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Comparison of *Arundo donax* L. and *Miscanthus x giganteus* in a long-term field experiment in Central Italy: Analysis of productive characteristics and energy balance

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ABSTRACT

Miscanthus x giganteus (miscanthus) and *Arundo donax* L. (giant reed) are two perennial crops which have been received particular attention during the last decade as bioenergy crops. The main aim of the present study was to compare the above-ground biomass production and the energy balance of these perennial rhizomatous grasses in a long-term field experiment. The crops were cultivated from 1992 to 2003 in the temperate climate of Central Italy with 20,000 plants ha^{-1}, 100–100–100 kg N, P_2O_5, K_2O per hectare, and without irrigation supply. For each year of trial, biomass was harvested in autumn to estimate biometric characteristics and productive parameters. Besides, energy analysis of biomass production was carried out determining energy output, energy input, energy efficiency (output/input) and net energy yield (output–input). Results showed high above-ground biomass yields over a period of 10 years for both species, with better productive performances in giant reed than in miscanthus (37.7 t DM ha^{-1} $year^{-1}$ *vs* 28.7 t DM ha^{-1} $year^{-1}$ averaged from 2 to 12 years of growth). Such high yields resulted positively correlated to number of stalks (miscanthus), plant height and stalk diameter (giant reed). Moreover, these perennial species are characterised by a favourable energy balance with a net energy yield of 467 and 637 GJ ha^{-1} (1–12 year mean) for miscanthus and giant reed respectively. With such characteristics, both grasses could be proposed as biomass energy crops in Southern Europe with a significant and environmentally compatible contribution to energy needs.

1. Introduction

Perennial rhizomatous grasses, as miscanthus (*Miscanthus x giganteus*) and giant reed (*Arundo donax* L.) are generating much interest in Europe, as new sources of biomass for energy production.

There are many benefits expected from the production and use of these perennial grasses. They can give an important contribution to reduce anthropogenic CO_2 emissions because the quantity of CO_2 released by combusting biomass is does not exceed the amount that has been fixed previously by photosynthesis while the plants were growing [1–3]. In the other hand, the situation of agricultural sector in UE, characterised by food surplus, can be improved introducing alternative non-food crops as energy crops that can represent a new opportunity for the population of rural areas [4].

Furthermore these perennial grasses show some ecological advantages in comparison with annual crops. In fact

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miscanthus and giant reed need to have a limited soil management (planting and related tillage), reducing risk of soil erosion [5] and determining a likely increase in soil carbon content and in biodiversity [6]. Moreover, due to the recycling of nutrients by their rhizome systems, perennial grasses have a low demand for nutrient inputs and since they have few natural pests, they may also be produced without pesticide use [7].

Giant reed native from East Asia is widely diffused in Mediterranean environment where it is frequently found in riparian habitats. Usually it does not set fruit because the pollen results unfruitful; consequently, the better propagation method, for this species, is the use of rhizomes [8].

Throughout the United States, from northern California to Maryland *A. donax* is an invasive weed [9], growing in water and is classified as an emergent aquatic plant [10]. Currently, in Europe this species has been indicated like one of the most promising for energy production for the Southern areas of Europe [11,12]. Its high biomass productivity has been observed also reducing crop inputs, such as fertilisation and plant density [13,14] and this high yield is furthermore stable in the long-term [15,16]. Giant reed has a C3 photosynthetic cycle, but it has high rates of photosynthesis and productivity similar to those of C4 species [17].

Miscanthus was a perennial C4 grass endemic to East Asia, introduced in Europe as ornamental plant about 50 years ago [18]. Therefore it is adapted to warmer climates [19] and in addition it has shown a good adaptation to the climatic conditions of Central and South Italy.

European research has focused on one single clone *M. x giganteus*, which is a sterile, triploid interspecific hybrid [20]. Its sterility necessitates vegetative propagation by rhizome division or in vitro cultures [21]. Yield above 30 t ha^{-1} $year^{-1}$ (dry matter) are reported for locations in southern Europe with high annual incident global radiation and high average temperatures but only with irrigation. In central and northern Europe where global radiation and average temperatures are lower, yields without irrigation are more typically 10–25 t ha^{-1} $year^{-1}$ (dry matter). Yield variation depends on the different rainfall amount and distribution and confirmed that water availability is an essential yield-determining-factor [22].

Miscanthus and giant reed were characterised by favourable energy balance and total input decreased from the establishment to following years of growth [22–24,7,15,16]. For miscanthus the input ratio is between 14:1 and 20:1 and nitrogen, energy and land use efficiencies were simultaneously highest with low nitrogen supply level [6].

The aim of this study is to carry out a 12-year long-term comparison of giant reed and miscanthus, in order to investigate the productive characteristics and the energy balance of these perennial grasses and to estimate their potentialities as energy crops under the climatic conditions of Central Italy.

2. Materials and methods

2.1. *Crop culture*

Two experimental fields were carried out in 1992, one with miscanthus (*M. x giganteus*) and one with giant reed (*A. donax* L.) at the experimental centre of Rottaia Pisa (43°40′N latitude, 10°19′E longitude; 2 m altitude).

The soil was a typical Xerofluvent, representative of the lower Arno River plan and it was characterised by a superficial water table, 120 cm deep in driest conditions (Table 1). The previous crop was barley. Tillage was conducted in the autumn of 1991 and consisted of medium-depth ploughing (30–40 cm). Seedbed preparation was conducted in the spring, immediately before planting, by a pass with a double-disk harrowing and a pass with a field cultivator. For miscanthus and giant reed planting rhizomes with a couple of buds weighing 500 g taken from plants were used. The rhizomes were planted at 10–20 cm of soil depth.

Pre-plant fertiliser was distributed at a rate of 100 kg P_2O_5 ha^{-1} (triple super phosphate), 100 kg K_2O ha^{-1} (potassium sulphate) and 100 kg N ha^{-1} (urea). Nitrogen fertiliser was applied in the establishment year (1992) as 50% pre-plant and 50% side dressing when plants were 0.30–0.40 m tall. In the following years, P_2O_5 and K_2O fertilisers were applied during the winter (approximately at the end of January) while N was applied entirely at the start of growth in the spring (approximately during March). Plots were kept weed-free by hoeing. No crop diseases were detected during the experimental period and irrigation treatment was never necessary during the different field experiments.

The experimental design was a randomised block with four replications (plots 10 m × 10 m each). Miscanthus and giant reed were grown in 0.50 and 0.50 m wide rows at a population of 20,000 plants ha^{-1}. From the establishment year onward, harvests were carried out in autumn at the end of each growing season.

The border plants in the outer rows were not included in the harvested area. Plants in a 10 m^2 area were harvested by cutting 5 cm above-ground level and weighed to determine fresh weight. Height, stem diameter and shoot number were also determined on a small sub-sample (plants on 2 m^2 area). The sub-samples were placed in a forced-draft oven at 75 °C for 72 h and ground after determination of the dry weight.

Daily changes in air temperature and daily rainfall were recorded along the growing cycle at nearby whether station. The mean thermal time in growing degree days (GDD) was

Table 1 – Soil physical and chemical characteristics in *Arundo donax* and *Miscanthus x giganteus* field trials.

	Arundo donax	*Miscanthus x giganteus*
Sand (2–0.05 mm) (%)	44.3	41.9
Silt (0.05–0.002 mm) (%)	42.3	44.5
Clay (<0.002 mm) (%)	13.4	13.6
pH	8.3	7.9
Organic matter (%)	1.63	1.81
Total nitrogen (Kjeldahl Method) (g kg^{-1})	1.35	1.17
Available phosphorus (Olsen) (mg kg^{-1})	8.8	10.7
Exchangeable potassium (Dirks and Scheffer) (mg kg^{-1})	106.2	108.2
Field capacity (wt %)	21.0	25.0
Permanent wilting point (wt %)	9.2	9.6

Soil horizon 0–0.30 m sampled on February 1992 before planting.

Table 2 – Climatic conditions along the 1992–2003 experimental period in comparison with long-term average (1918–1982) at the field experimental station (Pisa, Italy 43°N; 10°E).

Month	Total monthly rainfall (mm)		Maximum air temperature (°C)		Minimum air temperature (°C)	
	1992–2003[a]	Long-term 1918–1982	1992–2003[a]	Long-term 1918–1982	1992–2003[a]	Long-term 1918–1982
January	64.2	89	12.0	11.2	2.8	2.8
February	37.5	80	13.6	12.7	2.1	2.3
March	39.4	79	15.8	15.1	4.2	5.3
April	81.3	78	17.7	18.3	6.9	8.1
May	48.9	67	23.3	22.4	11.4	11.6
June	56.8	46	26.4	26.1	14.5	15.0
July	16.5	25	28.7	29.1	16.4	17.2
August	41.4	42	29.8	29.2	17.6	17.0
September	91.3	84	25.2	26.2	13.7	14.8
October	144.5	134	21.1	21.3	11.4	11.0
November	149.0	118	15.7	15.8	7.3	6.9
December	86.6	99	12.1	12.0	4.0	3.7
Total or mean	857.3	941	20.1	20.0	9.4	9.6

[a] Total/mean monthly value.

calculated for each year with NOAA method, above a base temperature of 10 °C and a maximum cut-off temperature of 30 °C as $\mathrm{GDD} = {}_{S1}\Sigma^{S_2}(T_m - b_0)$. T_m was the mean daily temperature, b_0 the base temperature and S_1 and S_2 were the growth start and the harvest time respectively, expressed in Julian day.

2.2. Biomass analysis for calorific value

All biomass was milled in a Retsch SM 1 rotor mill to <297 μm. The milled samples, spread in a thin layer were exposed to air for several days to equilibrate with atmospheric moisture. Carbon, hydrogen and nitrogen contents were determined by means of a Leco CHN 600 instrument and sulphur content by a Leco SC 432. Calorific value was determined using a Leco AC 300 calorimeter according to the ASTM D2015 standard method.

2.3. Energy balance

Energy analysis of biomass production was carried out by determining energy costs for machinery fabrication and repairs, for fertiliser and planting material and for fuel consumption for the various operations. Energy costs for delivering the production outside the field, for storage and drying were not calculated. In our research, giant reed and miscanthus were propagated by rhizome cuttings. Because the harvested plant material was anatomically similar to the organs or tissues used for establishing the crop, the quantity of material used for propagation was subtracted from the total crop yield. In our analysis, the propagation material energy

Table 3 – Harvest dates, rainfall, growing degree days (GDD) and cycle length in giant reed and miscanthus crops.

Year	*Arundo donax*				*Miscanthus x giganteus*			
	Harvest date	Rainfall (mm)	GDD[a] (°C)	Cycle length (days)	Harvest date	Rainfall (mm)	GDD[a] (°C)	Cycle length (days)
1992	20 October	549.6	1883	219	15 September	351.5	1601	184
1993	15 November	370.3	2076	245	28 September	144.3	1829	197
1994	11 October	335.2	2092	210	21 September	153.1	1905	190
1995	12 October	288.3	1712	211	12 October	288.3	1712	211
1996	25 October	524.6	1706	224	10 October	437.4	1649	209
1997	23 October	228.7	1835	222	24 September	211.6	1547	193
1998	30 October	412.9	1741	229	16 September	272.5	1576	185
1999	10 November	643.9	1898	240	14 September	307.6	1530	183
2000	28 November	480.9	1671	258	18 September	266	1564	187
2001	10 October	200	1775	209	9 October	200	1765	208
2002	7 October	414	1851	206	2 October	376.7	1797	201
2003	7 October	99.7	1877	206	23 October	105.7	1956	222
Mean		379	1843	224		260	1702	198
Standard deviation		158.4	135.8			100.6	146.6	

[a] Calculated with NOAA method. Accumulated daily mean temperature with a base temperature of 10 °C and a maximum cut-off temperature of 30 °C from crop re growth to harvest.

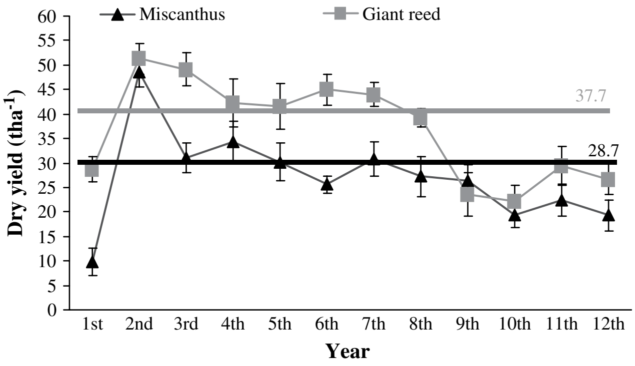

Fig. 1 – Giant reed and miscanthus above-ground dry yield from the crop establishment (1992) to the 12th year of growth in comparison, for each species, with the mean value calculated excluding the yield of the fist year. Vertical bars represent the standard deviation.

cost was considered negligible, since the biomass involved was <3% of the total crop yield. Energy inputs for machinery were determined by estimating energy consumption for the fabrication and the repair of the machinery utilised for miscanthus and giant reed cultivation, and by calculating the annual per hectare machinery cost [24] The energy input for fabrication and repair parts and materials of the machinery was calculated taking into account their weight with an energy cost of 108 MJ kg^{-1} [25]. We assumed that machinery and tools were used on 200 ha and machine life was 10 years. The energy cost for fertiliser manufacturing was 47.1 MJ kg^{-1} for N, 15.8 MJ kg^{-1} for P_2O_5, and 9.3 MJ kg^{-1} for K_2O, [25,26]. The fuel costs of various management operations were calculated by determining diesel consumption and by multiplying those values by the heat of diesel fuel combustion (42.7 MJ kg^{-1}) [27]. Lubricant consumption was calculated for each operation and multiplied by the energy coefficient of 80 MJ kg^{-1}[28]. The energy balance was assessed considering the energy costs of input production and the energy output obtained by the transformation of the final product. The efficiency of crop energy production was evaluated as net energy yield (calculated as the difference between energy output and energy input per hectare) and as energy production efficiency (as ratio between energy output and energy input per hectare).

2.4. Statistical analysis

For each species all variables were submitted to descriptive analysis using a randomised block experimental design with four replications.

Regression analyses between dry yield and the main plant biometric parameters were carried out and the correlation has been estimated by Pearson coefficient (r). All analyses used the statistical software CO-STAT Cohort 6.201, registration number 101240.

3. Results and discussion

3.1. Weather conditions and cycle length

The site is located in the Mediterranean region and the climate is characterised by rainfall mainly concentrated in autumn and spring. Mean minimum temperature is 9.4 °C and mean maximum temperature is 20.1 °C. Temperature and rainfall patterns for the site are shown in Table 2. Along the experiment the total mean rainfall from March to the crop harvest date was 379 mm and 260 mm for giant reed and miscanthus respectively. However during the 12 experimental seasons of growth, considerable variability of rainfall distribution was observed (Table 3). Every year for the lifetime of the both crops, new shoots emerge around March growing rapidly in June–July and producing stems and leaves. From late July the lower leaves start to dry. Crop drying accelerates during autumn when anthesis occurs from the beginning of October to the end of November for giant reed and from the middle of September to the end of October for miscanthus (Table 3). In this phenological stage moisture contents fall significantly, maximum dry biomass yield is achieved and therefore, crops are harvested. This behaviour has been observed also by Petrini et al. [22], Acaroglu and Semi Aksoy [23], and Ercoli et al. [24]. In winter-time plants stop their growth because of low temperatures and regrowth occurs in the following springtime. During the growing season from vegetative regrowth to

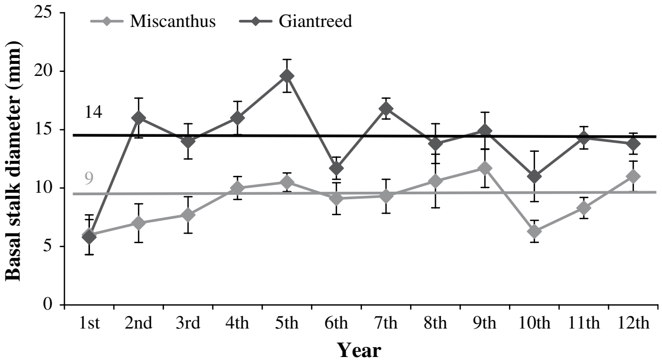

Fig. 2 – Giant reed and miscanthus basal stalk diameter from the 1st to the 12th year of growth for each species and in comparison with the mean value calculated excluding the value of the first year. Vertical bars represent the standard deviation.

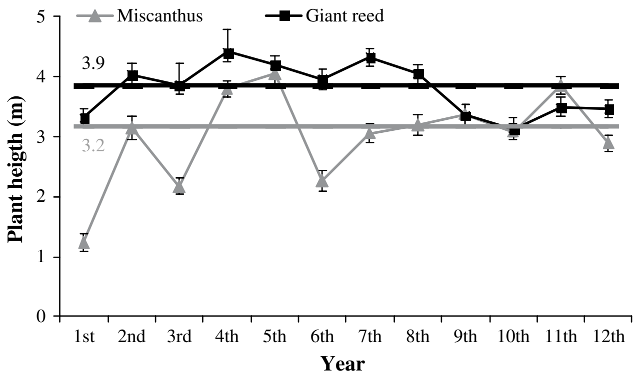

Fig. 3 – Giant reed and miscanthus plant height from the 1st to the 12th year of growth in comparison, for each species, with the mean value calculated excluding the value of the first year. Vertical bars represent the standard deviation.

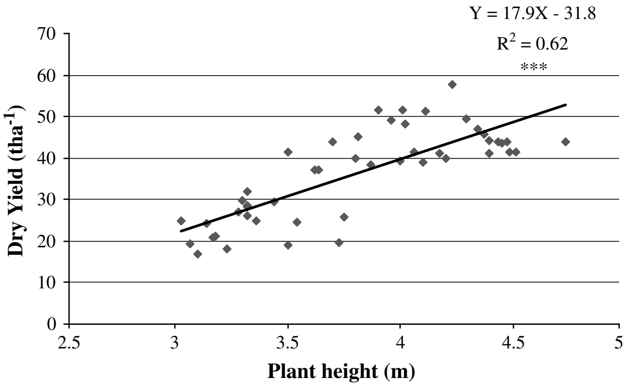

Fig. 5 – Relationship between plant height (*X*) and dry yield (*Y*) in giant reed. *, **, ***Significant at the 0.05, 0.01 and 0.001 probability level.

final harvest, giant reed and miscanthus crops accumulated 1843 °C and 1702 °C in 224 and 198 days respectively. During the same period the water supply received by rainfall was 379 mm and 260 mm for giant reed and miscanthus respectively (Table 3).

3.2. *Dry biomass yield*

Above-ground dry matter yield of giant reed and miscanthus, determined from the establishment year to the 12th year of growth is reported in Fig. 1.

In the climatic condition of Central Italy giant reed was characterised by higher dry yield than miscanthus (37.7 t ha^{-1} *vs* 28.7 t ha^{-1} averaged from 2 to 12 years of growth). For both species the crop yield was very poor in the first year. Thereafter the biomass yield increased rapidly from the young to the mature crops. From 1st to 2nd year biomass dry yield increased +79% (from 10 to 48 t ha^{-1} $year^{-1}$) in miscanthus and +43% (from 29 to 51 t ha^{-1} $year^{-1}$) in giant reed. The biomass yield of these species in the tested environment, obtained without irrigation supply, is higher than recorded by other authors in other Southern European regions. On typical clay soils of Padana plain (Emilia Romagna region, Italy), dry yields from 8 to 30 t ha^{-1} in the first and in the second year of growth for miscanthus and from 20 to 42 t ha^{-1} for giant reed were observed [29]. Moreover, in studies realised in South Italy on 39 giant reed clones, mean yields of 11 t ha^{-1} and 22 t ha^{-1} in the first and the second year of growth respectively were recorded [3]. For miscanthus, yields above 30 t ha^{-1} (dry matter) were reported for locations in southern Europe with high annual incident global radiation and high average temperatures but only with irrigation supply [18]. These differences in yield performance can be linked to soils' characteristics (differences in fertility, water retention, etc.), crop management (fertilisation, irrigation, plant density, etc.) and genetic characteristics of the used clone that plays a crucial role mainly in the establishment phase. In fact, other works showed the influence of N fertilisation, irrigation level and plant density on miscanthus [21,22,30] and giant reed biomass production [15,16]. Our results confirm the good adaptation of these rhizomatous grasses at the beginning of production cycle to the pedo-climatic conditions of the Arno River plain

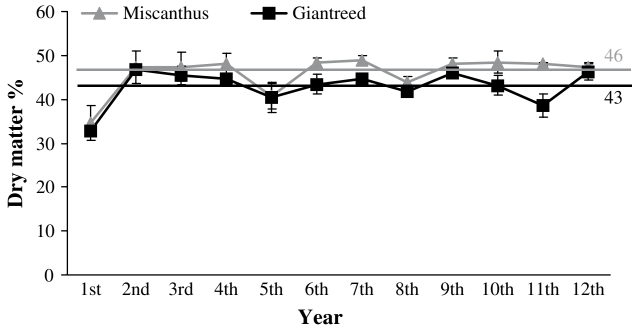

Fig. 4 – Giant reed and miscanthus dry matter percentage from the crop establishment (1992) to the 12th year of growth for each species in comparison with the mean value calculated excluding the value of the first year. Vertical bars represent the standard deviation.

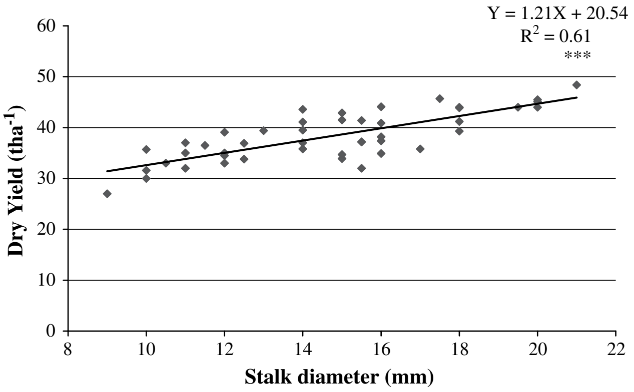

Fig. 6 – Relationship between stalk diameter (*X*) and dry yield (*Y*) in giant reed. *, **, ***Significant at the 0.05, 0.01 and 0.001 probability level.

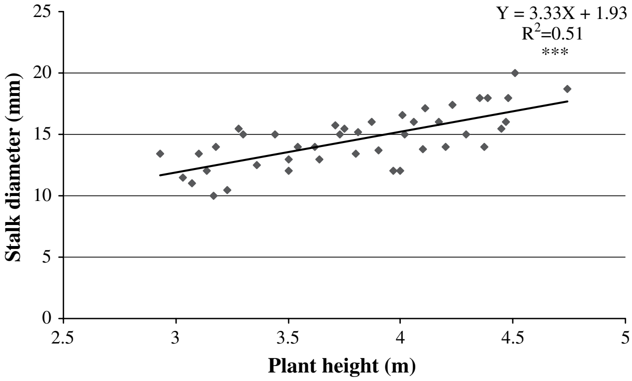

Fig. 7 – Relationship between plant height (*X*) and stalk diameter (*Y*) in giant reed. *, **, ***Significant at the 0.05, 0.01 and 0.001 probability level.

characterised by deep and fertile soils and mild winter temperatures.

Not including the first and the second year of growth, giant reed and miscanthus showed in the following years, a similar production trend characterised by two yielding phases: a maturity phase from 3rd to the 8th year of growth and a decreasing phase from 9th to 12th year of growth. Giant reed dry yield ranged from 49 to 39 t ha^{-1} from the 3rd to the 8th year with a mean value of 43.5 t ha^{-1} year^{-1}. From 9th to 12th year a decreasing trend was observed with 25.5 t ha^{-1} year^{-1} as mean value of dry biomass. A similar trend has been observed in miscanthus that showed 29.4 t ha^{-1} year^{-1} dry yield from 3rd to 8th year of growth. Thereafter the dry yield production level decreased to 20.4 t ha^{-1} from 9th to12th year of growth (Fig. 1). The higher dry yield of giant reed was due to higher plant height (3.85 m *vs* 3.17 m) and higher basal stalk diameter than miscanthus (15.1 mm *vs* 9.2 mm) (Figs. 2 and 3).

On the other hand, the dry matter content of biomass was always higher in miscanthus than giant reed. From year 1 to year 12 it ranged from 34.6 to 47.3% (mean value 46%) in miscanthus and from 32.8 to 46.9 (mean value 42.9%) in giant reed (Fig. 4).

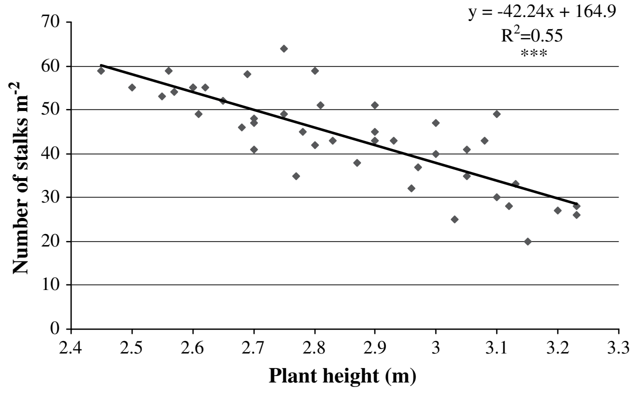

Fig. 8 – Relationship between plant height (*X*) and number of stalks m^{-2} (*Y*) in giant reed. *, **, ***Significant at the 0.05, 0.01 and 0.001 probability level.

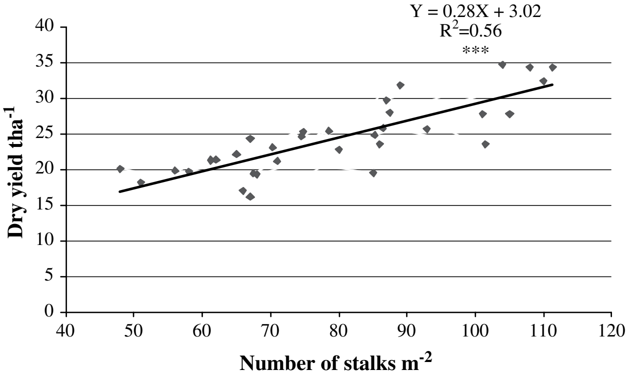

Fig. 9 – Relationship between number of stalks (*X*) and dry yield (*Y*) in miscanthus. *, **, ***Significant at the 0.05, 0.01 and 0.001 probability level.

To predict a relationship between giant reed yield and plant biometric characteristics, a regression analysis was performed. Results showed that biomass dry yield increased linearly with plant height and basal stalk diameter with a significant determination coefficient ($R^2 = 0.62$ and 0.61 respectively) (Figs. 5 and 6). Furthermore plant height is positively related with stalk diameter ($R^2 = 0.51$) (Fig. 7) while a negative correlation was observed with stalks number per square meter ($R^2 = 0.55$) (Fig. 8). These relationships indicate that high dry biomass yield can be largely due to plant apical growth and to the stalk diameter extension. Moreover, when plants grow in height at the same time they are characterised by stalk enlargement and it is negatively related with the number of shoots which arise from crown buds.

Results from regression analysis performed on miscanthus data showed that dry yield increased linearly with number of

Table 4 – Energy input (MJ ha^{-1}) for the production of *M. x giganteus* and *A. donax* biomass considering crop with 20,000 plants ha^{-1} from the crop establishment (1992) to the 12th year of growth.

Crop establishment	MJ ha^{-1}
Tillage (ploughing + harrowing)	3937
Planting rhizomes	521
Fertiliser distribution	423
N fertiliser	4710
P fertiliser	1580
K fertiliser	930
Hoeing (1 time)	955
Harvest	3942
Total	16,997
Cropping operations from 2nd year	MJ ha^{-1}
Fertiliser distribution	423
N fertiliser	4710
P fertiliser	1580
K fertiliser	930
Harvest	3942
Total from 2nd year	12,150

Table 5 – Global energy balance for giant reed (*A. donax*) and miscanthus (*M. x giganteus*) from the crop establishment (1992) to the 12th year of growth.

Year	Energy input ($GJ\,t\,ha^{-1}$)	Energy output[a] ($GJ\,t\,ha^{-1}$)		Efficiency of energy (output/input)		Net energy yield (output–input) ($GJ\,ha^{-1}$)	
		A. donax	*M. x giganteus*	*A. donax*	*M. x giganteus*	*A. donax*	*M. x giganteus*
Crop establishment	17	505	173	30	10	488	156
Year 2	12.1	903	858	75	71	891	846
Year 3	12.1	864	550	71	45	852	538
Year 4	12.1	744	609	62	50	732	597
Year 5	12.1	730	535	60	44	718	522
Year 6	12.1	792	453	65	37	780	441
Year 7	12.1	774	545	64	45	762	533
Year 8	12.1	690	481	57	40	678	469
Year 9	12.1	415	466	34	38	403	453
Year 10	12.1	389	343	32	28	377	331
Year 11	12.1	517	396	43	33	505	384
Year 12	12.1	470	342	39	28	458	330
Mean	12.5	650	479	53	39	637	467
Standard deviation		179	168	20	18	180	169

a To determine the energy output a calorific value of 17.6 and 17.7 $MJ\,kg^{-1}$ for *A. donax* and *M. x giganteus* respectively has been used.

stalks ($R^2 = 0.56$) (Fig. 9) and if the number of stalks doubles a 30% increment in dry yield occurs.

3.3. *Energy balance*

During the field trial the total energy input for miscanthus and giant reed was the same because the identical management has been used for both crops. For perennial grasses the establishment year is characterised by elevated energy input not only for mechanization (tillage and harvest 23% each of total energy input) and rhizome transplanting (3%), but also for fertilisation (45% of total energy input). The total energy input decreased from the establishment to the following years because the planting operation costs were not more included. It ranged from 17 $GJ\,ha^{-1}$ in the 1st year to 12.1 $GJ\,ha^{-1}$ in the following years (Table 4). The energy output (determined as calorific value for dry yield) showed different value in giant reed and in miscanthus. In fact, giant reed energy output was higher than miscanthus, excluding the 9th year of growth, and it ranged from 389 $GJ\,ha^{-1}$ in year 10 to 903 $GJ\,ha^{-1}$ in the second year with a mean value of 650 $GJ\,ha^{-1}$. In miscanthus energy output ranged from 173 $GJ\,ha^{-1}$ in the establishing year to 858 $GJ\,ha^{-1}$ in the second year with a mean value of 479 $GJ\,ha^{-1}$ (Table 5).

To evaluate the performance of *M. x giganteus* and *A. donax* agricultural production system, we considered the net energy yield (calculated as difference between energy output and energy input per hectare) and energy production efficiency (calculated as ratio between energy output and energy input per hectare). From the establishment year onward, the energy efficiency improved. In giant reed it increased from 30 to 55 (mean value from the 2nd to the 12th year of growth). Similarly the net energy yield increased from 488 to 891 $GJ\,ha^{-1}$ from the 1st to the following years of growth (Table 5). In miscanthus the energy efficiency ranged from 10 in the 1st year to 42 (mean value from the 2nd to the 12th year of growth). At the same time the net energy yield increased from 156 to 846 $GJ\,ha^{-1}$ (Table 5). Being the energy balance carried out over 12-year-period, the energy costs of crop establishment were distributed in a longer period thus decreasing and their influence. The differences about net energy production and energy efficiency between giant reed and miscanthus depend on the dry biomass yield having the crops similar calorific value and employing the same energy input. In fact, giant reed, after 12 years of growth, was characterised by a total dry yield about 443 $t\,ha^{-1}$ against 325 $t\,ha^{-1}$ dry yield of miscanthus. In Table 6 the petroleum and coal equivalents obtained from giant reed and miscanthus energy yield have been reported. The results showed that 1 ha cultivated with giant reed with a mean production of net energy of about 637 $GJ\,ha^{-1}$ could substitute 14 $t\,ha^{-1}$ and 20 $t\,ha^{-1}$ of petroleum and coal respectively for each year of cultivation thus contributing to the safeguard of environment connected with the use of renewable sources of energy.

Table 6 – Petroleum and coal energy equivalent in comparison with mean and total net energy yield derived from giant reed and miscanthus biomass from the 1st to the 12th year of growth.

		Net energy yield (output–input) ($GJ\,ha^{-1}$)	Petroleum equivalent ($t\,ha^{-1}$)	Coal equivalent ($t\,ha^{-1}$)
A. donax	Mean[a]	637	14	20
	Total	7644	169	246
M. x giganteus	Mean[a]	467	10	15
	Total	5604	124	180

Petroleum equivalent = 1 ton of petroleum that corresponds to 45.36 GJ; coal equivalent = 1 ton of coal that corresponds to 31.08 GJ.

a Mean values were calculated as net energy yield from the 1st to the 12th year of growth.

4. Conclusions

Following 12 years of observation giant reed and miscanthus appeared particularly suited for the cultivation environment of Southern European countries because of their high biomass yield and positive energy balance. Moreover, these perennial species showed a favourable energy balance better than annual herbaceous crops that require about 50% of total energy for tillage and seeding operations [16].

The results showed that these perennial rhizomatous grasses under the present climatic condition characterised by good water (summer rainfall not less than 50 mm) and macronutrients availability, can give high yields with minimum energy inputs. Furthermore in this experimental site, characterised by a rather superficial water table, these crops can be cultivated without irrigation obtaining stable dry yield (higher than 20 t ha^{-1}) with a production cycle over 10 years. These observations, although recorded in a particular location, could be extended to all Mediterranean agricultural areas with similar environmental conditions and characterised by 1800 °C GDD and useful rainfall availability not less than 300 mm during the growing season. Unfortunately water availability is a serious limiting production factor for many Mediterranean agricultural areas. In such environments giant reed and miscanthus crops were cultivated with irrigation supply thus worsening the energy balance of the biomass production system [24]. To improve the sustainability of bioenergy production on these grasses, further studies to compare irrigated and not-irrigated biomass production systems in dry agricultural areas could be useful to clarify the influence of irrigation on biomass production and energy balance.

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