BIOMASS PRODUCTION FROM PERENNIAL CROPS IN GREECE

Myrsini Christou, Michalis Mardikis and Efthimia Alexopoulou
Center for Renewable Energy Sources (CRES)
19th km Marathonos Avenue, 190 09 Pikermi, GREECE
Tel: +30 210 6603300, Fax: +30 210 6603301, e-mail: mchrist@cres.gr

ABSTRACT: The objective of this study was to evaluate the biomass production chain of three selected perennial crops under South EU conditions. The selected perennial crops, cardoon (*Cynara cardunculus*), switchgrass (*Panicum virgatum*) and giant reed (*Arundo donax*) have the advantage to be successively harvested, so as to ensure a year-round availability of raw material. Additionally, the influence of irrigation and nitrogen fertilization on the growth and yield characteristics of each crop was studied. The crops have been established in Central Greece, in small fields of about 0.2 ha each, in 2002. A split-split plot experimental design was followed for each crop. Giant reed and switchgrass had the same experimental layout consisting of three irrigation (I_0=no irrigated, I_1=50% of ET_0, I_2=100% of ET_0) and three fertilization rates (N_0=0 kg N/ha, N_1=40 kg N/ha and N_2=120 kg N/ha), while for cardoon only nitrogen fertilisation influence on growth and yields characteristics was looked at because cardoon is a winter rain-fed crop. Results indicated a clear effect of irrigation on the yields of giant reed and switchgrass. Giant reed plants of the dry treatment were statistically less productive. All irrigation levels had shown statistical influence on yields (stems, leaves and total) during both seasons. Yields in the second and third year ranged from 2.7 to 8.3 t ha^{-1} and from 6.3 to 18.6, respectively, depending on irrigation. Statistical effect was also noticed for all I x N interactions. Regarding switchgrass, each level of irrigation had a significant effect on dry matter yields (stems, leaves and total) and the relative moisture content, whereas nitrogen effect was not pronounced. Yields in the second and third year ranged from 15.4 to 21.7 t ha^{-1} and from 12.7 to 24.1 t ha^{-1}, respectively, depending on irrigation. Cardoon yielded much less, due to severe frost damage of the plantation in the second growing season. Dry matter yields ranged from 2.5 to 3.8 t ha^{-1} in all three growing periods.
Key words: giant reed, cardoon, switchgrass, irrigation and nitrogen influence.

1 INTRODUCTION

The introduction of plant species, which would provide high biomass yields using in a more efficient way the natural resources and the inputs, could serve towards the mitigation of water resources depletion and pollution problems and fully meet the EU Agricultural policy to introduce low input energy crops with reduced environmental pressure. Use of selective multicropping agricultural systems will offer the potential for year round operation without the need to store large quantities of materials, secure fuel supply diversification and reduce raw material shortages. Increased feedstock diversification leads to fuel security, which is the most decisive parameter in accelerating bioenergy applications.

In the literature, it was revealed that biomass yields achieved from the selected crops grown under low inputs of irrigation and nitrogen fertilization were relatively high. Dry matter yields from cardoon were 15-30 t ha^{-1} [4,7] with estimated biomass production costs of 24 euro/odt [10] (assuming yields of 20 odt ha^{-1} delivered 10km to energy plant). Certain varieties of switchgrass in Greece are reported to reach yields of 15-24 odt ha^{-1} [1] and with estimated biomass production costs of 39.24 euro/odt [6] (assuming a 10 years life time, average transport distance 64km). Finally, giant reed had achieved yields up to 30 odt [2,3,6] with estimated biomass production costs of 29-30 euro/odt [8,9] (assuming a 15 years life time, 30 odt ha^{-1} biomass yields and planting density 20,000 rhizomes/ha). All data mentioned above have been collected from small experimental fields.

Harvesting of the crops is signalled by their natural senescence on the field. According to our previous experience in growing these crops in Greek conditions [1,2,3,4], cardoon, switchgrass and giant reed complete their growing cycle and reach physiological maturity in successive periods of time, allowing thus a successive harvest and a year round availability of raw material.

The objective of this study is to evaluate the biomass production of the three selected perennial crops in Greece, cardoon (*Cynara cardunculus*), switchgrass (*Panicum virgatum*) and giant reed (*Arundo donax*) which have the advantage to be successively harvested (in summer, autumn and winter respectively), so as to ensure a year-round availability of raw material. The influence of irrigation and nitrogen fertilization on yields of each crop was also studied to provide information on crop yielding potential under reduced and abundant water and nitrogen supplies. This work refers to the EU project 'Bioenergy chains' ENK6-CT2001-00524.

2 APPROACH

The crops have been established in Central Greece in 2002. The experimental layouts are presented in Table 1. The main treatments were three levels of irrigation: I_0=no irrigated, I_1=50% of ET_0, I_2=100% of ET_0. Further treatments were three levels of nitrogen fertilization: N_0=0 kg N/ha, N_1=40 kg N/ha and N_2=120 kg N/ha. For cardoon only nitrogen fertilisation was applied in the same rates as previously, because it is a winter rain-fed crop.

The experimental field of giant reed covered a total area of 2,721m^2 and consisted of 27 plots of 100.8m^2 (12m x 8.4m) each. Giant red rhizomes were manually extracted for an old plantation, divided into smaller pieces and then planted in distances 1.5m between rows and 0.7m along the row.

The experimental field of switchgrass covered a total area of 2,128m^2 and consisted of 27 plots of 64m^2 (8m x 8m), each. Switchgrass seeds were sown in distances

0.4m between rows and broadcasted along the row. It was estimated that the planting density was 10 kg of seeds/ha, approximately.

The experimental field of cardoon covered a total area of 979.2m^2 and consisted of 9 plots of 96m^2 (10m x 9.6m), each. Seeds were sown in distances 0.8m between rows and 0.8m along the row. It was estimated that the planting density was 5 kg of seeds/ha, approximately.

Irrigation and nitrogen fertilisation were differentiated only in the second year, apart for cardoon, in order to ensure a successful establishment of the crops. The irrigation needs for each crop were determined from soil water content and reference evapotranspiration (ET_o) according to modified FAO Penman-Monteith method.

Growth data and yielding data were collected monthly. Samples from each harvest were laboratory analyzed for feedstock characterisation (gross and net calorific values, hydrogen, carbon, nitrogen and oxygen content, volatile, ash and fixed carbon content). Data were statistically analyzed by the ANOVA procedure. An error probability of P≤0.05 level was used in the multiple range tests to detect least significant differences (LSD test).

3 RESULTS

3.1 Giant reed yields

Dry matter yields in the establishment year were quite low, reaching only 1.37 t ha^{-1}, with moisture content of 54%. In the following year yields increased and ranged from 2.69 t ha^{-1} to 8.67 t ha^{-1} depending on the treatment. Dry mater averaged over the three irrigation and nitrogen fertilization rates is presented in Figures 1 and 2. Moisture content ranged accordingly from 48% to 56% (Fig. 3).

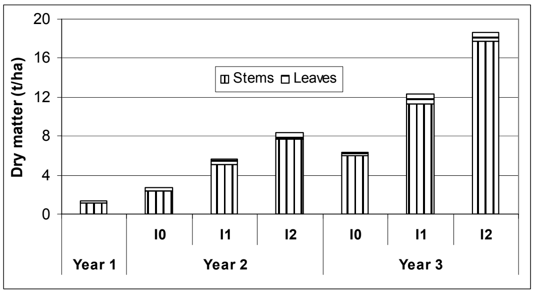

Figure 1: Dry matter yields in the giant reed field trial, averaged over the three irrigation rates.

In the third year yields doubled and ranged from 6.33 t ha^{-1} to 18.60 t ha^{-1} depending on the treatment. Dry mater averaged over the three irrigation and nitrogen fertilization rates is again presented in Figures 1 and 2. Moisture content ranged accordingly from 51% to 52% (Fig. 3).

Stem fraction contributed 86.13% on the total and dry matter in the first year. In the following year stem fraction on the total dry matter ranged from 89.79 % to 92.49% depending on the treatment. In the third year values were 92.11% – 95.22% depending on the treatment (Fig. 1 and 2). It seems that the crop in the first two growing periods produces more leaves, while from the third growing period the leaf part tends to decrease considerably.

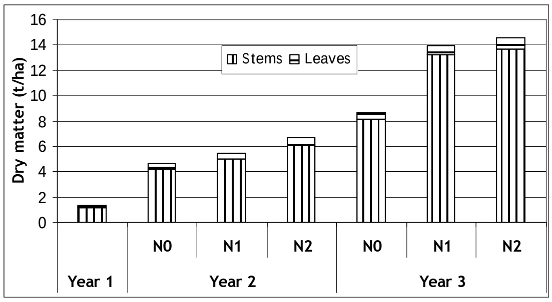

Figure 2: Dry matter yields in the giant reed field trial, averaged over the three nitrogen fertilization rates.

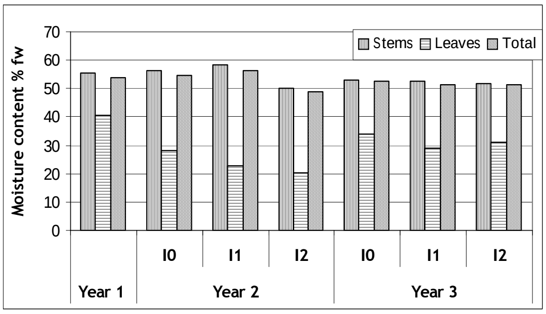

Figure 3: Moisture content of the harvested material in the giant reed field trial, averaged over the three irrigation rates.

Performing ANOVA's at the 0.05 p-level, on the estimated total yields and the two fractions (stems and leaves), it was noticed that both irrigation and age of the plantation had statistically significant effects on total dry matter and stem dry matter. As regards leaf dry matter, it was statistically affected only by the age of the plantation. Nitrogen fertilization did not have any clear effect on biomass production (Fig. 2).

Both studied factors, irrigation and nitrogen fertilization, seemed to regulate the growth cycle of the plants, as the non-irrigated plants did not flourish at all while the irrigated plants flourished but the time and the proportion of plants that flourish was influenced by irrigation and nitrogen fertilization. At the end of both growing periods (September) only plants of I_2N_2 treatment had flourished in a percentage of more than 50%. At that time, plants receiving treatments I_1N_2, I_2N_0 and I_2N_1 started to form inflorescences and after 2-3 weeks they reached 50% blossoming.

3.2 Switchgrass yields

Dry matter yields in the establishment year were considerably low, 8.42 t ha^{-1} with a moisture content of 24.75%. In the following year yields showed a sharp increase and ranged from 15.41 t ha^{-1} to 21.76 t ha^{-1} depending on the treatment. Dry mater averaged over the three irrigation and nitrogen fertilization rates is presented in Figures 4 and 5. Moisture content ranged accordingly from 44% to 53% (Fig. 6).

In the third year yields showed a slight decrease for the low and medium irrigation rates, while they increased for the high irrigation rate. They ranged from 12.69 t ha^{-1} to 24.05 t ha^{-1} depending on the treatment. Dry mater averaged over the three irrigation and nitrogen fertilization rates is again presented in Figures 4 and 5. Moisture content ranged accordingly from 35.3% to 39% (Fig. 6).

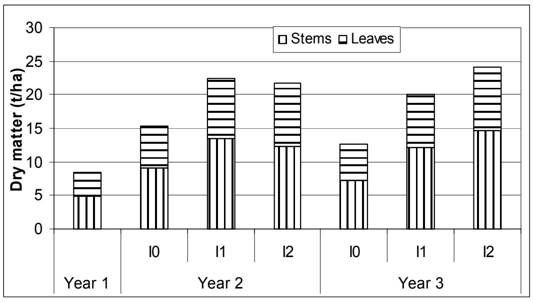

Figure 4: Dry matter yields in the switchgrass field trial, averaged over the three irrigation rates.

Stem fraction contributed 57.84% on the total dry matter in the establishment year. In the second year, stem fraction ranged from 56.39% to 60.27%. The same range was recorded in the following year that is 56.82% to 60.67%.

Performing ANOVA's at the 0.05 p-level on the total yields and the two fractions (stems and leaves), it was noticed that irrigation had statistically significant effects on total dry matter and stem dry matter. As regards leaf dry matter, it was statistically affected only by the age of the plantation. Nitrogen fertilization did not have any clear effect on biomass production (Fig. 5).

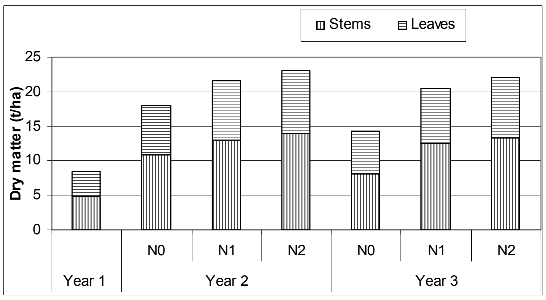

Figure 5: Dry matter yields in the switchgrass field trial, averaged over the three nitrogen fertilization rates.

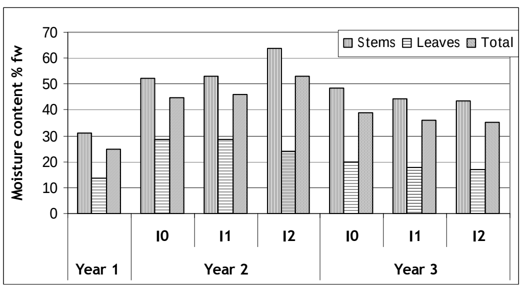

Figure 6: Moisture content of the harvested material in the switchgrass field trial, averaged over the three irrigation rates.

Like in the case of giant reed, both irrigation and fertilisation seemed to regulate the growth cycle of the plants, as the non-irrigated plants did not flourish at all while the irrigated plants flourished but the time and the proportion of plants that flourish was influenced by irrigation and nitrogen fertilisation. At the end of both growing periods (August) only plants of I_2N_2 treatment had flourished in a percentage of more than 50%. At that time, treatments I_1N_2, I_2N_0 and I_2N_1 started to form inflorescences and after 2-3 weeks they reached 50% blossoming.

3.4 Cardoon yields

Dry matter yields in the establishment year were quite low, ranging from 2.61 to 3.38 t ha^{-1}, with moisture content of 37.5%. In the following year yields increased and ranged from 2.53 t ha^{-1} to 3.87 t ha^{-1} depending on the nitrogen fertilization rate (Fig 7). At the beginning of this growing period (until December) when weather conditions were favourable (high precipitation and no frost events) cardoon plants grew vigorously. Then many frosts events occurred and interrupted plant growth. Furthermore there were two snow fallings occurring on January 24th and February 14th (recorded minimum temperature -12.41 and -2.92^{o}C, respectively), which resulted in destroying the plantation completely. Later on in early spring new growth of the survived plants took place from buds placing in the base of plants but it was late for cardoon to reach its yielding potential at the end of its vegetative cycle (August). This was the reason of the very low yields recorded.

In the third year yields showed the same trend and ranged from 1.40 t ha^{-1} to 3.42 t ha^{-1} (Fig 7). These figures depict clearly the shock of plants due to frosts. Even though during this period all recorded characteristics indicated the high potential of cardoon and bred an expectation for high final yields, cardoon proved to be susceptible to frost and biomass production was again very low.

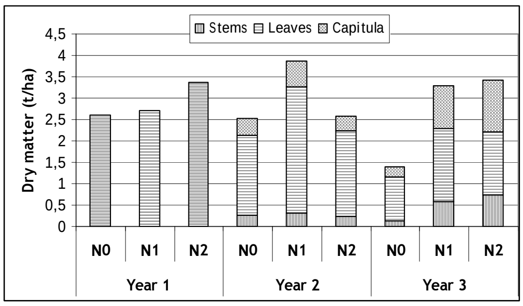

Figure 7: Dry matter yields in the cardoon field trial, averaged over the three nitrogen fertilization rates.

Consequently, the results presented this year can hardly be used for drawing conclusions about cardoon yielding potential in Greek conditions. In contrast to the other two crops tested, the leaf fraction of cardoon is much higher that the stem fraction. In the first year of establishment leaves were almost 100% of the harvested material. In the following growing period leaf fraction ranged from 74.2 % to 78.1 % depending on nitrogen fertilization and in the third year it ranged from 42.98% to 72.86% on the total dry matter. Accordingly, stem portion ranged from 8% to – 10% in the second year and 10% to 21.35% in the third year.

Moisture content ranged from 19.2% to 37.7% for the leaf fraction, 60% to 70% for the stems and 29.4% to 43.2% in the capitulas.

Performing ANOVA's at the 0.05 p-level, on the estimated total yields and the part fractions (stems, leaves and capitulas), it was noticed nitrogen fertilization effect on yields was not pronounced (Fig. 5).

It has to be noted that these yields were exceptionally low for this crop grown in Greece, due to the extreme climatic conditions that prevailed during its growth. From previous trials carried out in the frame of other European projects, yields of 15 to 30 t ha^{-1} dry matter were recorded.

4 CONCLUSIONS

In conclusion, all three crops were in the second growing period, therefore the yields presented are not considered as mature yields. The irrigation treatments had a more pronounced effect on the recorded characteristics than nitrogen fertilization. Nitrogen fertilization affected significantly several growth and yield characteristics but mainly in irrigated plants indicating that both irrigation and nitrogen fertilization are important for achieving high yields.

Regarding giant reed, a slight increase in biomass yields was noticed between the first and the second growing periods. Yields in the third growing period almost doubled. However the maximum values recorded differ considerably from the expected values based on our experience on giant reed. It could be attributed to the low planting density, which resulted in low plantation density. In the case of switchgrass the dry matter yields of the second and third growing periods were of the same range. Cardoon yields were much lower than the yields achieved in previous field trials in Greece. This was due to the frost that damaged the plantation in its second growing cycle. Also, the nitrogen fertilisation effect was impossible to be revealed.

Regarding the multicropping system, it is anticipated that yields of at least 15 t ha^{-1} dry matter could be harvested by cardoon from July until September. Switchgrass, when harvested in November until February can produce yields ranging from 12 t ha^{-1} to 22 t ha^{-1} dry matter. Then, in February to March giant reed can be harvested with yields ranging from 8 to 18 t ha^{-1}, closing thus a harvesting window of nine months a year.

Yielding data will continue to be taken in the following years in order to identify the yielding potential of these crops along the years and the resilience of the plantations.

5 REFERENCES

[1] Alexopoulou, E., Christou, M., Mardikis, M., Pigniatelli, V., Piscionerri, I., Sharma, N. and Elbersen W., 2000. Switchgrass in the Mediterranean region. Proceedings of the 1st World Conference on Biomass for Energy and Industry, Vol. II (2000) 1634.

[2] Christou, M., D. Papavassiliou, E. Alexopoulou and Chatziathanassiou, A., 1998. Comparative Studies of Two Potential Energy Crops in Greece. Proceedings of the 10th European Conference on Biomass for Energy and Industry (1998) 935.

[3] Christou, M., Mardikis, M. and Alexopoulou, E., 2000. Propagation material and plant density effects on the *Arundo donax* yields. Proceedings of the 1st World Conference on Biomass for Energy and Industry, Vol. II (2000) 1623.

[4] Curt, M. D., Aguado, P.L. and J. Fernandez. 1998. Adaptation of Cynara cardunculus photosynthesis to winter Mediterranean temperatures. Proceedings of the 10th European Conference on Biomass for Energy and Industry (1998) 846.

[5] Dalianis, C., Christou, M., Sooter, Ch., Kyritsis, S., Zafiris, C. and G. Samiotakis, 1994. Adaptation and biomass productivity of *Cynara cardunculus* in abandoned, marginal fields. Proceedings of the 7th European Conference on Biomass for Energy and Industry (1994) 1235.

[6] European Commission, 1997. Switchgrass (*Panicum virgatum* L.) as an alternative energy crop in Europe. Proposal description.

[7] Gominho, J., Fernandez, J. and Pereira, H., 2001. *Cynara cardunculus* L. – a new fibre crop for pulp and paper production. Industrial Crops and Products, 13, 1-10.

[8] Jodice, R., Vecchiet, M., Schenone, G., and Parrini, F., 1994. Giant reed multiplication and cultivation experiences. Proceedings of the 8th European Conference on Biomass, Vienna 1994, 686.

[9] Jodice, R., Vecchiet, M., Parrini, F., and Schenone, G., 1994. Giant reed as energy crop: Initial economic evaluation of production costs in Italy. Proceedings of the 8th European Conference on Biomass for Energy and Industry (1994) 695.

[10] Piscioneri, I., Sharma, N., Baviello, G. an for Energy and Industry d Orlandini, S., 2000. Promising industrial energy crop, *Cynara cardunculus*: a potential source for biomass production and alternative energy. Energy Conversion and Management, 41, 1091-1105.