (20-20-20 strategy) (European Commission, 2011). EU primary sectors of member states are expected to play a key-role for the success of this attempt. In many cases agricultural activities have focused environmentalists' attention regarding environmental degradation, such as misuse of energy resources, high CO_2 emissions, or overuse of nitrogen fertilizers (Haberl et al., 2004).

According to the above strategies, a solution could be the use of biofuels, produced especially from energy crops. On the purpose of this directive, experiments had to be conducted in Greece to determine the potential yield of new alternative energy crops

* Corresponding author. Tel.: +30 2421093129; fax: +30 2421093127; mobile: +30 6945550015.
E-mail addresses: Kyriakos.giannoulis@gmail.com (K.D. Giannoulis), gvlontzos@agr.uth.gr (G. Vlontzos), theodorekaryotis@gmail.com (T. Karyotis), dbartz@uth.gr (D. Bartzialis), danal@uth.gr (N.G. Danalatos).

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and the required cultivation inputs. Moreover, the increasing price of fossil fuels and energy, the greenhouse gases reduction and the country's dependence on foreign energy sources urge the use of more and more renewable energy. Biomass which can be applied for several uses (heat, electricity, transportation fuel, etc.) is an important renewable energy source. "Direct utilization" (heat-electricity) and "indirect utilization" (transportation fuel) are two alternative classifications, of biomass energy (Mizsey and Racz, 2010).

Energy crops, with emphasis on the perennial ones, seem to fulfill these goals. It has been worldwide accepted, that they produce high yields, depending on the crop species and the geographic location, which can be converted into energy, while sinking large amounts of carbon into the soil (Tolbert et al., 2002).

Furthermore, carbon emission released to the atmosphere is negative or equal to zero because during the process of photosynthesis the absorbed CO_2, during every cultivation cycle, is released in combustion progress on a yearly basis. Moreover, second generation biofuels from lignocellulosic crops, have high energy efficiency and low greenhouse gases emissions (Borjesson and Tufvesson, 2011).

The perennial energy crops have received higher attention, due to their suitability for marginal land, their high productivity under low water (Tolbert and Wright, 1998) and nutrient requirements and the environmental benefits associated with their cultivation (Venturi and Venturi, 2003). Due to the crops' perennial nature, cultivating practices (e.g. harrowing, plowing, seeding, etc.) take place only once in the establishment year, preventing soil degradation during subsequent years (Vaughan et al., 1989).

Several perennial herbaceous crops have been evaluated for energy purposes in past. Among the aforementioned crops, perennial grasses such as miscanthus [*Miscanthus* × *giganteus* (Greef & Deuter ex Hodkinson & Renvoize)] and switchgrass (*Panicum virgatum* L.) appeared as the most promising ones, because of the yield levels they achieve, the significant environmental attributes regarding the production functions they use, like soil and water and possible farmers' income increase (Lewandowski et al., 2003). The disadvantage of miscanthus is that is propagated by expensive rhizomes compared with the achieved revenue, while switchgrass is established by seeds. This makes switchgrass easily integrated into existing farming practices, as already purchased mechanical equipment can still remain operational (Monti et al., 2001).

Switchgrass comprises an important energy crop, due to its perennial character and its high productivity as a warm-season C4 grass. Tolerance to heat, cold and drought have enabled adapted ecotypes of switchgrass to inhabit regions throughout North America (Casler et al., 2007). Switchgrass is divided into two general ecotypes: (i) lowland ecotypes (vigorous, tall, thick-stemmed, well adapted to wet conditions) and (ii) upland ecotypes (shorter, thinner-stemmed, well adapted to drier conditions) (Gunter et al., 1996).

It is only recently that switchgrass has been introduced into Europe as a potential energy crop. However, several studies presented promising results and it is now clear that switchgrass, depending on its ecotype, can be cultivated throughout Europe according the proper ecotype adjusted to the prevailing climate conditions (Venturi et al., 2004).

The prospect of switchgrass for Greek farmers as an alternative crop depends on the possibility to obtain large biomass amounts at low production cost. To evaluate this, agronomic and cultivation parameters such as water and nitrogen input requirements, cultivar selection, and harvesting time-scheme should be determined. Considerable information on switchgrass agronomy and biomass productivity has been reported mainly from USA (VanLoocke et al., 2012; Boyer et al., 2013).

In field experiments carried out in Italy and southern Greece (Aliartos site) was shown that switchgrass yield increased in Italy until the third year of establishment, while in Aliartos, the yield was stabilized at the second year for a range of cultivars (Alexopoulou et al., 2008). Finally, Piscioneri et al. (2001) found that cv. Alamo reached a maximum plant height of 187 cm and performed dry matter yield of 15.5 t ha^{-1}.

Few data are reported about the economic performance of switchgrass in Europe and especially in Greece and this is surprising as the feasibility of growing switchgrass will depend on it. Only few studies in North America have been published, showing that switchgrass has low cost per dry ton of biomass (Downing and Graham, 1996; Hanegraaf et al., 1998). Different market prices are reported to be ranging from 44 to 85 US $ t^{-1} for switchgrass dry yield, with the profitable price being in the range of 70–85 US $ t^{-1} (McLaughlin and Kszos, 2005; Fox et al., 1999). The minimum price of 44 US $ t^{-1} would be more profitable than conventional crops on at least 13 Mha of American farmland (Hallam et al., 2001).

Nowadays, switchgrass is grown in Greece on an experimental basis to produce solid biofuels. There are few data available on growth and productivity of switchgrass as energy crop from southern Greece and almost none for the cultivation costs of this crop. Considering that any assessment of land use performance needs to quantify the biophysical production potential, followed by analyses of productivity at lower levels of inputs and intensity of management practices, this paper sought to report the cultivation costs and estimate the yield and the harvesting system under which switchgrass cultivation is economically viable in Greece and the Mediterranean basin in general.

Materials and methods

Field experiment

To evaluate the economic efficiency of switchgrass cultivation for biomass and solid biofuel (pellets) production, two field experiments were established in two different soils, e.g. in Palamas (West Thessaly or Karditsa plain) and in Velestino (East Thessaly or Larissa plain), central Greece, in the period 2009–2012.

Palamas soil is a deep, calcareous (pH = 8.3), sandy loam to loam (sand 37–45%, loam 51–43%, clay 12%), moderately fertile (0.9% organic matter content at 40 cm depth). Moreover, the soil is characterized by a groundwater table fluctuating from some 2 m below the soil surface (receives artificial drainage) in May, to deeper layers later in the summer and is classified as Aquic Xerofluvent. On the other hand, Velestino soil is a calcareous (pH = 8.1–8.3), clay loam to clay (sand 19–21%, loam 39–41%, clay 38–42%), fertile (organic matter content of 2.3–2.7% at 40 cm depth) and was classified as Calcixerollic Xerochrept, according to USDA.

At both sites, the tested cv. Alamo was sown (lowland ecotype supplied from Colorado, USA) in June 2009, applying 7 kg seed ha^{-1} at a row distance of 12.5 cm, using a modern cereal machine.

A 2 × 4 split–plot experimental design was used with four replications (blocks) and eight plots per replication (8 × 4 = 32 plots). Irrigation comprised the main factor [I1 = 0 mm, I2 = 250 mm (250 mm is the quantity of water that Greek farmers are able to supply due to their equipment and the water availability of the field drillings)], and N-fertilization comprised the sub-factor (N1 = 0, N2 = 80, N3 = 160, and N4 = 240 kg N ha^{-1}; the used fertilizer was urea 46-0-0). Plot size was 48 m^2 (6 m width × 8 m length).

In this paper, only the harvest biomass data are further analyzed, as they refer to the use of switchgrass biomass for solid biofuel production.