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Comparison of two perennial energy crops for biomass production at the end of their life cycle

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Abstract. Nowadays fossil fuels are decreasing, causing the world's interest in renewable energy sources to rapidly grow. One of the most interesting renewable and ecologically pure fuels is biomass, which is considered to be carbon neutral. Biomass is a promising source of energy, as it can be used directly as an energy resource. Its quality characteristics such as gross calorific value and ash content are of paramount importance so as to improve the combustion process. Furthermore, during the last three decades, there has been an increasing interest in the production of biomass pellets for domestic and industrial use. Alternative feed stocks will need to be sourced to meet the demand for biomass pellets. Investigation for new energy crops that produce high amounts of biomass under low inputs and of high energy efficiency are the main tasks of this field. Therefore, the aim of this study is to assess the biomass yield and the quality characteristics (gross calorific value and ash content) of two perennial energy crops (*Cynara cardunculus* L. and *Panicum virgatum* L.) growing in a typical soil (*Fluventic Xerochrept*) of the main agricultural land of central Greece. The comparison for both cultivated crops was made in order to show the results during their 8th growing year. The examined factors were the irrigation (two levels: irrigated and rainfed) and the nitrogen fertilization (two levels: 0 and 80 kg N ha^{-1}) as well as their effect on the dry biomass yield and the gross calorific value. It was found that higher dry biomass yield was produced from cardoon (21.3 vs. 14.23 t ha^{-1}), while the higher average gross calorific value was observed for switchgrass biomass (17.31 vs. 15.65 Mj kg^{-1}). Finally, multiplying the dry biomass yield (t ha^{-1}) with the gross calorific value (Mj kg^{-1}) it was found that 334 and 245 Gj ha^{-1} from a cardoon and a switchgrass cultivation could be produced, respectively. Cardoon has better results than switchgrass probably due to the fact that switchgrass is growing from March till October; while cardoon's growing period is from October to June and in such areas precipitation is in shortage during summer months. Both crops could achieve high amounts of energy per hectare and thus their introduction in future land use systems, for an environmentally friendly energy production should be seriously taken into consideration.

Key words: cardoon, switchgrass, yield, gross calorific value, biomass.

INTRODUCTION

Nowadays fossil fuels which are used by people on a daily basis are decreasing and therefore the world's interest in renewable energy sources is rapidly growing. One of the most interesting renewable and ecologically pure fuels is biomass (Li et al., 2012; Kosov et al., 2014; Nishiguchi & Tabata, 2016). The use of biomass for energy generation is considered to be carbon neutral, since its harvest is carried out from a source achieved in a sustainable way (Acda & Devera, 2014).

Biomass is an organic product generated by a natural process (Kunecova & Hlavač, 2019) and constitutes a promising source of energy, as it can be used directly as an energy resource and will help to reduce greenhouse gases (Pizzi et al., 2018). Biomass quality characteristics such as moisture content, gross calorific value, volatile matter, fixed carbon, and ash content are of paramount importance. Such knowledge is quite important so as to improve the combustion process (Torgrip et al., 2017). In particular, calorific value is an essential parameter in the specification of biomass quality to set the price of the product. It has been referred that moisture content affects biomass gross calorific value negatively (Preece et al., 2013; Posom et al., 2016), while increases the final costs due to increased transportation and drying costs (Everard et al., 2012; García et al., 2014). Ash content affects combustion efficiency (García et al., 2014; Toscano et al., 2016), its knowledge is applied for the operating combustion systems (Liu et al., 2014) and finally, the remaining amount must become known so that it could be stored for further management (e.g. use in compost manufacturers).

Furthermore, during the last three decades, there has been an increasing interest in the production of biomass pellets for both domestic and industrial use (Gil et al., 2010; Toscano et al., 2014). In the beginning, pellet manufacturers were using sawdust and wood shavings as a feedstock (Arshadi et al., 2008; Carroll et al., 2012). The rapid increase of pellet use for heating in many countries raised the issue of consuming sawdust but in some countries firewood as well (Carroll et al., 2012). Therefore, alternative feedstocks will need to be sourced to meet the demand for biomass pellets.

Investigation for new energy crops that produce high amounts of biomass under low inputs and of high energy efficiency are the main tasks of this field. There is a considerable number of energy sources from biomass for biofuel production. These sources are mainly plant remains of agricultural crops, waste of woodworking industry and energy crops such as miscanthus, giant reed etc., (Christou et al., 2001; Da Borso et al, 2018).

There are different divisions that someone could make for energy crops. The most common one is in annual and perennial, according to their nature. Perennial energy crops are well acclimatized to the certain conditions and form high yield of biomass grown on non efficient soils, indicating their low input requirements. Such crops are cardoon, silver grass, switchgrass, miscanthus and others.

Switchgrass (*Panicum virgatum* L.), a warm-season (C4) perennial grass with a deep-root system, requires limited use of fertilizers (Giannoulis & Danalatos 2014). Switchgrass has been investigated as a biofuel co-fired with coal for power generation (McLaughlin et al., 2005; Qin et al., 2006). Switchgrass produces its biomass mostly in dry Mediterranean areas during spring and summer, where extended and extreme summer drought occurs frequently, which can be a major factor in the reduced yields and survival of plants (Clifton-Brown et al., 2001; Vamvuka et al., 2010). In literature a remarkable decrease is mentioned in both the leaf area index (Barney et al., 2009) and biomass productivity (Petrini et al., 1996; Vamvuka et al., 2010; Cosentino et al., 2014; Giannoulis & Danalatos, 2014), which was the result of prolonged severe drought. Therefore, irrigation support in such areas as the Mediterranean basin is needed in order to ensure high biomass production, where crop growth is restricted by low water availability and high evapotranspiration rates during the summer (Vamvuka et al., 2010; Zema et al., 2012).

On the other hand, cardoon (*Cynara cardunculus* L.) is a perennial C3 crop, sown early in autumn (Giannoulis et al., 2011). Cardoon is characterized as a crop of its deep-root system which forms a leaf rosette during winter, while flowering stem elongates in spring, and the flowering heads appear in June. Cardoon produces its high biomass during spring and summer (Danalatos et al., 2006), and re-grows after the first rains in autumn. The dry biomass is harvested during July (with a plant moisture content of 15%). The crop produces annual biomass up to 10 years (Fernadez et al., 2006).

The increasing interest for new crops with modest inputs and cultivation requirements, as well as the increasing interest for alternative renewable environmental friendly energy has led the scientific community to the investigation of the yield of energy crops. These crops are divided into two large categories: i) the annual and the perennial. In the case of the perennial crops, most of the studies refer to the biomass production till the fourth year of their growth (Christou et al., 2001; Danalatos et al., 2006; Fernadez et al., 2006; Giannoulis & Danalatos, 2014; Giannoulis et al., 2016). There is none or limit of literature about the yield and the gross calorific value of the biomass produced at the end of the productive life cycle of such perennial crops like cardoon and switchgrass (8–10 and ≥ 10 productive years for cardoon and switchgrass, respectively; Fernández et al., 2005; Angelini et al., 2009; Amarasekara, 2014). Therefore, the aim of the current study was the investigation of the yield of these perennial plants (cardoon and switchgrass) towards the end of their production cycle (8th growing year) and the energy efficiency of the above-mentioned biomass yield under moderate low inputs.

MATERIALS AND METHODS

Two field experiments were established in 2008–2009 in a typical soil-climatic Mediterranean environment in Thessaly plain, central Greece (East Thessaly; Velestino area; Magnesia) to evaluate the effect of moderate irrigation and distinct nitrogen dressings on cardoon and swithcgrass (Alamo variety) yield. The results of the present study refer actually to the experimentation year 2017–2018, where the cultivations were in their 8th growing year. The experimental site is located at 39° 02′ N and 22° 45′ E (Velestino area; Magnesia). Velestino soil was classified as Calcixerollic Xerochrept, according to USDA (1975). Soil characteristics are presented in Table 1.

Table 1. Soil characteristics in depth 0–40 cm

	pH	Composition			Organic	Total N,	Available P	Available K
		Sand, %	Silt, %	Clay, %	Matter, %	%	(mg kg^{-1})	(mg kg^{-1})
0–10 cm	8.3	21	41	38	2.7	0.47	8	254
10–40 cm	8.1	19	39	42	2.3	0.1	4	178

A 2×2 factorial split-plot design was used (during all the cultivating years) with four replications (blocks) and four plots per replication (4×4 = 16 plots per crop). Irrigation comprised the main factor (two levels: moderate irrigation-150 mm and rainfed) and the nitrogen fertilization as the sub-factor (two levels: 0 and 80 kg N ha^{-1}) with four replications. Plot size was 33 m^2 (11 m width ×3 m length). The choice of moderate irrigation was made because there is an increased cultivation cost in the wider area due to the high cost of pumping water from the deep underground aquifer (average pumping depth 170 m). In the last fifteen years there has been an effort to find crops of satisfactory yield using low inputs. It has to be mentioned that irrigation water was supplied by 5 equal doses (30 mm each) during March - May in cardoon case and during May - August in the case of switchgrass cultivation.

No pesticides were used because the crops were in their 8^{th} growing year and were more competitive, but even during the establishment year all plots were hand weeded and no pesticides were used.

Biomass yield and calorific value measured during final harvest (end of June and end of September for cardoon and switchgrass Alamo variety, respectively). The plants were cut 8–10 cm above ground and in order to avoid any border effect, 1 m^2 in the inner plot was harvested. The samples were weighed in the field and then a sub-sample was taken for further laboratory measurements and air drying. Even in cardoon case where biomass was almost dried the sub-samples where air-dried so as to have the same moisture content (about 8%) in all studied samples.

Thereafter, the dry samples were chopped and grounded. After grinding, samples were placed in a stack of sieves, so as to obtain the geometric mean diameter of the sample and geometric standard deviation of particle diameter according to ASAE standard S319.3 (2001). Thereafter, an oxygen bomb calorimeter (Model C5000 Adiabatic Calorimeter, 2004) was used to determine the calorific value of each grind sample.

The weather data was recorded by an automated meteorological station on a daily basis, which was installed next to the experimental field.

Finally, the statistical package GenStat (7^{th} Edition) was used for the analysis of variance (ANOVA) within sample timings for all measured and derived data. The $LSD_{0.05}$ was used as the test criterion for assessing differences between means (Steel & Torrie, 1982) of the main and/or interaction effects.

RESULTS AND DISCUSSION

Weather condition

The experimental area is characterized by a typical Mediterranean climate with cool humid winters and hot and dry summers. Fig. 1 illustrates measured weather data during the cultivating period September 2017 (reemergence of cardoon) till September 2018 (switchgrass harvest). Actually, as depicted from Fig. 1, average temperatures in January and February were closed to 7 °C, showing a mild winter with no frosts that could offset the cultivation of cardoon which was at the rosette stage. Then, air temperature fluctuated around 12–13 °C in March and the first half of April and increased up to 20 °C in May. Finally, during the summer months the average air temperature fluctuated between 21.3 to 26.1 °C.

During cardoon growing period (September to half of June) about 320 mm of rain were recorded while only the 90 mm in spring and in June till harvest date (moderate irrigation period as shown above). On the other hand, during switchgrass growing period (reemergence in March and final harvest at the end of September) about 290 mm were recorded (Fig. 1). During May and the first ten days of June only 34 mm of precipitation were recorded, followed by a period of 20 days with high recorded rainfall (120 mm) and then (July till the first ten days of September) the observed rainfall remained low (90mm; moderate irrigation period, see above).

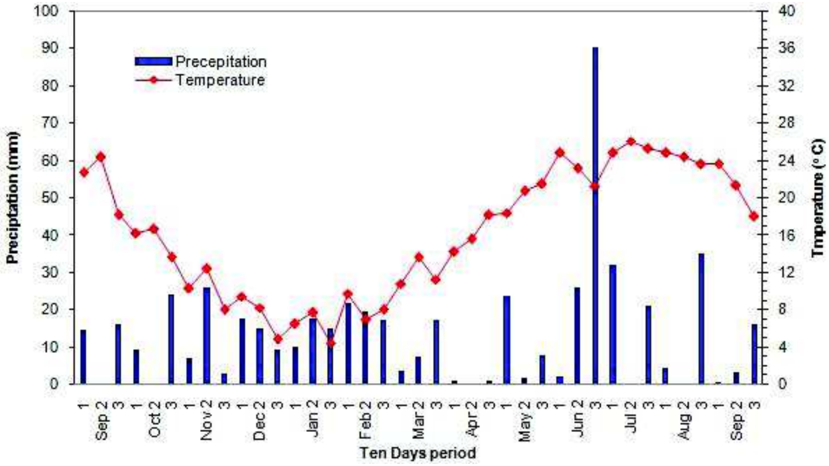

Figure 1. Mean 10-day air temperature and precipitation, recorded in the study area during the growing period of 2017–2018.

Yield

Switchgrass dry biomass yield was significantly affected ($P > 0.05$) by irrigation while nitrogen fertilization had no effect (Fig. 2). Dry yield was fluctuated between 9.34 to 14.23 t ha^{-1}, with the higher dry yield corresponds to the irrigated treatment without fertilization. This yield is lower than the reported yield of literature (Kimura et al., 2015; Collins et al., 2010; McLaughlin & Kszos, 2005) and almost the same (decreased by 2–2.5 t ha^{-1}) with the reported yield by Kimura et al. (2018), Nazli et al. (2018) and Boyer et al. (2013), although the switchgrass was in its eighth growing year. This fact proves that this crop retains its productivity even at an age that tends to embody its productive life cycle (≥ 10 growing years). However, due to the absence of groundwater table in such soils like the soil of the current site, biomass yields may remain at low levels even under (moderate) irrigation. As in these soils the effect of capillary rise is absent, 150 mm of irrigation water plus approximately 290 mm of rain (Fig. 1) comprise only 55% of the potential evapotranspiration.

In cardoon case, dry biomass yield was significantly affected only by nitrogen fertilization. The higher yield (21.31 t ha^{-1}) was found at rainfed treatments fertilized with 80 kg N ha^{-1}, while the lower (19.10 t ha^{-1}) for the irrigated unfertilized treatments.

The current results are generally in agreement with the available scientific literature from other studies in Mediterranean basin. Foti et al. (1999) reported a yield of about 18.8 t ha^{-1} in wild cardoon under low irrigation input (100 mm), while lower yields have been reported under rainfed conditions (Piscioneri et al., 2000; 10–15 t ha^{-1}). The dry biomass yields were equal with a 3–4 year average yield, reported by Mauromicale & Ierna (2004) and Raccuia & Melilli (2007) under low irrigation input (50 mm). Finally, the measured yield is in agreement with the dry biomass produced under supplementary irrigation (90 mm) that was reported by Vasilakoglou & Dhima (2014) in Central Greece, a site close to the study area. The difference with the previous reported study is that the cultivation was at the zenith of its productive life cycle whereas in the case of the present study cardoon was in the nadir, indicating that this crop retains its productivity even at an age close to the end of its productive life cycle (8–10 growing years).

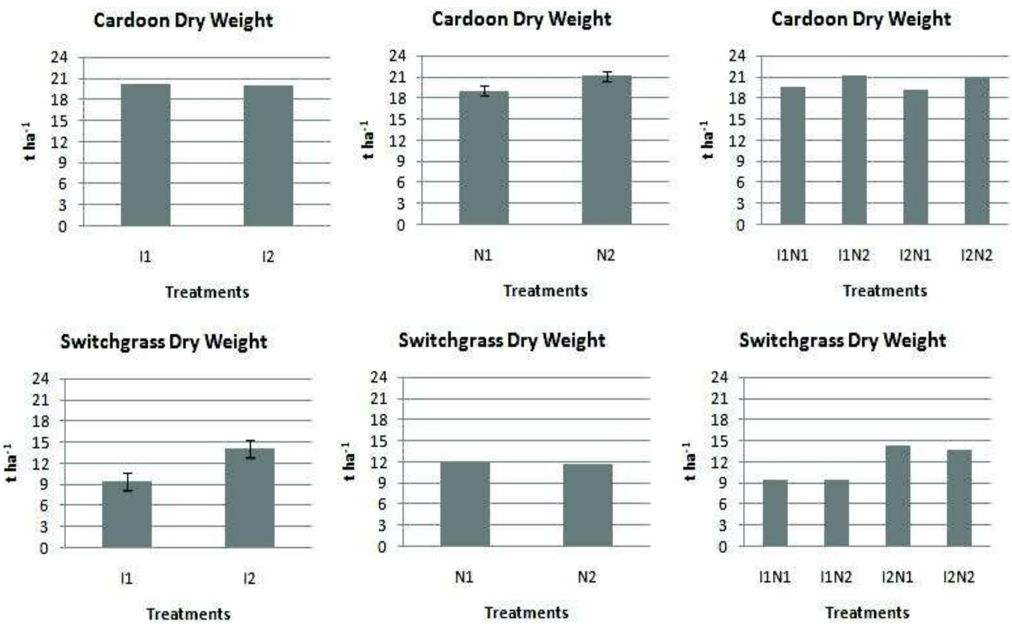

Figure 2. Effects of different irrigation (irrigated-150 mm and rainfed) and N-fertilization levels (0 and 80 kg ha^{-1}) on dry yield of the crops (cardoon upper graphs, switchgrass bottom graphs). $LSD_{0.05}$ is illustrated with (I) were it was found.

Calorific value

The energy content of biomass is determined by its calorific value. The calorific value is influenced by biomass elemental composition. Fig. 3 shows average GCV (MJ kg^{-1}) for all the samples of the studied treatments.

Only in irrigation case statistical significant differences of cardoon calorific values were found. The average values were 15.57 and 15.24 MJ kg^{-1} with the rainfed treatments having higher calorific values. In the case of nitrogen fertilization no significant differences were found. The above values are between the reported values for the cardoon pellets (14.8 MJ kg^{-1}, González et al., 2004; 17.3 MJ kg^{-1}, Christodoulou et al. 2014), the calorific value of cardoon biomass (without seeds) is 13.7 MJ kg^{-1} and the case that seeds are included in biomass 17.1–17.3 MJ kg^{-1} (Fernández et al., 2006; Grammelis et al., 2008).

On the other hand, in switchgrass case no significant differences were found for the tested irrigation and N-fertilization levels to the found biomass calorific values. The average calorific values were 17.29 and 17.26 MJ kg^{-1} for I1 and I2, respectively, while in the case of N-fertilization the average calorific values were 17.25 and 17.29 MJ kg^{-1} for N1 and N2, respectively, (Fig. 3). The above values are lower according to previous studies, where the average calorific value for switchgrass is reported to be 18.7 MJ kg^{-1} (Kludze et al., 2013) while it is the same with sorghum dry biomass calorific value (17.17 MJ kg^{-1}) that is reported by Pannacci & Bartolini (2018). The above found calorific value is a little bit lower compared to the calorific value of the most common hardwood species for energy production in Brazil (Chiteculo et al., 2018). It is reported that the calorific value of maize straw pellets ranged from 16.63 to 17.80 MJ kg^{-1} (Krizan et al., 2018) values similar with the switchgrass calorific value of the current study.

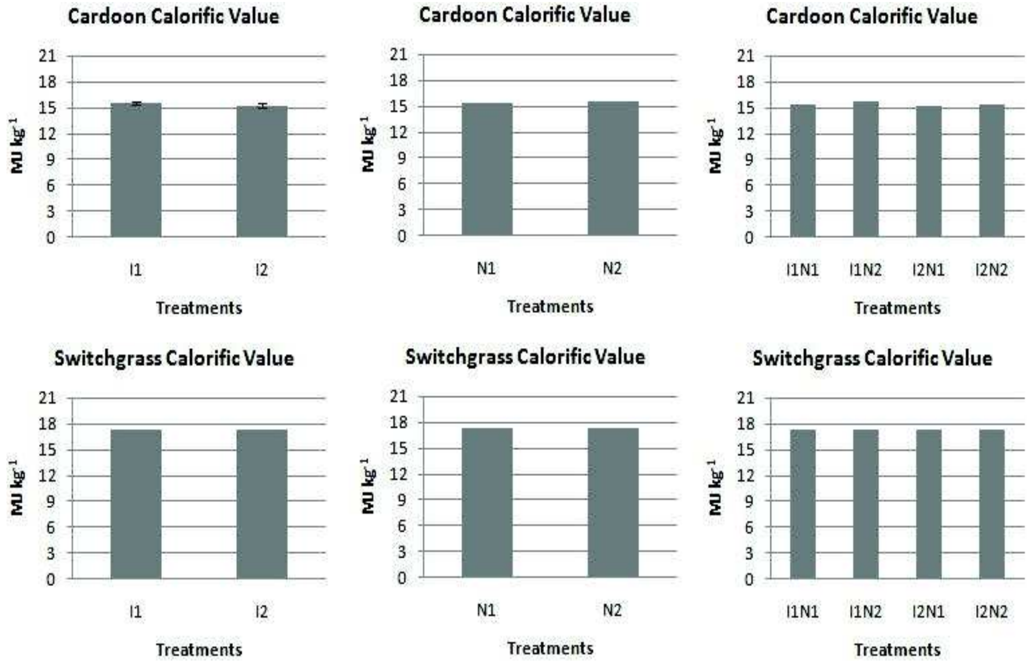

Figure 3. Effects of different irrigation (irrigated-150 mm and rainfed) and N-fertilization levels (0 and 80 kg ha^{-1}) on calorific value of the crops (cardoon upper graphs, switchgrass bottom graphs). $LSD_{0.05}$ is illustrated with (I) were it was found.

Multiplying the heating value by the dry yield of biomass produced in each treatment reflects the production of energy per hectare. As it is illustrated in Fig. 4, statistical significant differences were found for the nitrogen fertilization in case of cardoon (291 and 328 GJ ha^{-1} for the N1 and N2, respectively) and for the irrigation in switchgrass case (162 and 241 GJ ha^{-1} for the I1 and I2, respectively).

Furthermore, as it is illustrated in Fig. 4, it was found that cardoon in every case could produce higher energy per hectare (average 300 GJ ha^{-1}) than switchgrass (200 GJ ha^{-1}).

It has been reported that the annual energy produced by hectare is depending on the biomass type. There are many types of biomass that have been tested for their energy production per hectare, like wheat straw which can produce 123 GJ ha^{-1}, poplar (173–259 GJ ha^{-1}), SRC willow (187–280 GJ ha^{-1}) and coppiced willow chips (108 GJ ha^{-1}), miscanthus (222–555 GJ ha^{-1}), switchgrass which is reported to produce 139–150 GJ ha^{-1} and cardoon producing energy equal to 171–346 GJ ha^{-1} (Duffy & Nanhoue, 2002; McKendry P. 2002; Tharakan et al., 2005; Fernández et al., 2006; Grammelis et al., 2008). Therefore, it seems like both tested cultivation, cardoon and switchgrass, even at the end of their perennial life cycle they have the ability to produce large amounts of energy per hectare and makes them interesting solutions of low-input energy crops.

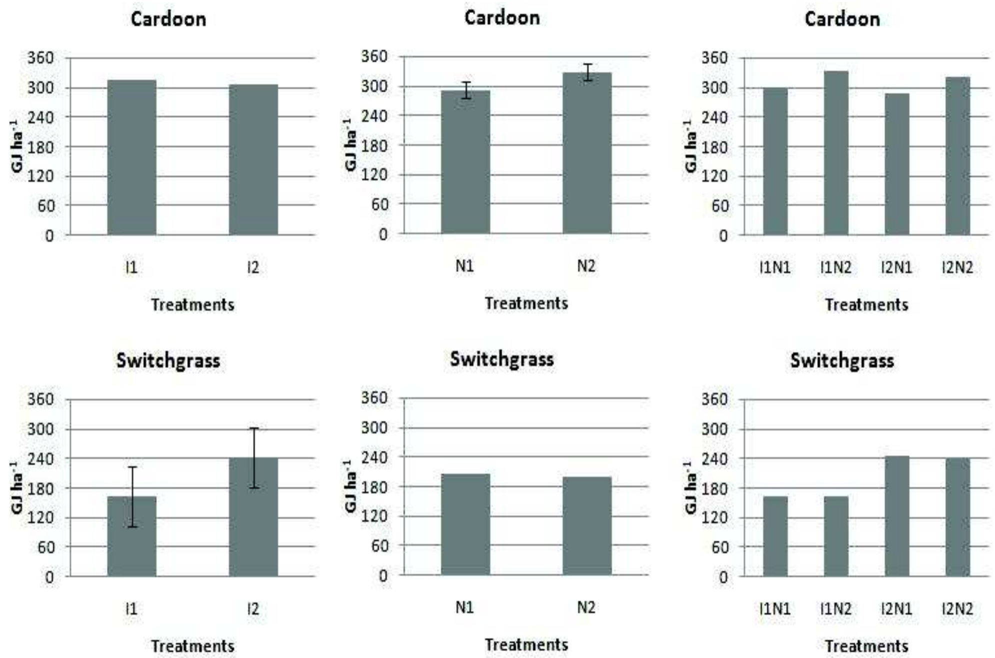

Figure 4. Effects of different irrigation (irrigated-150 mm and rainfed) and N-fertilization levels (0 and 80 kg ha^{-1}) on energy produced per hectare by the crops (cardoon upper graphs, switchgrass bottom graphs). $LSD_{0.05}$ is illustrated with (I) were it was found.

CONCLUSIONS

The main conclusion that may be drawn from this study is that even in their 8th growing year, cardoon and switchgrass can achieve remarkable dry biomass yield characterized of a high calorific value ranging from 15.4–17.3 MJ kg^{-1}. The energy produced by hectare is higher for cardoon cultivation than in switchgrass.

Furthermore, it was found that irrigation affected switchgrass dry biomass while in the case of cardoon dry biomass the higher nitrogen fertilization produced higher yield. Both cultivations can produce high amounts of dry biomass which can lead to high energy production. The differences to the calorific value are mainly due to different carbon content (main energy source) or the experimental site.

Therefore, depending on the experimental site (if there is or not the possibility to irrigate the cultivation) and the climatic conditions of the area, cardoon and switchgrass could achieve high amounts of energy per hectare, forming a promising solution for biomass production and their use in future cultivating scenarios for an environmentally friendly energy production should be seriously taken into consideration.

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