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Long-Term Yields of Switchgrass, Giant Reed, and Miscanthus in the Mediterranean Basin

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10 **Long-term yields of switchgrass, giant reed and miscanthus in the**
11 **Mediterranean basin**

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Abstract

Uncertainty in predictions of long-term yields of perennial grasses makes business plans untenable in the short run. Long-term data across varied environments, including marginal lands, will help in preventing uncertainty while providing farmers and entrepreneurs with sound information to estimate reliable and affordable strategies on what, where and how long to grow perennial grasses. In the present study, the long-term yields (11 to 22 years) of switchgrass (*Panicum virgatum* L.), miscanthus (*Miscanthus × giganteus* Greef et Deuter) and giant reed (*Arundo donax* L.) grown in northern and southern Mediterranean environments are reported. Switchgrass was grown in Greece and northern Italy, giant reed in southern and northern Italy, and miscanthus in southern Italy. Furthermore, lowland and upland switchgrass ecotypes were compared in Greece. Despite similar biomass productions (9.8 and 10.0 Mg DM ha⁻¹ for uplands and lowlands, respectively), the upland ecotypes showed a significantly higher yield stability (CV of 24% and 32% for uplands and lowlands, respectively) over a 17-year period. Biomass yield varied considerably across years and locations; giant reed outperformed switchgrass under northern Italy environment (21.2 and 13.6 Mg DM ha⁻¹ for giant reed and switchgrass respectively). Annual yield of switchgrass was 30% higher in the north than south Mediterranean; miscanthus showed intermediate production compared to giant reed and switchgrass (average of 22 years) and a CV similar to switchgrass. In summary these results evidence that multi-location, long-term trials are strongly needed to reduce uncertainties on crop yield variability and provide more accurate data from which optimized socio-economic and environmental predictions can be achieved.

Keywords: Marginal land, biomass crop, biofuel, bioeconomy, yield prediction models

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Introduction

Switchgrass (*Panicum virgatum* L.), miscanthus (*Miscanthus × giganteus* Greef et Deuter) and giant reed (*Arundo donax* L.) are attractive feedstocks to produce advanced biofuels or bio-based products because of their high biomass yields and cellulose/hemicellulose composition. They are also recognized for providing substantial environmental benefits in term of greenhouse gas savings, soil erosion mitigation, soil fertility, and increased biodiversity [1–3]. Moreover, being perennial biomass grasses successfully grown on marginal or degraded lands, controversies over competing land-use for food would be allayed [4–7].

From the beginning of the 1990’s, several European projects (Miscanthus productivity networks, Giant reed network, Switchgrass for Energy, Bioenergy Chains, 4FCROPS, EUROBIOREF, etc.) addressed miscanthus, switchgrass and giant reed for energy or biorefinery purposes. The current EU research project OPTIMA (www.optimafp7.eu) was inspired by the aforementioned projects with the aim to provide insights into perennial grasses grown on marginal lands in the Mediterranean area. In this regard, long-term trials established in previous EU research projects were used.

Marginality of Mediterranean lands mostly concerns water scarcity and salt and/or nutrient stresses. Water availability is the most significant constraint to spring-summer crop production. This is particularly true in semi-arid Mediterranean type climates (e.g. southern Europe), due to both low annual rainfall and/or its irregular distribution during the year and from year to year. Perennial grasses, like other common crops, their yields varied considerably in response to climatic conditions, crop management, experiment type and stand age [8–16]. Such variation is exacerbated when they are grown under rainfed conditions in Mediterranean areas [15, 16]. Nonetheless, little is known about long-term yield across different environments, including marginal lands. In a persuasive review on biomass crop models [17], the authors concluded that detailed information on biomass production is scarce, and considerable work remains regarding the parameterization and validation of process-based models for bioenergy crops. Therefore, high-quality and representative

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8 field data are imperative for reliable, high-resolution and efficient simulations of biomass
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10 production. On the other hand, long-term agricultural studies are difficult to find and very few
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12 studies on long term yields of perennial grasses have been published, mostly due to the limited
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14 duration of research projects (generally 3–4 years), while the putative lifetime of these crops is
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16 much longer. Furthermore, most of these studies refer to one location [12–14, 18] and very few
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18 compare different species in variable environments [10, 11, 19]. Moreover, as switchgrass,
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20 miscanthus and giant reed are not yet grown on a commercial scale, a solid database is far from
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22 exhaustive, while the majority of results derives from plot and various experiments whose results
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24 are difficult to -compare [10,11], since adopted experimental protocols are different and not always
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26 reported in detail.

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28 In the present study, we report the long-term productivity (11 to 22 years) of switchgrass,
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30 miscanthus and giant reed grown under low input in Mediterranean North and South [20], with the
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32 aim of providing insights into the bioenergy and biorefinery industry's planning and forecasting
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34 processes. This study will provide a clearer picture of the real potential of these crops in southern
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36 Europe under low input management (i.e., rainfed and unfertilized conditions).

37 **Materials and Methods**

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39 Four long-term (11, 17, 18 and 22 years) field trials were carried out in central Greece (Aliartos),
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41 northern Italy (Bologna) and southern Italy (Catania) (Table 1). Soil characteristics of the three
42
43 locations are reported in Table 2. Meteorological characterization was performed in the three
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45 locations between 2005 and 2014 (common years, not including the establishment year), according
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47 to Monti and Venturi [21], in order to compare yearly rainfall patterns of different locations (uneven
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49 rainfall distribution - U_R [21]) in the whole year or within the crop maximum development growing
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51 season (March-October). This approach was chosen in order to better evidence differences among
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53 locations, since the only rainfall amount would partially mask environmental effects on crop
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55 growth. Air temperature was also monitored in all locations.

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Plantations

Mediterranean South (Greece)

In 1998, at the beginning of the EU project ‘Switchgrass for Energy’ (www.switchgrass.nl), five switchgrass ecotypes—Alamo, Pangburn, Kanlow (lowland ecotypes), Blackwell and Cave-in-Rock (upland ecotypes)—were manually seeded [1.04 g m⁻² of pure live seeds (PLS), 0.13 m row spaced] in central Greece, in a low fertility sandy loam soil previously left for more than 20 years as fallow land (Table 2). Before sowing, 33 kg ha⁻¹ of P and 83 kg ha⁻¹ of K were applied. Switchgrass was irrigated about once a week in the establishment year, while from the second year onwards, about three watering were performed in the period May to July. Weed control was necessary only in the establishment year. Harvest was carried out in wintertime (January–February). Aboveground biomass was determined on a sampling area of 12 m² per plot; biomass sub-samples were collected and oven-dried at 105 °C until constant weight for dry matter determination.

Mediterranean South (southern Italy)

Miscanthus and giant reed were grown on a typical sandy-clay-loam soil (Table 2) at the experimental farm of the University of Catania (south Italy). Micro-propagated miscanthus plants, provided by Piccoplant (Oldenburg, Germany), were transplanted in summer 1993 (4 plants m⁻²) and weekly irrigated (80 mm in total) to guarantee the desired plant density. Irrigation was also applied in summertime 1994 and 1995, about every 20 days (215.5 and 76.5 mm, respectively) to sustain crop growth. Subsequently, irrigation was not applied. Giant reed plantlets were produced in summer 1996 from stem cuttings of the local ecotype “Fondachello”, and transplanted manually in spring 1997 at a density of 2.5 plants m⁻². Irrigation was applied after transplant and only during the first summertime in order to guarantee a successful establishment. In both trials, autumn ploughing followed by spring disc-harrowing was performed before transplant. Mechanical weeding was also performed in the first year only. No fertilization

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120 was applied; neither at transplant nor in subsequent years in both species. The detailed methodology
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121 of the two trials is reported elsewhere [15, 16].
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122 Harvest was carried out in wintertime (between January and February). Aboveground biomass yield
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123 was determined on a sampling area of 20 m² per plot; biomass sub-samples were oven-dried at 105
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124 °C until constant weight for dry matter determinations.
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17 18 *Mediterranean North (northern Italy)* 19

20 Switchgrass (variety Alamo) and giant reed were compared in an 11-year (2004–14) side-by-side
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127 trial located in northern Italy (Bologna) in the Po Valley. Climate is characterized by cold humid
128
23 winters and hot summers. Soil was classified as silty loam (Table 2).
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25 Seedbed preparation was disc-ploughing, harrowing and rotary cultivator. Phosphate (44 kg ha⁻¹)
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26 was applied before seeding/transplanting; fertilizers were not applied from the second year onward.
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131 Switchgrass was seeded in May 2004 at a density of ~0.4 g PLS m⁻², 0.48 m row-spaced. Irrigation
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29 was used only in the first year: three applications (25 mm each) were made during the establishment
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30 and three others (30 mm each) from June to July. Giant reed plantlets (provided by the University of
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34 Catania) were manually transplanted (1 plant m⁻²) in July 2004. Irrigation was applied after
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35 transplant in order to ensure a successful stand. Chemical and/or mechanical weeding was necessary
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135 on both species only in the first year. Harvest was carried out in wintertime (January–February).
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136 The aboveground biomass was determined on a sampling area of 6 m² per plot; dry matter content
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137 was measured on biomass sub-samples of approx. 500 g oven-dried at 105 °C until constant weight.
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45 *Statistical analysis* 46

47 One-way ANOVA was performed to compare biomass yields of switchgrass and giant reed in
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142 northern Italy (Bologna), and lowland and upland switchgrass ecotypes in Greece (Aliartos). Given
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50 the different establishment year of perennial grasses in and among locations, one-way analysis of
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52 covariance (ANCOVA) was used. Fisher's LSD test ($P \leq 0.05$) was used to separate means. The
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146 Shapiro–Wilk test was developed to test residuals for normality. Coefficients were considered
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147 significant when P -value was ≤ 0.05 . All analyses were run with XLSTAT's (AddinSoft S.A.R.L.).
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13 **Results**

15 *Meteorological characterization of the three sites*

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157 Although the three sites are located in Mediterranean area, differences were evident between north
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159 and south Mediterranean in terms of mean temperature, mean rainfall and rainfall distribution
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151 (Table 3). Southern Italy (Catania) was the warmest site (17.7 ± 0.4 and 20.4 ± 0.7 °C, mean annual
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154 and growing season temperatures, respectively), while northern Italy (Bologna) the coldest
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154 (13.4 ± 0.6 and 17.8 ± 0.6 °C, respectively). Greece (Aliartos) had the lowest precipitation rate
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156 (485 ± 108 and 218 ± 42 mm annual and growing season means, respectively). Northern and southern
27
157 Italy did not differ in the annual amount of rainfall (Table 3), but rainfall patterns varied
29
158 considerably: within the growing season (March to October) the north (Bologna) had almost 30%
30
159 more rain than the south (Catania), which showed the most uneven distribution among the three
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160 sites (significantly higher U_R), while Bologna presented the most regular pattern (lower U_R). Year
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165 to year rainfall variation was more pronounced in southern Italy than Greece and northern Italy.
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38 *Long term productivity of switchgrass, miscanthus and giant reed*

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164 Seventeen-year dry biomass yields of switchgrass ecotypes grown in Greece (Aliartos) are shown in
41
162 Figure 1a. Lowlands and uplands performed similarly in terms of biomass yield, with the exception
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164 of the second year in which lowlands outperformed uplands ($P \leq 0.05$). Despite similar biomass
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167 yields of lowlands and uplands (10.0 and 9.8 Mg DM ha⁻¹), the coefficient of variation (CV), which
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168 accounts for yield stability, was clearly higher in the uplands (32% vs. 24% for lowland ecotypes).
49
169 Miscanthus and giant reed were compared in southern Italy (Catania, Fig. 1b). Miscanthus required
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170 a shorter period than giant reed to reach ceiling yields, however giant reed showed slightly higher
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173 potential yield in the long term. It is worth noting that, unlike giant reed, miscanthus was irrigated
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172 for three consecutive years, which explains the faster yield ceiling of miscanthus (3rd year)
173 compared to giant reed (7th year). After yield ceiling, relatively stable yields were observed in giant
174 reed for 16 years; miscanthus showed a significant decrease of biomass yield after 5 years, then
175 fluctuating yields for 14 years before a visible decline of productivity. Mean annual biomass
176 production of miscanthus and giant reed were 13.3 and 15.7 Mg DM ha⁻¹, respectively. Yield
177 stability was slightly higher in giant reed than miscanthus (CV 28% and 31%, respectively).
178 Side-by-side comparison of switchgrass (ecotype Alamo) and giant reed in north Italy (Bologna) is
179 shown in Figure 1c. Aside from the establishment year, in which productivity of switchgrass was
180 clearly higher than giant reed (6.2 and 2.4 Mg DM ha⁻¹), two periods could be distinguished: i) year
181 2 to 7, in which switchgrass and giant reed produced similar amount of biomass; ii) year 8 to 11, in
182 which giant reed clearly exceeded switchgrass (about 50% more biomass per year). Thus, in the
183 long term, giant reed resulted in a clearly higher productivity than switchgrass (21.2 and 13.6 Mg
184 DM ha⁻¹yr⁻¹, respectively), while yield stability of the two crops was quite similar (CV of 34% and
185 37% for giant reed and switchgrass, respectively).

186 *Site effects on long-term productivity of switchgrass and giant reed*

187 Since switchgrass (ecotype Alamo) and giant reed were grown either in Mediterranean South
188 (switchgrass in Greece and giant reed in southern Italy) or in Mediterranean North (both species in
189 northern Italy), local effects on biomass productivity and stand longevity can be discussed (Figs. 2
190 and 3).

191 Mean annual yield of switchgrass was significantly ($P=0.039$) higher in the north than in the south
192 (13.6 vs. 10.6 Mg DM ha⁻¹) (Fig. 2). The yield stability was also higher (CV 37%) in north than
193 south (48%), which might reflect the even rainfall distribution in the north during the growing
194 season. The considerably higher biomass yields of switchgrass in Greece in the establishment year
195 (14.0 and 6.2 Mg DM ha⁻¹, Greece vs. northern Italy, respectively) were likely due to a two-fold
196 plant density adopted.

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198 Giant reed was grown in northern (Bologna) and southern Italy (Catania) (Fig. 3). As with
199 switchgrass, mean annual biomass yield of giant reed was significantly higher in north (21.2 Mg
200 DM ha⁻¹) than south (15.6 Mg DM ha⁻¹) Mediterranean. In northern Italy, giant reed productivity
201 increased from year 1 to 4; thereafter, biomass yield was consistently above 20 Mg DM ha⁻¹. In
202 southern Italy, giant reed reached yield ceiling after seven years, after which biomass yield was
203 similar in the two environments. Yield stability (CV) of giant reed was also very similar: 33% and
204 32% in north and south Mediterranean, respectively.
205

206 **Discussion**

207 Long-term yield studies, particularly in large fields, are challenging and difficult to maintain due to
208 the limited duration of research projects (usually 3–4 years), discontinuity of funding, and changing
209 research objectives. Therefore, limited information is available on long-term productivity of
210 perennial grasses, and prediction models are generally used to estimate biomass yields [22–25].
211 These models, however, are often based on few short-term studies, variable assumptions, different
212 species, genotypes and biomass end-uses [26]. Furthermore, to the best of our knowledge, no model
213 has been specifically developed for giant reed due to its relatively limited history as a biomass crop.
214 Thus prediction studies on this crop are performed through models developed for other perennial
215 grasses [27]. Therefore, in most cases, predicted yields are not straightforward with other
216 parameters included in the models [24, 25], thus the uncertainty/risk of exploitation and business
217 plans could become sometimes unacceptable to farmers or entrepreneurs, since significant changes
218 on stand lifespan could heavily condition final profitability of the plantation. It follows that
219 comprehensive real yield data over a plant's lifespan, not short time frames, would be necessary for
220 providing more reliable information to farmers and entrepreneurs with consistent and affordable
221 economic plans, such as adequate plantation size and tailor-designed processing plants.

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222 Although all perennial grasses showed similar yield patterns—an upward trend in the first 2–4
223 9 years, then fluctuating yields during the maturity stage, and finally a gradual decrease associated
224 10 with stand decline—our results clearly show that biomass production was very uneven, both
225 11 spatially and temporally, and as such very difficult to predict (Figs. 1a-c). These results are also in
226 12 agreement with long term studies carried out in northern Europe [7, 28].
227 16 Generally speaking, giant reed showed considerably higher yields than switchgrass (about 50%
228 17 higher) under northern Mediterranean conditions. In south Mediterranean, giant reed also
229 18 outperformed miscanthus and switchgrass, but differences among the three crops, especially
230 19 between giant reed and miscanthus, were much less evident than in the north Mediterranean.
231 23 Therefore, although a more comprehensive analysis including economic, logistic and environmental
232 24 assessments would be needed, given the considerably higher plantation cost of giant reed (sterile
233 25 seeds) compared with switchgrass, the actual yield potentiality of giant reed seems to remain more
234 26 locally defined.
235 27 Moreover, the ability of miscanthus to maintain high photosynthetic rates at low temperatures [29,
236 28 30] can likely offset the lower biomass accumulation rate compared with giant reed during hot
237 29 periods, which is characterized by inefficient PAR interception in late summer/early autumn [31].
238 30 Switchgrass also showed remarkably lower yield stability (i.e., a higher CV) than giant reed in
239 31 south Mediterranean: switchgrass biomass yield fluctuated considerably between 5 and 18 Mg ha⁻¹
240 32 yr⁻¹ over a short period of 5 years in the maturity stage. Similar results were also reported by
241 33 Wullshleger et al. [26], who showed a much higher potential of switchgrass (24 Mg DM ha⁻¹)
242 34 across the U.S. in comparison with our results. In the northern Mediterranean the CV of switchgrass
243 35 and giant reed, even if still remarkable (38% and 33%, respectively), were not that different as they
244 36 were in the south Mediterranean. It is worth noting that all these crops were grown using low input
245 37 techniques (no fertilization supply except at the establishment); therefore, apart from the different
246 38 environmental conditions of the sites, soil characteristics might have played a crucial role in
247 39 determining the biomass production level. For example, in north Italy (Bologna), along with higher

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248 and evenly distributed (higher U_R , Tab. 3) precipitation during the summer, soils are characterized
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249 by higher water holding capacities (clay soils) compared to Greece (Aliartos) and south Italy
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250 (Catania) (sandy soils), that make drought stress less frequent in Bologna. Moreover, Greece and
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251 south Italy sites are characterized by lower soil fertility (organic matter content of 0.5% and 1.4%,
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252 respectively) than northern Italy (2.7%) (Table 2).
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253 Although biomass yield of the lignocellulosic perennial grasses evaluated in the present study might
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254 resemble low values as compared to the broad range reported in literature [32], mainly for southern
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255 environments, it must be pointed out that yields were likely affected by rainfed condition and
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256 unfertilized management. According to Cosentino et al. [16], the yields of giant reed were
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257 significantly increased (40%) under high input management (well-watered conditions + 120 kg N
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258 $\text{ha}^{-1} \text{yr}^{-1}$ fertilization) as compared to rainfed and no-nitrogen treatment in the same environment. In
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259 miscanthus, Cosentino et al. [15] found similar yield increases by raising nitrogen and irrigation
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260 water. Thus, higher yields can be obtained by using high-input management systems; however, the
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261 question remains on the sustainability of biomass crop cultivation. Nonetheless, the transition
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262 toward a modern bio-based economy implies challenges, such as the sustainability of biomass raw
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263 material, efficiency in biomass use and economy of scales in biomass mobilization, among others
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264 [33]. The need to raise biomass availability when land is limited (e.g., European Union) might lead
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265 to increased use of water, fertilizers and pesticides with additional problems linked to pollution and
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266 water scarcity [33].
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45 **Conclusions**

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270 The increased use of models needs to be accompanied by more detailed information on the
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271 parameterization, validation, and uncertainty quantification. Our knowledge is still insufficient to
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272 interpret and determine key productivity factors of perennial grasses toward the challenges facing
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273 the modern bio-based economy. The generation of high quality/resolution field data from an
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274 integrated framework will be useful to improve the quality of the models by reducing the
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275 uncertainty of yield predictions, an imperative aspect for industrial development planning models.
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276 Studies like this can greatly contribute to a more comprehensive view of the real potential of these
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277 crops in Europe.
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278 Long-term yields of switchgrass, giant reed, and miscanthus grown in the Mediterranean basin
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279 under low-input management were highly variable across years and locations. Generally, giant reed
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280 and switchgrass were the highest and lowest yielding crops, respectively. Compared with
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281 switchgrass and miscanthus, giant reed also showed lower yield variability over time and across
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282 locations. Such variability may entail practical implications for planning and developing new value
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283 chains. We emphasized the need to investigate real long-term production, since projections based
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284 on short term studies of perennial grasses might easily lead to misinterpretation of the real potential
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285 of these species.
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40 (www.cres.gr/bioenergy_chains) and Switchgrass for Energy (www.switchgrass.nl).
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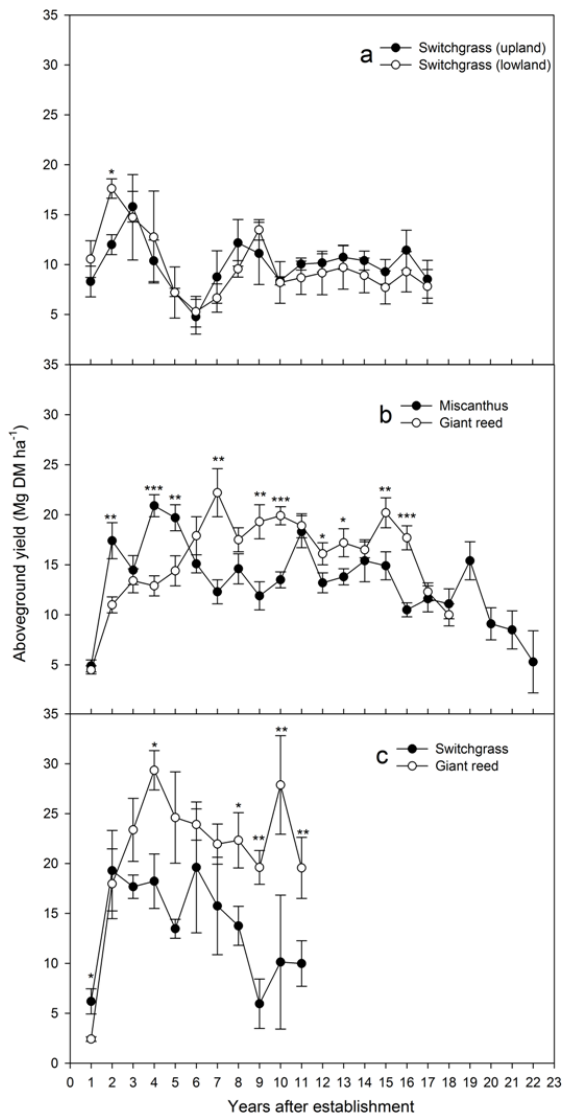
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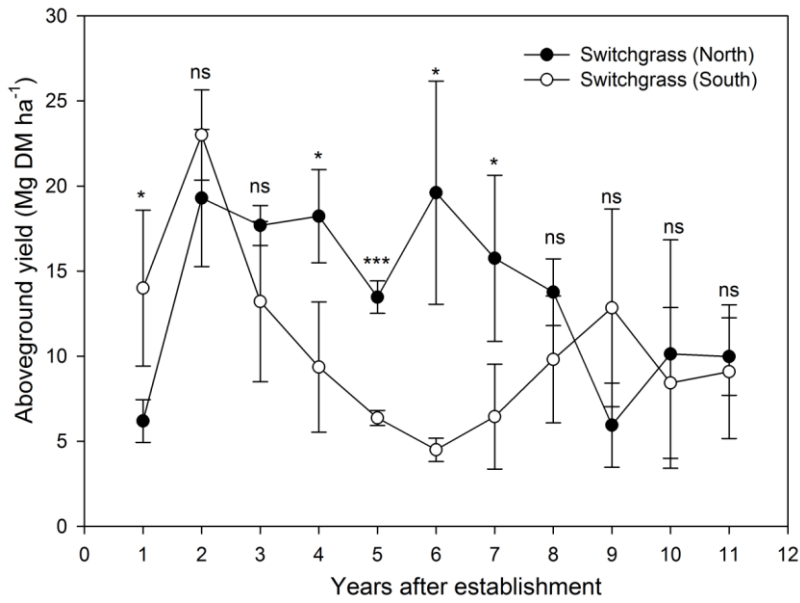
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378 Figure 1. (a) Long-term aboveground biomass yield (Mg DM ha⁻¹) of different
 379 switchgrass ecotypes (upland: Blackwell, Cave-in-Rock, vs. lowland: Alamo,
 380 Kanlow, Pangburn) grown in Greece (Aliartos). (b) Long-term aboveground biomass
 381 yield (Mg DM ha⁻¹) of giant reed and miscanthus grown in southern Italy (Catania).

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7 382 (c) Long-term aboveground biomass yield (Mg DM ha⁻¹) of giant reed and
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9 383 switchgrass grown in northern Italy (Bologna).
10 384 Mean values ± standard deviation of three replications. ANOVA (a and c) and
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12 385 ANCOVA (b) per $P \leq 0.05$. $P \leq 0.05$ (*); $P \leq 0.01$ (**); $P \leq 0.001$ (***).
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388 Figure 2. Aboveground biomass yield (Mg DM ha⁻¹) comparison between switchgrass

389 ecotype Alamo grown in North (north Italy-Bologna) and South Mediterranean

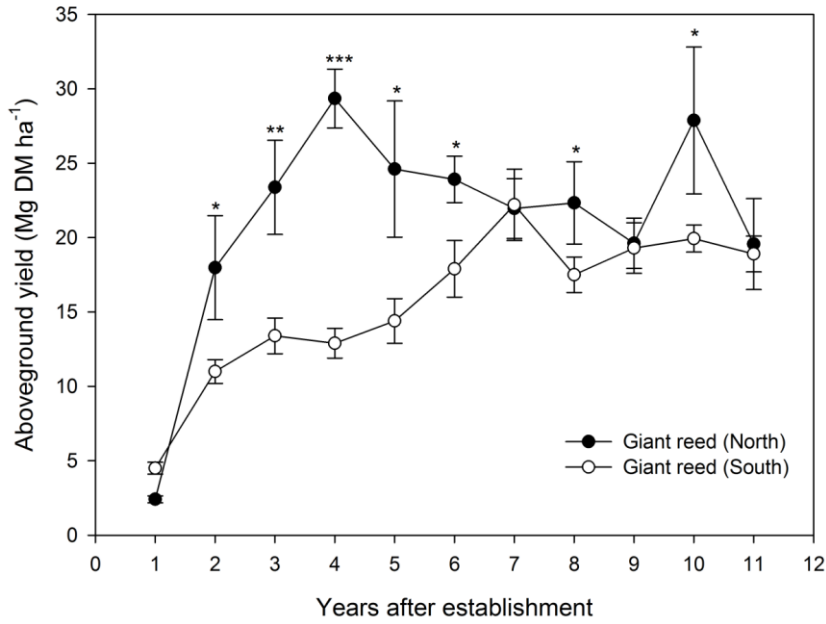
390 (Greece-Aliartos). Mean values ± standard deviation of three replications (ANCOVA

391 per $P \leq 0.05$). $P \leq 0.05$ (*); $P \leq 0.01$ (**); $P \leq 0.001$ (***)

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395 Figure 3. Aboveground biomass dry matter yield (Mg DM ha⁻¹) comparison between
396 giant reed grown in North (north Italy-Bologna) and South Mediterranean (south
397 Italy-Catania). Mean values \pm standard deviation of three replications (ANCOVA per
398 $P \leq 0.05$). $P \leq 0.05$ (*); $P \leq 0.01$ (**); $P \leq 0.001$ (***)

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Table 1. Characterization of long-term field trials in Greece and Italy (Bologna and Catania in north and south Italy, respectively; Aliartos in central Greece)

Sites	Species	Establishment method	Experimental layout	Plot size (m ²)	Trial duration
Aliartos (GR); latitude 38°22'N, longitude 23°10'E, altitude 114 m a.s.l.	Switchgrass	Seed	Randomized blocks (n=3)	47.25	1998-2014
Catania (IT); latitude 37°24'N, longitude 15°03'E, altitude 10 m a.s.l.	Miscanthus	Micro-propagated plant	Randomized blocks (n=3)	134.4	1993-2014
	Giant reed	Plantlet			1997-2014
Bologna (IT); latitude 44°34'N, longitude 11°47'E, altitude 5 m a.s.l.	Switchgrass	Seed	Randomized blocks (n=3)	2250	2004-2014
	Giant reed	Plantlet			

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Table 2. Soil characteristics at the three sites (Bologna and Catania, IT; Aliartos, GR) for the layer depth (0-0.5 m).

Soil characteristics	Greece (Aliartos)	Southern Italy (Catania)	Northern Italy (Bologna)
Loam (%)	25.4	22.4	51.0
Sand (%)	62.8	49.3	21.0
Clay (%)	11.7	28.3	28.0
Organic matter (%)	0.5	1.4	2.7
pH	8.0	8.6	7.5
N (ppm)	756	1000	1370
P ₂ O ₅ (ppm)	NA	5.0	12.0
K ₂ O (ppm)	NA	244.8	315.0

NA: data not available

Table 3. Meteorological characterization of the three sites (Bologna and Catania, IT; Aliartos, GR) between 2004 and 2014 (common years for all localities, excluding establishment year).

Location	Year	Rainfall (mm)	U_R	Mean T° \pm SD ($^{\circ}$ C)	Rainfall ^{GS} (mm)	U_R^{GS}	Mean $T^{\circ\text{GS}} \pm$ SD ($^{\circ}$ C)
Greece (Aliartos)	2005	544	2.78	NA	212	1.30	NA
	2006	555	3.98	16.0 \pm 9.5	227	3.55	19.7 \pm 8.3
	2007	442	3.67	16.8 \pm 9.3	217	2.33	20.1 \pm 8.9
	2008	285	4.01	16.8 \pm 9.3	198	3.46	20.5 \pm 8.2
	2009	460	2.41	16.4 \pm 8.9	212	1.74	19.6 \pm 8.5
	2010	332	1.06	17.4 \pm 9.0	239	2.21	20.2 \pm 8.6
	2011	544	5.71	15.8 \pm 9.3	205	1.87	19.3 \pm 8.9
	2012	599	4.48	NA	290	3.07	NA
	2013	482	2.94	16.9 \pm 9.3	127	0.57	20.6 \pm 8.7
	2014	606	5.31	17.3 \pm 9.0	251	2.54	20.4 \pm 8.8
mean \pm SD		485 \pm 108	3.63 \pm 1.39	16.7 \pm 0.2	218 \pm 42	2.26 \pm 0.94	20.1 \pm 0.2
Southern Italy (Catania)	2005	640	4.37	17.0 \pm 6.4	313	2.37	20.0 \pm 5.3
	2006	922	8.09	17.9 \pm 6.3	333	5.89	20.9 \pm 5.3
	2007	721	7.32	18.1 \pm 5.9	361	4.51	20.9 \pm 5.0
	2008	468	6.43	17.5 \pm 5.4	220	2.72	20.0 \pm 4.4
	2009	504	3.70	18.0 \pm 5.9	329	4.80	20.5 \pm 5.3
	2010	623	4.69	17.7 \pm 5.6	259	2.69	20.1 \pm 4.9
	2011	859	4.73	17.1 \pm 5.7	457	4.40	19.7 \pm 4.8
	2012	623	8.62	18.3 \pm 6.8	251	3.82	21.6 \pm 5.4
	2013	397	2.30	18.0 \pm 6.1	209	1.92	21.1 \pm 4.7
	2014	404	3.46	17.4 \pm 5.3	164	1.76	19.5 \pm 4.9
mean \pm SD		616 \pm 180	5.37 \pm 2.13	17.7 \pm 0.4	290 \pm 86	3.49 \pm 1.39	20.4 \pm 0.7
Northern Italy (Bologna)	2005	653	4.08	12.3 \pm 8.6	449	3.35	16.9 \pm 6.2
	2006	495	1.29	13.1 \pm 8.4	390	1.43	17.5 \pm 6.3
	2007	562	1.45	13.5 \pm 7.7	434	2.59	17.8 \pm 5.5
	2008	614	2.28	13.6 \pm 8.0	376	2.22	17.7 \pm 6.1
	2009	561	1.96	13.5 \pm 8.5	324	2.48	18.1 \pm 6.1
	2010	846	0.98	12.7 \pm 8.5	537	1.26	17.1 \pm 6.2
	2011	390	1.71	13.6 \pm 8.7	270	1.61	18.2 \pm 6.3
	2012	457	3.81	13.6 \pm 9.6	321	2.77	18.9 \pm 6.5
	2013	769	3.23	13.4 \pm 8.2	498	2.29	17.7 \pm 6.0
	2014	780	1.98	14.4 \pm 6.7	486	1.77	17.9 \pm 5.0
mean \pm SD		613 \pm 150	2.28 \pm 1.07	13.4 \pm 0.6	409 \pm 87	2.18 \pm 0.66	17.8 \pm 0.6

¹ U_R , is uneven rainfall distribution (the sum of square of the distances of the actual cumulated rainfall points from the respective evenness lines), for more details on unevenness calculations see [21]; ²GS, growing season from March 01 until October 31; NA data not available.