Crop growth analysis and yield of a lignocellulosic biomass crop (*Arundo donax* L.) in three marginal areas of Campania region

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Abstract

The depletion of energy resources from fossil fuels and global warming have pushed to consider the agro-energy as one of the renewable energy sources for mitigation of climate change. In this context, agro-energy based on cultivation of *energy crops* in marginal lands allows to reduce competition with food crops and marginal lands abandonment, producing incomes for farmers. The aim of this work is to improve the knowledge on a promising crop (*Arundo donax* L.) for the production of bio-energy in marginal lands. Therefore, the behaviour of this crop was evaluated in three study areas of Campania region, under different energy inputs: two levels of nitrogen fertilisation, N100 and N50 in Sant'Angelo dei Lombardi (SA) and Bellizzi (BL). In Acerra (AC) site compost fertilisation was made to verify its effect on pollutant phytoextraction. In the last year, also crop growth analysis was done in the three sites. The results showed that giant reed confirms its adaptability to low fertility soils, allowing interesting biomass yield also in marginal lands. In more fertile environments, effect of fertilisation is not significant at least in the short term. Nevertheless, nitrogen uptake (65-130 kg N ha^{-1}), also if lower than other high-yielding crops, needs to be compensated with fertilisation to avoid depletion of soil nutrient reserves and to guarantee sustainability of this cropping system. Giant reed had a positive environmental impact, due to the improvement in soil fertility (soil organic matter and nitrogen increase) and to the mitigation of climate change (C storage in the soil). In marginal soils of Southern Italy this crop confirms an increasing trend of yield during the first 3-4 years. High productivity levels of this crop are related to the extremely high duration of the vegetative period and thus of the photosynthetic activity (from March to November in the Mediterranean area). These last are well expressed by the leaf area duration index, which is more than double than other high-yielding crops such as maize (280 *vs* 140 days).

Introduction

In recent years the concerns about the depletion of energy resources derived from fossil fuels have led to a greater attention on renewable energy sources obtainable from agro-energy sector. With the aim to reduce competition for land with food crop, renewable energy must be obtained from crop residuals or from energy crops cultivated in marginal soils not suitable for food crops, such as polluted soils, marginal lands subjected to accelerated erosion or salinisation (Fiorentino *et al*., 2010; Fagnano *et al*., 2012, 2015; Impagliazzo, 2014).

Among the different biomass crops, one of the most interesting is giant reed (*Arundo donax* L.), because of its tolerance to different environmental stresses and its capacity to produce interesting amount of ligno-cellulosic biomass also in marginal areas (Angelini *et al*., 2005b; Fiorentino *et al*., 2013; Nassi o Di Nasso *et al*., 2013). It is a perennial, herbaceous plant, occurring over a wide range of climatic habitats and growing spontaneously and abundantly all over Italy. Usually it does not produce viable seeds because the pollen results unfruitful; consequently, the better propagation method, for this species, is the use of rhizomes (Christou *et al*., 2000).

It has a C3 photosynthetic cycle, but has high photosynthetic rate (37 μmoli m^{-2}s^{-1}) and productivity similar to C4 species (Rossa *et al*., 1998; Christou, 2001).

The average biomass yield in Italy ranges between 21 and 51 t ha^{-1} under medium-low supply of nitrogen (N) (100-120 kg ha^{-1}year^{-1}) and water (from no irrigation to 75% evapotranspiration restitution) (Angelini *et al*., 2005a, 2005b, 2009; Cosentino *et al*., 2006; Mantineo *et al*., 2009).

It can grow in all types of soils, from clay to sandy, with presence or not of rocks, with soil pH ranging from 5 to 8.7 (Di Tomaso, 1998) and tolerate salinity and water stress (Lewandosky *et al*., 2003).

The lignocellulosic biomass of giant reed represents an interesting source of cellulose for the production of paper (Ververis *et al*., 2004), rayon (Facchini, 1941), second-generation ethanol and biopolymers (Williams and Biswas, 2010), biogas production (Dragoni *et al*., 2015), for the cultivation of oleaginous yeasts for biodiesel production (Pirozzi *et al*., 2010, 2015).

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Key words: Giant reed; Biomass yield; Growth analysis; LAD.

Conference presentation: SIA XLIV Congress, Bologna, 2015.

Received for publication: 30 January 2016.
Revision received: 23 June 2016.
Accepted for publication: 9 July 2016.

Italian Journal of Agronomy 2017; 12:755
doi:10.4081/ija.2016.755

As regards the relations between yield and mineral fertilisation, there are contrasting results (Dalianis *et al*., 1994; Christou *et al*., 1999; Monti and Venturi, 1999; Cosentino *et al*., 2005), maybe due to the different fertility levels or to the different age of standings. Plant growth analysis is a tool able to better analyse plant behaviour. Moreover, it is an explanatory, holistic and integrated approach to study and describe the various processes of plant system (*i.e*. plant morphology, physiology and phenology), with the advantage of use simple primary data such as weights and leaf area (Evans, 1972; Causton and Venus, 1981; Hunt, 1990).

The main objective of this research was to improve the knowledge about growth and yield of giant reed, under different pedo-climatic conditions.

Materials and methods

Environmental aspects of study areas

The experimental site of Sant'Angelo dei Lombardi (AV, Italy) (SA) was located in the experimental farm *Centro Rotary* of the Department of Agriculture of the Naples University Federico II, in the inland hills of Campania region (40°92'N, 15°12'E, 700 m asl).

This field is characterised by clay soils with low content of organic matter and a 10% slope (Table 1). The climate is typical of inland hills of Campania region, with cold winter and frequent snowfalls, and hot and dry summer. Driest months are June, July and August and the rainfall events are concentrated in the autumn and winter months with the presence of frequently extreme events (thunderstorms).

During the long-term field experiment (2004 to 2013), the average annual temperature was 12°C, with an absolute minimum temperature ranging between -2 and -10°C and a maximum between 24.0 and 37°C (Table 1). The annual rainfall was 1079 mm and the reference evapotranspiration (Hargreaves *et al*., 1985) was 929 mm on the average.

The experimental site of Bellizzi (SA, Italy) (BL) was located in the experimental farm *Torre Lama* of the University of Naples Federico II, (40°37'N, 14°58'E, 30 m asl) in the Sele alluvial plain.

The soil has silt-loam texture and low content organic matter and N (Table 1). The climatic conditions are typical of Mediterranean areas with temperate and rainy winter and hot and dry summer, the rainfall events are concentrated in the autumn-winter period, with the maximum peak in January and the minimum in July.

During the experimental period (2008-2013), the average annual temperature was 17°C, with an absolute minimum temperature ranging between 0 and -3°C and maximum between 35 and 37°C (Table 1). The annual rainfall was about 621 mm and the reference evapotranspiration was 1105 mm on the average.

The third field experiment was carried out in a private farm of Acerra plain (*Campania region*) (AC) (40°60N, 14°21'E, 21 m asl), characterised by volcanic soils particularly suitable for intensive horticultural crop production. The soil texture is sandy-loam, with a sub alkaline pH and a high content of organic matter and N (Table 1). Moreover, the Regional Agency for Environmental Protection has classified this soil as not suitable for farming on the base of its cadmium contamination (Fiorentino *et al*., 2013).

The climate is that typical of the coastal plain with mild winters and frequent rainfall events during the autumn periods and with hot and dry summer. During the experimental period (2009-2012), the average annual temperature was about 16°C, with the daily absolute minimum and maximum temperatures ranging between -3 and -6°C and 37 and 42°C, respectively (Table 1). The annual rainfall was 1060 mm and the reference evapotranspiration was 1264 mm on the average.

Crop management

At SA, seedbed preparation started in August 2003 with deep ripping (60 cm) followed by mouldboard ploughing (40 cm) and rotary hoeing (20 cm). Giant reed rhizomes were collected from wild stands of the same area. They were cut (10 cm with at least three buds) and transplanted on February 2004 in 140 m^2 (10×14 m) plots at the density of 1×1 m. No irrigation was made and two doses of N fertilisation were compared (100 and 50 kg N ha^{-1} from urea). At BL, soil preparation was made in autumn 2007 with deep ripping (60 cm) followed by soil milling (20 cm), pre-plant fertilisation of 150 kg ha^{-1} of K_2O (potassium sulphate) and 150 kg ha^{-1} P_2O_5 (triple superphosphate). Giant reed rhizomes were collected from wild stands of this area. They were cut (10 cm with at least three buds), planted on February 2008 at 10-20 cm of soil depth, at the density of 1×1 m and transplanted in 528 m^2 (16×333 m) plots. No irrigation was made and two doses of N fertilisation were compared (100 and 50 kg N ha^{-1} from urea). Plants were watered only after transplanting (April 2008) in order to ensure good root contact with the soil. At AC giant reed rhizomes were collected from the farm *Torre Lama* of the University of Naples Federico II. They were cut (10 cm with at least three buds), planted on April 2009 at 10-20 cm of soil depth, at the density of 0.60 m × 0.60 m and transplanted in 132 m^2 (6×22 m) plots. No irrigation was made and two doses of compost (0 and 20 t ha^{-1}, corresponding to 130 kg N ha^{-1}) were compared with the aim to study the effect of compost on pollutant phytoextraction (Fiorentino *et al*., 2013).

Table 1. Soil and climatic characteristics of experimental sites.

Site	Soil texture (0-40 cm)			Soil chemical characteristics			Climatic information over the years of the long term experiment				
	Sand (%) (2-0.05 mm)	Silt (%) (0.05-0.002 mm)	Clay (%) (<0.002 mm)	pH	OM (%)	total N (g kg^{-1})	Temperature (C°)			Rainfall	ET_0
							Annual average	Absolute minimum	Absolute maximum	Annual average (mm year^{-1})	
SA*	37.1	24.8	38.1	8.1	1.1	0.9	11.8 (±0.6)	-10	35.5	1050 (±263)	916 (±62)
BL°	29.3	43.3	27.5	7.3	1.9	1.2	17.0 (±0.2)	-2.6	37.4	651 (±135)	1105 (±14)
AC#	58.5	25.1	16.3	7.7	2.9	1.8	16.3 (±0.2)	-5.8	41.9	1060 (±176)	1264 (±47)

OM, organic matter; N_{tot}, total organic nitrogen; ET_0, evapotranspiration; SA, Sant'Angelo dei Lombardi; BL, Bellizzi; AC, Acerra. *Soil sampled in October 2004 before planting, climatic period (2004-2013); °soil sampled in February 2008 before planting, climatic period (2008-2013); #soil sampled in April 2009 before planting, climatic period (2009-2013).

Crop and soil monitoring

Yield data refer to standings of 10 years at SA (2004-2013), 6 at BL (2008-2013) and 4 at AC (2009-2012). Harvests of the above-ground biomass were manually made, on sampling areas of 10 m^2, in the winter after each growing cycle (February 2014 at SA, and BL and February 2013 at AC). The plants were cut at about 5 cm from the ground with subsequent separation in leaves and in culms for the determination of the fresh weight. Sub-samples of each fraction was oven-dried at 65°C until constant weight for determining the percentage of dry matter. In the last year, subsamples of leaves and culms were milled (4 mm) with Knife Mill SM 300 [Retsch Italy S.r.l., Torre Boldone (BG), Italy] and sent to the laboratory for the determination of the content in organic N (Kjeldahl method). In the same dates, soil samples of two layers (0-20, 20-40 cm) were collected for measuring organic N and organic C content by the Kjeldahl and Walkley-Black methods, respectively.

Crop growth analysis

Crop growth analysis was made on the last growth cycle that corresponded to the 10th growth period at SA, 6th at BL and 4th at AC. For the three sites, crop sampling began 10 days after crop regrowth. For each date, a sampling area of 1 m^2 repeated 3 times was chosen. Aboveground fresh biomass (leaves and stems) and leaf area were measured. Samples of each fraction were oven-dried at 65°C until constant weight for determining the percentage of dry matter. The leaf area was measured by LI-3100C Area Meter (LI-COR, Lincoln, NB, USA). The collected data have been used to calculate the following indices: dry weight (DW): quantity of dry matter per unit area ($g\ m^{-2}$); leaf area index (LAI): ratio between leaf area and ground area ($m^2 m^{-2}$); leaf area duration (LAD): the integration of leaf area over the growth period.

This last is the average value of the time intervals of LAI, derived from the following expression:

$$LAD=(LAI2 + LAI1) * (t_2 - t_1)/2$$

where, LAD=leaf area duration ($m^2\ m^{-2}\ d$), LAI1, LAI2 = LAI at days t_1 and t_2 respectively, and t_1, t_2=days of the year in the two sampling dates.

Statistical analysis

All data were subjected to analysis of variance by using the software MSTAT-C (Crop and Soil Science Department, Michigan State University, East Lansing, MI, USA). A split plot randomised block design with 2 factors, locations (main factor) and fertilisation (sub-factor) was used. All means were separated using LSD test for a $P \leq 0.05$ (*) and $P \leq 0.01$ (**). The data of growth analysis were subjected to linear regression analysis.

Results

Above-ground biomass yield

The trend of biomass yield over the years (Figure 1) was similar in the three sites, with increasing values in the first 3-4 years. Yield levels are very similar in the fields of SA and BL, with peaks of 20 and 25 t ha^{-1} DW, while they were higher at AC where yield reached 35 t ha^{-1} DW in the 4th year. The effect of the higher dose of fertiliser was significant at BL (+15.6% on the average) and SA (+16% on the average); of course in the highly fertile soil of AC, compost fertilisation did not have effect of crop yield.

Crop nitrogen uptake

Nitrogen uptake was significantly higher (131.5 kg ha^{-1}) at AC, according to the greater yield, with N content in the culms and in the leaves of 0.4 and 1.5 g 100 g^{-1}, respectively (Table 2). Nitrogen uptake was very much lower at SA and BL (65.7 and 73.1 kg ha^{-1} respectively).

Carbon and nitrogen balance during the crop periods in the three sites

The soil organic carbon content (SOC) was evaluated in the topsoil (0-20 cm) for the period 2004-2013 at SA, 2008-2013 at BL and 2009-2012 at AC (Table 3).

Table 2. Crop nitrogen content and uptake in the three sites in the year of crop growth analysis.

	Total N uptake (kg ha^{-1})	N content (g 100 g^{-1})	
		Culms	Leaves
Site			
SA	65.7^b	0.3	0.9^b
BL	73.1^b	0.3	1.6^a
AC	131.5^a	0.4	1.5^a
Mean	90.12	0.3	1.3
Significance			
Location	≤0.01	ns	≤0.01
Fertilisation	ns	ns	ns
Loc.×Fert.	ns	ns	ns

N, nitrogen; SA, Sant'Angelo dei Lombardi; BL, Bellizzi; AC, Acerra; ns, not significant. ^{a,b}Values within a column with the same letters are not significantly different at $P<0.05$.

Table 3. Organic carbon content in the topsoil (0-20 cm) at planting and at harvest of the year of crop growth analysis.

	Years	Organic carbon (g C/100 g)					
		Time 0		Harvest		Variation	
		Low input	High input	Low input	High input	Low input	High input
Site							
SA	2004-2013	0.79^c	0.79^c	0.92^b	0.89^c	0.12^a	0.10^b
BL	2008-2013	1.19^b	1.09^b	1.01^b	1.20^b	-0.17^{bc}	0.10^b
AC	2009-2012	1.73^a	1.73^a	1.82^a	1.95^a	0.09^b	0.22^a
Significance							
Location		≤0.01	≤0.01	≤0.01	≤0.01	≤0.01	≤0.01
Fertilisation		ns	ns	ns	ns	ns	ns
Loc.×Fert.		ns	ns	ns	ns	ns	ns

SA, Sant'Angelo dei Lombardi; BL, Bellizzi; AC, Acerra; ns, not significant. ^{a,c}Values within a column with the same letters are not significantly different at $P<0.05$.

At SA, the 2 fertiliser doses (N50 and N100) showed the same levels of SOC with an increase 0.11 g C 100 g^{-1} at the end of the 10th crop cycle, on the average, corresponding to a 14% increment. The increase of organic N during the 9 years was 0.32 g N kg^{-1} soil corresponding to a 36% increment (Table 4).

In contrast, at BL after 6 years of copping period, organic carbon increased only with the highest dose of N (100 kg ha^{-1}), while with the lowest dose of fertiliser, there was a depletion of the reserves of soil organic carbon. Organic N in the topsoil did not changed with the lowest dose of fertiliser, while increased by 11% with the dose of 100 kg N ha^{-1}.

Finally, at AC inputs of compost (3.5 t C ha^{-1}), after 4 years significantly contributed to the SOC in the top-soil, increasing the values by 0.22 g C 100 g^{-1}, corresponding to a 13% of increment (Table 3), while in the not fertilised plots, SOC increased in 4 years by 0.09 g C 100 g^{-1}, corresponding to a 5% increment. In this site the increase of organic N was very limited in both the fertiliser levels, with an increase of 0.16 g kg^{-1}, on the average, corresponding to a 9% increment (Table 4).

Growth analysis

Above-ground biomass

The growth rates of the aboveground biomass were similar in SA and BL and much higher in AC (Figure 2).

At SA (Figure 2A) there was an effect of fertilisation dose, with values 14% higher on the average with the dose of 100 kg N ha^{-1}. The seasonal peak of biomass accumulation was reached in November (2065 g m^{-2} DW and 1741 g m^{-2} DW, respectively for N100 and N50). At BL (Figure 2B) the effect of fertiliser increased from June until November. Also in this site the peak of biomass accumulation was attained in November (1875 g m^{-2} DW and 1209 g m^{-2} DW respectively for N100 and N50).

The highest values of accumulation of above-ground biomass in absolute terms during the growing season, as already highlighted for yield, were recorded at AC site (Figure 2C) with a peak of production in September and with a reduced effect of fertiliser doses (3576 g m^{-2} DW on the average).

Leaf area index

LAI pattern (Figure 3) was similar to that of biomass, with similar trend in SA and BL and higher values in AC. The peak was attained in July at SA (Figure 3A), September at BL (Figure 3B) and AC (Figure 3C).

The maximum values at SA were higher than at BL, with the reduced N fertiliser dose (3.8 and 2.6 m^{2}m^{-2} respectively, corresponding to a 46% difference). The highest dose of N fertiliser reduced the differences between the two sites (4.2 and 3.5 m^{2}m^{-2} respectively at SA and BL, corresponding to a 20% difference).

The maximum values of LAI were much higher in AC site (10 m^{2}m^{-2} on the average).

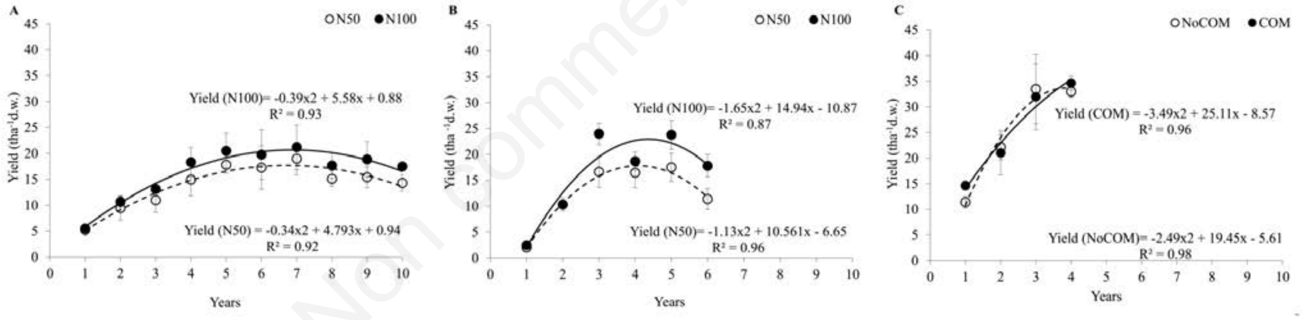

Figure 1. Above-ground giant reed biomass yield over the long-term experiment in the three experimental sites: A) Sant'Angelo dei Lombardi; B) Bellizzi; C) Acerra. Bars indicate standard errors (n=3).

Table 4. Organic nitrogen content in the topsoil (0-20 cm) at planting and at harvest of the year of crop growth analysis.

	Years	Organic					
		Time 0		Harvest		Variation	
		Low input	High input	Low input	High input	Low input	High input
Site							
SA	2004-2013	0.81^{b}	0.81^{b}	1.16^{b}	1.09^{c}	0.35	0.28
BL	2008-2013	1.14^{ab}	1.22^{ab}	1.14^{b}	1.35^{b}	0.00	0.13
AC	2009-2012	1.75^{a}	1.75^{a}	1.92^{a}	1.90^{a}	0.15	0.17
Significance							
Location		≤0.01	≤0.01	≤0.01	≤0.01	ns	ns
Fertilisation		ns	ns	ns	ns	ns	ns
Loc.×Fert.		ns	ns	ns	ns	ns	ns

N, nitrogen; SA, Sant'Angelo dei Lombardi; BL, Bellizzi; AC, Acerra; ns, not significant. ^{a,b}Values within a column with the same letters are not significantly different at P<0.05.

The leaf area duration (LAD) was lower at BL (677 *vs* 477 m^{2}m^{-2} × days, for the two N doses respectively), higher at SA (800 *vs* 611 m^{2}m^{-2} × days, for the two N doses respectively) and very much higher at AC (1410 m^{2}m^{-2} × days, on the average).

Discussion

Biomass yield

The trend of biomass yield during the years confirms the results reported by Angelini *et al*. (2009), who identified three phases in growth of giant reed: an increasing phase until the 3rd-4th year, a stationary phase from the 4th to the 8th year and a decreasing phase from the 9th to the 12th year of growth.

The different fertility levels and the environmental constraints influenced the growth and yield of giant reed and also the effect of fertilisers.

The higher yield was obtained at AC, already in the first year of growth. These results are in line with those reported by Cosentino *et al*. (2006) who compared 39 clones of common reed grown in southern Italy whose yield in the first and second year amounted to 11 - 22 t ha^{-1} DW Of course the effect of compost fertilisation was not significant in this site, both for the well-known very high fertility levels of the volcanic soils of Campania plain (Di Vito *et al*., 2013) and for the slow mineralisation rate of composted organic matter that make this fertiliser unable to guarantee N available for crops, as already noticed in previous trials made with the same compost in the same environment (Alluvione *et al*., 2013). The effect of compost on pollutant phytoextraction was discussed by Fiorentino *et al*. (2013). Lower yield was recorded in the other two sites, both for the lower fertility of soils and for environmental constraints: winter cold at SA and the extreme drought at BL. At SA, yield levels of biomass and uptake of N were similar to those obtained in Italy on marginal lands (Nassi o Di Nasso *et al*., 2010, 2011b, 2013), but lower than those reported in most fertile environments (Angelini *et al*., 2005a; Cosentino *et al*., 2006).

In this site, a 16% of yield increase was obtained with 100 kg ha^{1} of N on the average, with increasing differences over the time. Therefore, the restitution of N uptake with fertilisation is necessary for allowing good yield levels and for not depleting native soil resources. Among the compared sites, the lowest yield was obtained at BL, in which a decreasing trend is evident starting from the 5th year, maybe mainly due to water limitations that do not allow high photosynthetic rates and assimilate availability for the reservoir organs (*i.e.* rhizomes), thus limiting the regrowth in the following years (Mann *et al*., 2013; Sanchez *et al*., 2015).

Carbon and nitrogen variations

The giant reed cropping system can have a positive effect on the storage of C in the soil thanks to the absence of soil tillage and abundance of crop residues that every year return to the soil. Compost fertilisation before planting has led to a significant increase of soil C (+0.22 g C 100 g^{-1}), confirming that compost fertilisation can contribute to climate change mitigation (Alluvione *et al*., 2013). This increase corresponds to 5.7 t C ha^{-1} (18.7 t CO$_2$

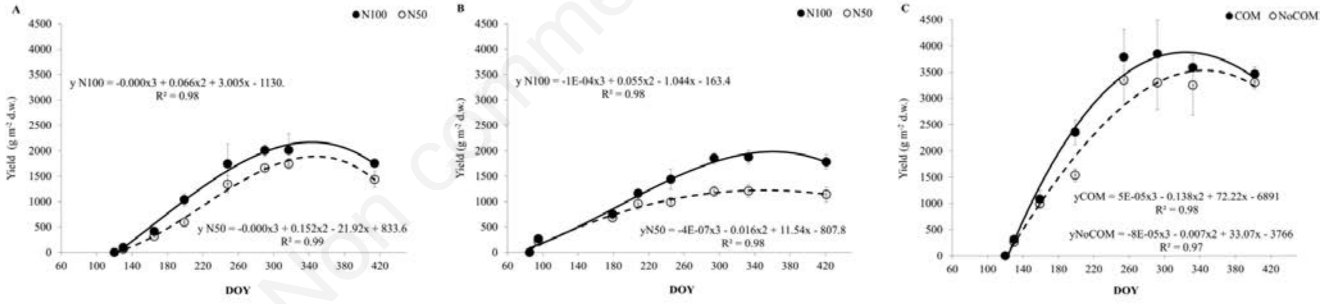

Figure 2. Development of above-ground biomass (gm^{-2} dry weight) in the last crop cycle. A) Sant'Angelo dei Lombardi (10th); B) Bellizzi (6th); C) Acerra (4th). Bars indicate standard errors (n=3).

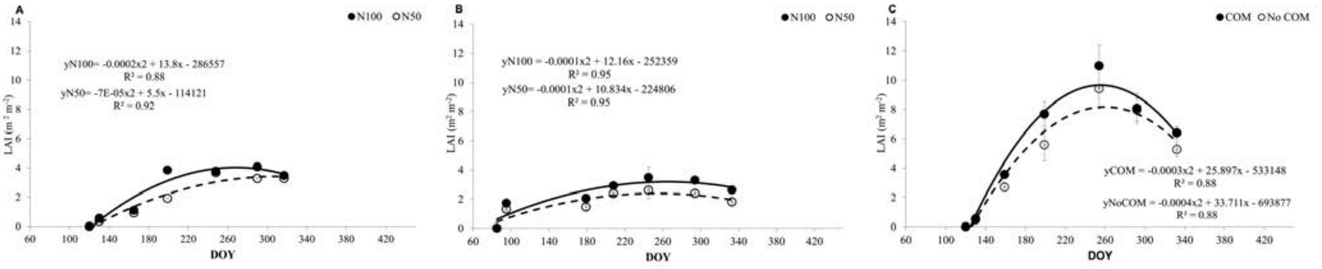

Figure 3. Leaf area index (m^{2}m^{-2}) in the last growing season. A) Sant'Angelo dei Lombardi (10th); B) Bellizzi (6th); C) Acerra (4th). Bars indicate standard errors (n=3).

ha^{-1}) and considering that the compost provided an initial input of 3.5 t C ha^{-1}, these results indicate that, in addition to the contribution of stabilised organic matter, soil C increase may be due to the contribution of leaf fall, root exudates and turnover, and soil C protection by the litter effect and by the absence of soil tillage (Fagnano *et al*., 2015).

This is also confirmed by the higher increases of soil C that have been recorded in the more productive conditions (Swinnen *et al*., 1995). Organic N into the topsoil was higher at SA, mainly because the environmental constraints (summer drought and winter cold) may have reduced the mineralisation thus enhancing its accumulation in soil organic matter, as already reported by Fagnano *et al*. (2015). At BL site, C and N variation were null or negative with lower fertiliser doses, thus confirming that fertilisation rate that not compensate N uptake by crops is not sustainable not only for yield levels and stability but also for soil fertility.

Growth analysis

Giant reed in all the three sites have a growing season starting in March-April and ending in October-November, confirming what observed by Nassi or Di Nasso *et al*. (2011a). Maximum values of biomass and leaf area index recorded at AC in the autumn period were similar to those reported by Nassi o Di Nasso *et al*. (2011a) and from Triana *et al*. (2015), while the values were lower in the other two sites thus confirming their lower fertility levels. LAD increased with fertilisation by 42% at BL, 31% at SA, thus proving to be a good indicator of productive potential of cropping systems: correlation between biomass yield and LAD was highly significant ($P \leq 0.001$) (Figure 4). This could be related to the higher intercepted PAR as reported by Ceotto *et al*. (2013).

On the average, LAD values calculated in 2013 were 1415, 706, 477 m^{2}m^{-2} × d at AC, SA, BL respectively and they were very higher than those of high productivity crops such as maize. In particular, LAD values measured in Campania Region were 353 m^{2}m^{-2} × d (Basile and Terribile, 2008); in international literature (Bukhsh *et al*., 2010) very much lower values are reported for maize (169 m^{2}m^{-2} × d). These differences are not due to maximum values of LAI, that were not different from our data, but to the higher duration of vegetative period and thus of photosynthetic activity of giant reed: 284 days on average for *vs* 131-140 days of maize (FAO class 700).

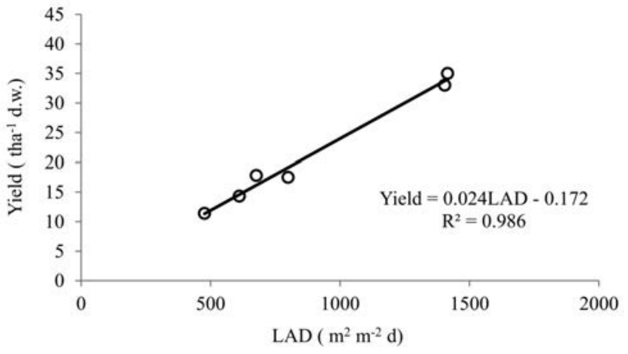

Figure 4. Linear regression: leaf area duration *vs* above-ground biomass yield.

Conclusions

Giant reed (*Arundo donax* L.) confirms its adaptability to low fertility soils, allowing interesting biomass yield also in marginal lands. Nevertheless, N uptake, even if lower (65-130 kg ha^{-1}) than other high-yielding crops, has to be compensated with fertilisation for avoiding soil nutrient depletion, with the aim to guarantee the sustainability of this cropping system. Its cultivation had a favourable environmental impact, thanks to the improvement in soil fertility (soil organic matter and N increase) and to mitigation of climate change (C storage in the soil) due to both the contribution of leaf fall, root exudates and turnover and to soil C protection by the litter effect and by the absence of soil tillage. In marginal soils of Southern Italy, this crop also confirms the presence of an increasing trend during the first 3-4 years, then followed by a constant phase whose duration depends on environmental constraints and sustainability of cropping systems (*i.e*. fertilisation). High productivity levels of this crop are related to the extremely high duration of the vegetative period (from March to November in Mediterranean area), well expressed by LAD that is more than double as compared with other high-yielding crops like maize.

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