

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 behavior of this crop was evaluated in three study areas of Campania region, under different energy inputs: two levels of nitrogen fertilization, N100 and N50 in Sant'Angelo dei Lombardi (SA) and Bellizzi (BL). In Acerra (AC) site compost fertilization was made with the aim 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 fertilization is not significant at least in the short terms. Nevertheless, N uptake ($65\text{--}130\text{ kg ha}^{-1}$), also if lower than other high-yielding crops, needs to be compensated with fertilization for avoiding depletion of soil nutrient reserves, with the aim 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 N increase) and to the mitigation of climate change (C storage in the soil).

This crop confirms in marginal soils of Southern Italy, 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 vegetative period and thus of photosynthetic activity (from March to November in Mediterranean area), well expressed by LAD index that is more than double as compared with 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 salinization (Fiorentino *et al.*, 2010; Fagnano *et al.*, 2012; Impagliazzo, 2014, Fagnano *et al.*, 2015).

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; Nasso o Di Nasso, 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 ($37 \mu\text{moli m}^{-2} \text{s}^{-1}$) 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 N (100–120 kg ha⁻¹ year⁻¹) and water (from no irrigation to 75% ET restitution) (Angelini *et al.*, 2005 a; 2005 b; 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).

As regards the relations between yield and mineral fertilization, there are contrasting results (Dalianis *et al.*, 1994; Cristou *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 analyze plant behavior. 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 (Avellino) 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 a.s.l.).

This field is characterized 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 36.5° 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 (Salerno) was located in the experimental farm *Torre Lama* of the University of Naples Federico II, (40°37'N, 14°58'E, 30 m a.s.l.) in the Sele alluvial plain.

The soil has silt-loam texture and low content organic matter and nitrogen (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 (Napoli - Campania felix) (40°60'N, 14°21'E, 21 m a.s.l.), characterized 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 nitrogen (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).

Climate is that typical of the coastal plain with mild winters and frequent rainfall events during the autumn period 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.

Table 1. Soil and climatic characteristics of experimental sites.

Experimental Site	Soil Texture (0-40 cm)			Soil chemical characteristics			Climatic information over the years of the long term experiment				
	Sand	Silt	Clay	pH	OM	N _{tot}	Temperature			Rainfall	ET ₀
	(2-0.05 mm)	(0.05-0.002 mm)	(<0.002 mm)				Avg. Annual	Min Abs.	Max Abs.	Avg. Annual	
	(%)						(C°)			(mm year ⁻¹)	
Sant'Angelo dei Lombardi*	37.0	24.2	37.9	8.1	1.1	0.9	11.8 (± 0.6)	-10	35.5	1050 (± 263)	916 (± 62)
Bellizzi°	29.3	43.3	27.5	7.3	1.9	1.2	17.0 (± 0.2)	-2.6	37.4	651 (± 135)	1105 (± 14)
Acerra [#]	58.5	25.1	16.3	7.7	2.9	1.8	16.3 (± 0.2)	-5.8	41.9	1060 (± 176)	1264 (± 47)

*Soil sampled on October 2004 before planting, climatic period (2004-2013); °soil sampled on February 2008 before planting, climatic period (2008-2013);

[#]soil sampled on April 2009 before planting, climatic period (2009-2013).

OM, Organic Matter; N_{tot}, Total Organic Nitrogen.

Crop management

At Sant'Angelo dei Lombardi, 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 m² (10×14 m) plots at the density of 1×1 m. No irrigation was made and two doses of N fertilization were compared (100 and 50 kg ha⁻¹ of N from urea).

At Bellizzi, soil preparation was made in autumn 2007 with deep ripping (60 cm) followed by soil milling (0.20 m), pre-plant fertilization of 150 kg ha⁻¹ of K₂O (potassium sulphate) and 150 kg ha⁻¹ P₂O₅ (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 m² (16×33 m) plots.

No irrigation was made and two doses of N fertilization were compared (100 and 50 kg ha⁻¹ of N from urea). Plants were watered only after transplanting (April 2008) in order to ensure good root contact with the soil.

At Acerra 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 x 0.60 m and transplanted in 132 m² (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).

Crop and soil monitoring

Yield data refer to standings of 10 years at S. Angelo (2004–2013), 6 at Bellizzi (2008–2013) and 4 at Acerra (2009–2012).

Harvests of the aboveground biomass were manually made, on sampling areas of 10 m², in the winter after each growing cycle (February 2014 at S. Angelo and Bellizzi and February 2013 at Acerra). 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.) and sent to the laboratory for the determination of the content in organic nitrogen (Kjeldahl method). In the same dates, soil samples of two layers (0–20, 20–40) 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 S. Angelo dei Lombardi, 6th at Bellizzi and 4th at Acerra.

For the three sites, crop sampling began 10 days after crop re-growth. For each date, a sampling area of 1 m² 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*.

The collected data have been used to calculate the following indices: i) *DW* (Dry weight): quantity of dry matter per unit area (g m⁻²); ii) *LAI* (*Leaf Area Index*): ratio between leaf area and ground area (m²m⁻²); iii) *LAD* (*Leaf Area Duration*): 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:

$$LAD = (LAI_2 + LAI_1) * (t_2 - t_1)/2 \quad (1)$$

LAD = Leaf Area Duration (m² m⁻² d)

LAI₁, LAI₂ = LAI at days t₁ and t₂ respectively

t₁, t₂ = days of the year in the two sampling dates

Statistical analysis

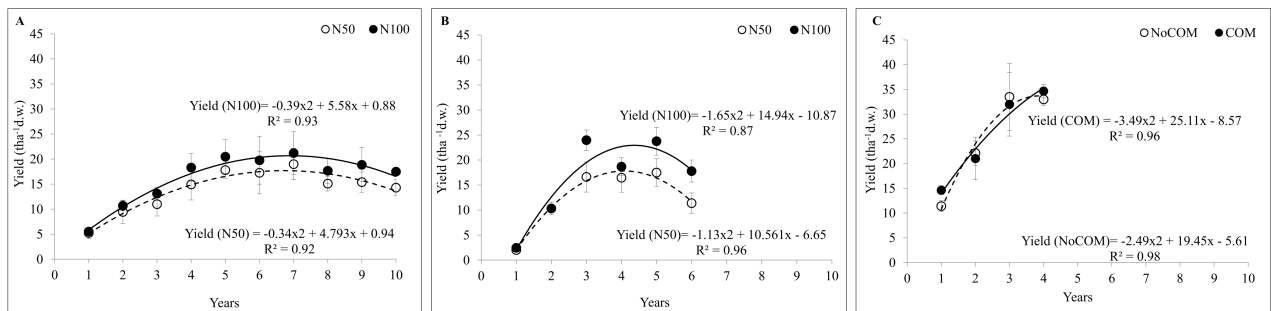
All data were subjected to Analysis of variance by using the software MSTAT-C (Crop and Soil Science Department, Michigan State University). A split plot randomized block design with 2 factors, locations (main factor) and fertilization (sub-factor) was used. All means were separated using the test of DMS for a p-value ≤0:05 (*) and p-value ≤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 Sant'Angelo dei Lombardi (SA) and Bellizzi (BL), with peaks of 20 and 25 t ha⁻¹ d.w., while they were higher at Acerra (AC) where yield reached 35 t ha⁻¹ d.w. in the 4th year. The effect of the higher dose of fertilizer was significant at Bellizzi (+ 15.6% on the average) and Sant'Angelo dei L. (+16% on the average) Of course in the high fertility soil of Acerra, compost fertilization didn't have effect of crop yield.

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).



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% respectively (Table 2). Nitrogen uptake was very much lower at SA and BL (65.7 and 73.1 kg ha⁻¹ respectively).

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

Site	N uptake	N content (g:100g)	
	Kg ha ⁻¹ tot	Culms	Leaves
S.Angelo dei L.	65.7 b	0.3	0.9 b
Bellizzi	73.1 b	0.3	1.6 a
Acerra	131.5 a	0.4	1.5 a
<i>mean</i>	<i>90.12</i>	<i>0.3</i>	<i>1.3</i>
<i>Significance</i>			
<i>Location</i>	≤ 0.01	<i>n.s.</i>	≤ 0.01
<i>Fertilization</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>
<i>Loc.xFert.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>

C and N Balance during the crop periods in the three sites.

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

At SA, the 2 fertilizer doses (N50 and N100) showed the same levels of SOC with an increase 0.11 g C/100g 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 soil corresponding to a 36% increment (Table 4).

In contrast, at BL after 6 years of cropping period, organic carbon increased only with the highest dose of N (100 kg ha⁻¹), while with the lowest dose of fertilizer, there was a depletion of the reserves of soil organic carbon. Organic N in the topsoil did not changed with the lowest dose of fertilizer, 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/100g, corresponding to a 13% of increment (Table 3), while in the not fertilized plots, SOC increased in 4 years by 0.09 g C/100g, corresponding to a 5% increment. In this site the increase of organic N was very limited in both the fertilizer levels, with an increase of 0.16 g/kg, on the average, corresponding to a 9% increment (Table 4).

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

Site	Years	Organic Carbon (g C/100g)					
		Time 0		Harvest		Variation	
		Low input	High input	Low input	High input	Low input	High input
S. Angelo dei L.	2004-2013	0.79c	0.79c	0.92b	0.89c	0.12a	0.10b
Bellizzi	2008-2013	1.19b	1.09b	1.01b	1.20b	-0.17bc	0.10b
Acerra	2009-2012	1.73a	1.73a	1.82a	1.95a	0.09b	0.22a
<i>Significance</i>							
<i>Location</i>		≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01
<i>Fertilization</i>		<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>
<i>Loc.xFert.</i>		<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>

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

Site	Years	Organic N (g kg ⁻¹)					
		Time 0		Harvest		Variation	
		Low input	High input	Low input	High input	Low input	High input
S. Angelo dei L.	2004-2013	0.81b	0.81b	1.16b	1.09c	0.35	0.28
Bellizzi	2008-2013	1.14ab	1.22ab	1.14b	1.35b	0.00	0.13
Acerra	2009-2012	1.75a	1.75a	1.92a	1.90a	0.15	0.17
<i>Significance</i>							
<i>Location</i>		≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	<i>n.s.</i>	<i>n.s.</i>
<i>Fertilization</i>		<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>
<i>Loc.xFert.</i>		<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>

Growth Analysis

Above-ground biomass

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

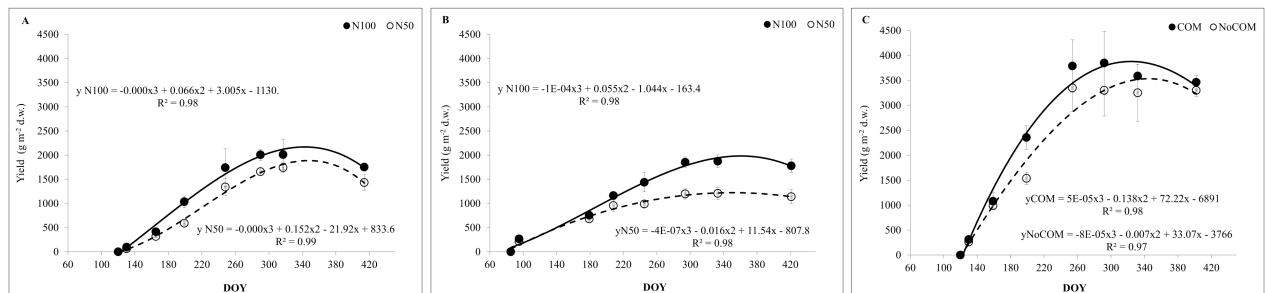
At SA (Figure 2A) there was an effect of fertilization dose, with values 14% higher on the average with the dose of 100 kg N ha⁻¹. The seasonal peak of biomass accumulation was reached

in November ($2065 \text{ g m}^{-2} \text{ d.w.}$ and $1741 \text{ g m}^{-2} \text{ d.w.}$, respectively for N100 and N50).

At BL (Figure 2B) the effect of fertilizer increased from June until November. Also in this site the peak of biomass accumulation was attained in November ($1875 \text{ g m}^{-2} \text{ d.w.}$ and $1209 \text{ g m}^{-2} \text{ d.w.}$ 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 fertilizer doses ($3576 \text{ g m}^{-2} \text{ d.w.}$ on the average).

Figure 2. Development Above-ground Biomass ($\text{g m}^{-2} \text{ d.w.}$) in the last crop cycle. A - Sant'Angelo dei Lombardi (10th). B - Bellizzi (6th). C - Acerra (4th). Bars indicate standard errors ($n=3$).



Leaf Area index

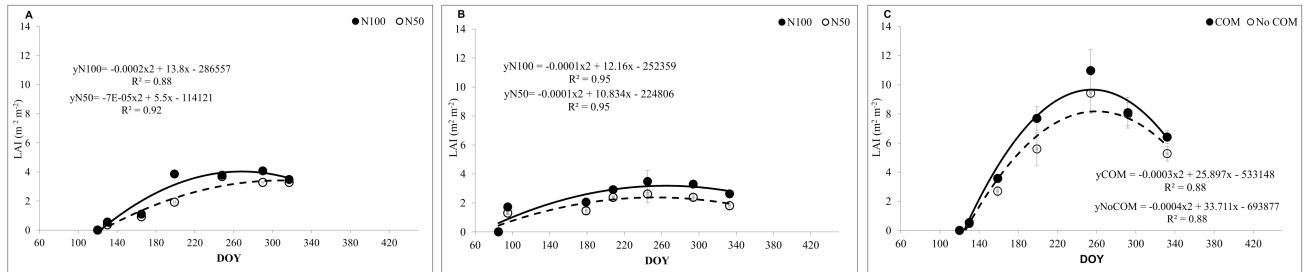
The development of the Leaf Area index (LAI) (Figure 3) was similar to that of biomass, with similar trend in SA and BL and higher values in AC. The peak was attained in July at SA (Figure. 3A), September at BL (Figure 3B) and AC (Figure 3C).

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

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

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

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



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 fertilizers.

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 d.w. Of course the effect of compost fertilization 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 mineralization rate of composted organic matter that make this fertilizer 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). 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 nitrogen were similar to those obtained in Italy on marginal lands (Nassi or 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 ha¹ of N on the average, with increasing differences over the time. Therefore, the restitution of N uptake with fertilization 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 site, in which a decreasing trend is evident starting from the 5th year, maybe mainly due to water limitations that don't 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 fertilization before planting has led to a significant increase of soil C (+0.22 g C/100 g), confirming that compost fertilization can contribute to climate change mitigation (Alluvione *et al.*, 2013). This increase corresponds to 5.7 t C ha⁻¹ (18.7 t CO₂ 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 stabilized 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 mineralization thus enhancing its accumulation in soil organic matter, as already reported by Fagnano *et al.* (2015).

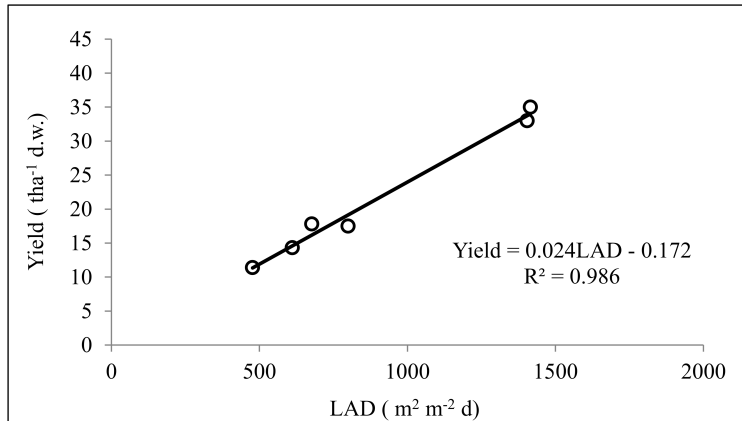
At BL site, C and N variation were null or negative with lower fertilizer doses, thus confirming that fertilization rate that not compensate N uptake by crops is not sustainable not only for yield levels and stability but also for soil fertility.

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 or 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 fertilization 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).

Figure 4. Linear regression: Leaf Area Duration (LAD) vs Above-ground Biomass Yield.



On the average, LAD values calculated in 2013 were 1415, 706, 477 $\text{m}^2\text{m}^{-2} \times \text{d}$ 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 $\text{m}^2\text{m}^{-2} \times \text{d}$ (Basile and Terribile, 2008); in international literature (Ahmad M. alias Bukhsh H. A. *et al.*, 2010) very much lower values are reported for maize (169 $\text{m}^2\text{m}^{-2} \times \text{d}$). 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).

Conclusions

Giant reed (*Arundo donax* L.) confirms its adaptability to low fertility soils, allowing interesting biomass yield also in marginal lands.

Nevertheless N uptake, also if lower (65–130 kg ha^{-1}) than other high-yielding crops, have to be compensated with fertilization for avoiding soil nutrient depletion, with the aim to guarantee the sustainability of this cropping systems.

Accepted paper

Its cultivation had a favorable 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 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.

This crop confirms also in marginal soils of Southern Italy, 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.* fertilization).

High productivity levels of this crop are related to the extremely high duration of 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 such as maize.

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