YIELD COMPARISON BETWEEN SWITCHGRASS AND *MISCANTHUS* BASED ON MULTI-YEAR SIDE BY SIDE COMPARISON IN EUROPE

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ABSTRACT: Energy crops are expected to provide a significant amount of biomass to achieve the European targets on renewable energy. Here we focus on switchgrass (*Panicum virgatum* L.) and *Miscanthus* (*Miscanthus x giganteus* Greef & Deuter) two rhizomatous perennial grasses which have received particular interest during the last decade as bioenergy crops. Although the two grasses have been recently investigated deeply in U.S.A. and Europe, a significant uncertainty still exists in literature on measured or predicted potential yields. In order to understand the role these species can play, a study was carried out aimed at collecting measured side by side data on *Miscanthus* and switchgrass yields across Europe. Biomass productivity of the two crops significantly varied depending on location, however the relative yield (RY), i.e. *Miscanthus* to switchgrass yields ratio, was rather constant across Europe (78% ± 9.2), thus indicating parallel yield variation by switchgrass and *Miscanthus* at different locations. By assessing RY a more reliable economic and LCA comparison and then choice among crops could be provided.
Keyword: Switchgrass, *Miscanthus*, energy crop, yield potential, N ratio, Land suitability

1 INTRODUCTION

Energy crops may be a new market opportunity for farmers in a short-term [1]. However, an emerging biofuel industry needs to understand how biomass yield varies with management and environmental conditions [2]. Today, energy crops suffer the competitiveness of the currently more economic fossil fuels, thus optimising land allocation and productivity while reducing the environmental impacts will be an essential point for the competitiveness of biofuels and the establishment of a new energy marketplace.

Miscanthus and switchgrass were selected in this study for their high biomass yields and high environmental adaptation to a vast range of climatic condition across Europe [3,4]. Switchgrass, native to North-America, is a warm season (C4) perennial grass widely adapted to extremely different environmental conditions thanks to several cytotypes having different habitat preference [5,6]. *Miscanthus* is a high-yielding perennial grass native to Asia and introduced in Europe in the 1930s [7].

Although it a common opinion that *Miscanthus* has an higher potential yield than switchgrass [8], though how much higher is not clear, few studies have compared the yields of these two species across U.S.A and Europe [9,10,11], and sometimes contrasting results are reported.

For example, Heaton et al. [9] asserted that *Miscanthus* produced approx. 12 Mg ha^{-1} yr^{-1} more biomass than switchgrass, while Aravindhakshan et al. [11] showed lower yields by *Miscanthus* compared to switchgrass in a 3-year plantation.

It is important to assess available side by side field trials in order to remove the environmental effects from crops comparison even if a significant 'crop x environment' interaction cannot be excluded *a priori*. We collected long term (> = 5 years) yield data from side by side fields of switchgrass and *Miscanthus* across Europe with the following objectives:

1) to evaluate the best switchgrass cytotype in each site;
2) to quantify the relative yield , i.e. the percent of switchgrass yield in comparison with *Miscanthus* yield;
3) to assess the effect of nitrogen doses on biomass productivity of the two crops;
4) to calibrate crop-growth models in order to make yield predictions in high, medium and low productive soils across Europe. This point is still in progress and is not presented later on.

2 MATERIAL AND METHODS

2.1 Experimental sites

Six location were identified for having long-term data (>= 5 years) on switchgrass and *Miscanthus* plants in Europe. The latitude and longitude of the locations are: Delfzijl (NL, 53° 19' N; 6° 55' E), Rothamsted (UK, 51° 47' N; 0° 23' E); Estrées-Mons (FR, 49° 25' N; 2° 38' E), Bologna (North IT, 44° 33' N; 11° 21' E), Trisaia (South IT, 40° 10'N;16° 31' E), Aliartos (GR, 38° 22'–N; 22º 00' E).

For *Miscanthus*, the hybrid *Miscanthus x giganteus* was used in all locations, while for switchgrass different varieties were used depending on local conditions. The switchgrass variety selected for our study was based on latitude of origin and best yield performance [12,13].

From North (Delfzijl) to South (Aliartos) the varieties considered in each location were Cave in Rock> Cave in Rock >Kanlow> Alamo>Alamo>Carthage.

Field management differed across the experimental sites: irrigation during the establishment year was required in Trisaia, Aliartos and Bologna (1000, 1002 and 845 m^3 ha^{-1}, respectively).

Table I: Side by side trials locations and plants age.

Sites*	Location	Plant age	Environmental zone	Site coordinates
NL	Delfzijl	11	Atlantic North	53^0 19' N
				6^0 55' E
UK	Rothamsted	13	Atlantic Central	51^0 47' N
				0^0 23' E
FR	Estrées-Mons	5	Atlantic Continental	49° 25' N
				2° 38' E
N.IT	Bologna	11	Mediterranean North	44^0 33' N
				11^0 21' E
S.IT	Trisaia	13	Mediterranean South	40^0 09' N
				16^0 38' E
GR	Aliartos	6	Mediterranean South	38^0 22' N
			Mountains	23^0 10' E

*NL (Delfzijl), UK (Rothamsted), FR (Estrées-Mons), N.IT (Bologna), S.IT (Trisaia), GR (Aliartos)

Table II: Plot size, soil type, soil organic matter (SOM) and N- fertilization levels at each experimental site.

Sites	Plot size (m^{-2})	Soil texture	SOM ($mg\ g^{-1}$)	N-Fert.$^{SW.}$ ($kg\ ha^{-1}$)	N-Fert.$^{MISC.}$ ($kg\ ha^{-1}$)
NL	3000	Heavy-silty-loam	19	0	0
				50	75
UK	100	Silty-clay-loam	21	0	0
				120	120
FR	360	Deep-silt-loam	22	0	0
				120	120
N.IT	90	Clay-loam,	11	0	0
				120	120
S.IT	50	Silty-loam	21	0	0
				120	120
GR	50	Silty-loam	13	0	0
				120	120

SOM determination method if available. For Bologna we applied the method by Walkley & Black (1934)

Plot size differed with locations, however it was always enough large to guarantee a reliable yield estimation according to Wullshleger et al., 2010 [14].

Information about location, site coordinates, plant age, soil characteristics and agronomic management were collected and shown in Table I and II.

In all sites, only one cut per year was done during wintertime, except for Estrées-Mons where two cut per year was done. For our study the first 6-year period was taking into account for all site except for Estrées-Mons where only four year data are available. Only the winter harvest were considered to determine relative yield.

2.2 Data analysis and RY (relative yield)

In order to assess the yield potential of *Miscanthus* and switchgrass across Europe, long term data on the two species were collected and analyzed by ANOVA assuming as variables location, N fertilizer rate and Species.

ll variables were analyzed using a standard three factors design, to test the effects of location, N rate, species and their interactions. Statistical analysis was performed using package *agricolae* of R software.

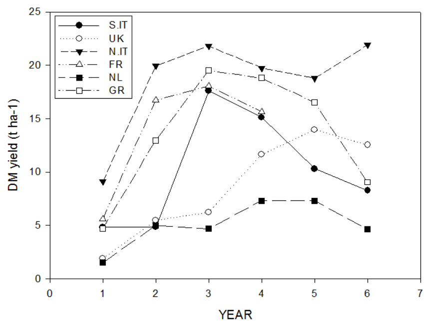
When ANOVA revealed significant differences among means, the LSD Fischer's test ($P \leq 0.05$) was applied to separate means.

For the relative yield, a simple *Miscanthus* to switchgrass yields ratio were calculated for each year in each location and shown as percentage.

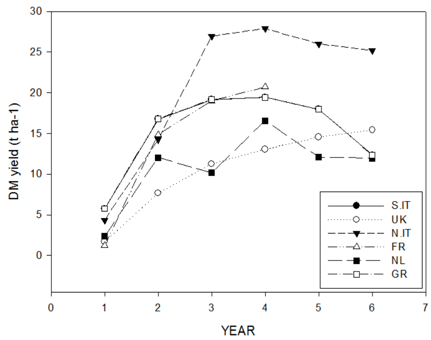
3 RESULTS AND DISCUSSION

3.1 Potential production across Europe "switchgrass *vs Miscanthus"*

Although switchgrass showed general higher yields in the two first years (Fig 1a), the overall productivity of *Miscanthus* was significantly higher than switchgrass in the long-term (14.96 Mg ha^{-1} yr^{-1} vs 11.93 Mg ha^{-1} yr^{-1}, respectively). Similar results were found by Aranvindhakshan et al., 2010 [11] who reported 15.64 and 12.75 Mg ha^{-1} yr^{-1} for switchgrass and *Miscanthus*, respectively. Nonetheless, it should be recognized that the *Miscanthus* yield was about 25% higher than switchgrass and not three times higher as reported by Heaton et al., 2004 [9].



a. Switchgrass



b. *Miscanthus*

Figure 1: Average biomass yield (d.w.) over a 6-year period from switchgrass and Miscanthus respectively in side by side fields at six locations across Europe. a. switchgrass, b. *Miscanthus*

So, affirming that *Miscanthus* has an higher potential yield than switchgrass would be a biased information, as switchgrass performs better than *Miscanthus* in some locations and *vice versa*.

As expected yields were generally lower at northern locations compared to central and southern ones, due to the shorter growing season. Moreover, in southern locations the highest yields were achieved in only 2 years, while in northern locations 3-4 years were needed (Fig 1 a,b).

3.2 Treatment effect on yield performances

Results from statistical analysis shown that the average yield for switchgrass and *Miscanthus,* during the first six years of side by side data, were significantly different between species and across sites as show in Fig 3.a,b. On the contrary, N fertilization rate did not affect yield productivity.

Moreover, no significant interaction was found between these factors (Table III).

Overall, *Miscanthus* yield was 25 % higher compared with switchgrass across Europe as show in Fig. 3a (14.20 ± 1.9 vs 11.75 ± 2.2 Mg ha^{-1} yr^{-1}) respectively. The highest yields (19.64 Mg ha^{-1} yr^{-1}) were observed in (N.IT), that differ from Central location with 14.41 and 13.94 Mg ha^{-1} yr^{-1} for (GR) and (FR) respectively compare with 12.70, 9.61 and 7.83 Mg ha^{-1} yr^{-1} ha^{-1} yr^{-1} for (S.IT), (UK) and (NL) respectively.

Table III: Results from analysis of variance of dry yield (Mg ha^{-1}) in relation to the studies treatments : Species (S) Nitrogen Levels (N) and Location (L)

Treatment	DM yield (Mg ha^{-1})
Species (S)	***
N rate (N)	ns
Location (L)	***
S x N	ns
S x L	ns
L x N	ns
S x N x L	ns

***, ** and * indicate, respectively, significance at 0.001, 0.01 and 0.05 P level

Our results on nitrogen disagreed with those reported by Heaton et al., 2004 [9] (Table III). It seems N response is very limited in winter harvested switchgrass and *Miscanthus*.

This result can be explained by the minimal N fertilizer required from perennials crops, due to efficient remobilization of reserves especially when winter harvest is done, allowing a high remobilization of the reserve to the root system, available for the next year [17].

The lack of N response could also explained by the good soil fertility in all locations as show in Table 2, which can be expected to have been further increased due to the abundant carbon storage by perennial grasses [9].

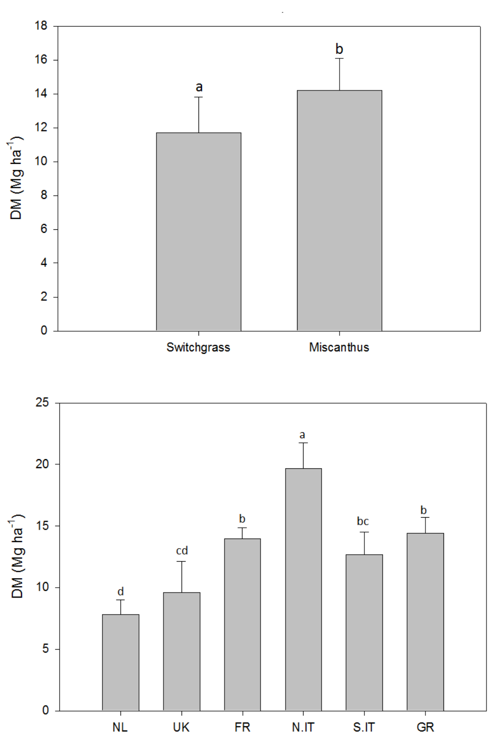


Figure 2: Results from analysis of variance of dry yield (± standard deviation) of switchgrass and Miscanthus (Mg ha^{-1}yr^{-1}) as effected by location (L) and species (S).

3.3 Relative yield across Europe

Key objective of this analysis was to examine the relative yield advantage of switchgrass and *Miscanthus* in differing environments in Europe. The yields for switchgrass and *Miscanthus* for a number of years at six location across Europe are shown in Fig. 3. Clearly, there was a strong trend for increasing yield of switchgrass and *Miscanthus* for those sites with longer growing season.

This seemed to be particularly true in Central and South Europe which resulted in greater yields for both species compare with Northern locations.

In general, switchgrass yields exceeded the yields of *Miscanthus* in the first two years of plantation especially in North-Central location (Fig. 3). This can be explained with the need of this two species to develop and growth, during the first year, the root system (rhizomes), especially in *Miscanthus*[16].

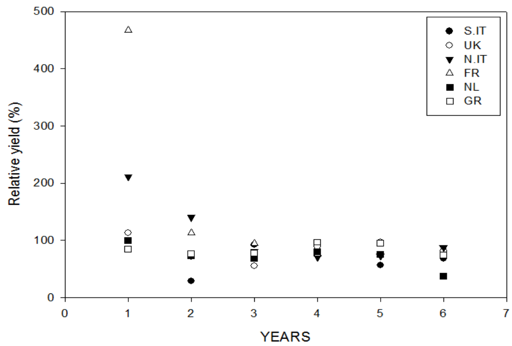


Figure 3: Relative yields (% RY) calculated in side by side fields of switchgrass and *Miscanthus* over the first 6-year period of plant life.

Mean annual relative yield values are shown in Figure 3. The relative yield was higher than 100 % in the two first years due to the overrunning yields by switchgrass compared to *Miscanthus.*

Averaging RY was (78% ± 9.2) from the third to the sixth year. However, (RY) mean value vary from (176 ± 30) in years one, to (76% ± 10.2) in year six.

4 CONCLUSION AND PROSPECTS

4.1 *Miscanthus* and switchgrass potential in Europe

Through this assessment we can affirm that switchgrass and *Miscanthus* present a good dry yield potential across Europe and lower input requirement.

Infects, several studies shown that perennial grasses achieves high DM yield with minimal N fertilizer, due to efficient remobilization of reserves [17]. It should be notice that association of microorganism are known for perennial crops, and their contribution to the overall N budget is evaluated. Moreover the association with N-fixing bacteria enhances N supply to the plant, thus potentially contributing an important saving to the greenhouses gas [17].

In conclusion, these results suggest that fertilization with N is not a limiting factor for both species, demonstrated with the “high-good” yield response of the two species in several climatic zone in Europe.

However, further research is needed to evaluate the productivity of these two species in relation to soil characteristics and weather conditions, in a long time period (> 6 years).

4.2 Future research

Biomass yield is likely the main driving parameter for environmental and economic performance.

A key factor to ensure a long term biomass supply is to selected the most suitable crop and variety per location in relation to economic (LCA and economical analysis) and environmental (soil characteristics and weather conditions) aspects.

A good understanding of the RY under different environmental conditions in Europe is an important basis for: 1. a more accurate economic feasibility (e.g. Net Present Value calculations) of perennial cropping; 2. LCA analysis and 3. for calibrating crop-growth models and enabling the yield predictions in high, medium and low productive soils across Europe and in particularly in the marginal lands, where these crops would be grown without competing against food.

Several studies have been conducted to identify suitable areas for biomass production [19]. However, most of these were based on expert knowledge because of limited availability of empirical and practical information on yield levels under different environmental conditions and management.

With our findings we contribute to filling the knowledge gap by giving a more comprehensive picture of the practical yields from switchgrass and *Miscanthus* under different environmental conditions, particularly marginal and/or abandoned lands.

5 REFERENCES

[1] Soldatos P., Lychnaras V., Panoutsou C., Cosentino S.L. (2010) Economic viability of energy crops in the EU: the farmer's point of view. Biofuels, Bioproducts and Biorefining. Volume 4, Issue 6, pages 637–657

[2] Zegada-Lizarazu W., Elbersen H.W.,. Cosentino S. L, Zatta A., 4, Alexopoulou E., Monti A., (2010) Agronomic aspects of future energy crops in Europe Bioproducts and Biorefining. Volume 4, Issue 6, pages 674–691

[3] Lewandowski I.,. Olsson R, Bacher W., Huisman, Nikolaisen L. and Paavilainen L. (1998) Production and use of perennial rhizomatous grasses (PRG) in the energy and industrial sector of Europe. Agricultural Systems. 96:224-236

[4] Sanderson, M.A., R.L. Reed, S.B. McLaughlin, S.D. Wullschleger, B.V. Conger, D.J. Parrish, D.D. Wolf, C. Taliaferro, A.A. Hopkins, W.R. Ocumpaugh, M.A. Hussey, J.C. Read, and C.R. Tischler, (1996). Switchgrass as a sustainable bioenergy crop. Bioresource Technology. 56: 83-93.

[5] Christian D. C. and Elbersen H. W.(1998) Switchgrass (*Panicum virgatum* L.). In: N. El Bassam. Energy plant species. Their use and impact on environment and development. London: James a James publishers p. 257-263.

[6] Casler M.D., Vogel K.P., Taliaferro C.M., Ehlke N. J., Berdahl J. D., Brummer E. C., Kallenbach R. L., West C. P. and Mitchell R. B, (2007). Latitudinal and longitudinal adaptation of switchgrass populations. Crop Science, 47-6, pp 2249-2260.

[7] Linde-Laursen I (1993) Cytogenetic analysis of Miscanthus ‘Giganteus’, an interspecific hybrid. Hereditas, 119, 297–300.

[8] Clifton-Brown J.C., Lewandowski I., Andersson B., Basch G., Christian D.G., Kjeldsen J.B., Jorgensen U., Mortensen J.V., Riche A.B., Schwarz K.-U., Tayebi K. & Teixeira F. (2001) Performance of 15 Miscanthus genotypes at five sites in Europe. Agron Journal 93:1013-1019.

[9] Heaton E.A., Voigt T., Long SP. (2004),A quantitative review comparing the yield of two candidate C4 perennial biomass crops in relation to nitrogen, temperature and water. Biomass and Bioenergy 27:21-30.

[10] Khanna M., Dhungana B. & Clifton-Brown J. (2008) Costs of producing Miscanthus and switchgrass for bioenergy in Illinois. Biomass and Bioenergy 32:482-493.

[11] Aravindhakshan, S.C., Epplin, F.M., and Taliaferro, C.M. (2010). Economics of switchgrass and miscanthus relative to coal as feedstock for generating electricity. Biomass and Bioenergy 34:1375-1383.

[12] Hopkins, A.A., K.P. Vogel, K.J. Moore, K.D. Johnson, and I.T. Carlson, (1995). Genotype effects and genotype by environment interactions for traits of elite switchgrass populations. Crop Sci., 35:125-132.

[13] Moser, L.E., and K.P.Vogel, (1995). Switchgrass, Big Bluestem, and Indiangrass. In: An introduction to grassland agriculture. R. F. Barnes, D. A. Miller and C. J. Nelson (eds.). Forages, 5th ed. Vol.1, Ames, IA: Iowa University Press, pp. 409-420

[14] Wullschleger S.D, Davis E.B., Borsuk M.E., Gunderson C.A. and Lynd L.R. (2010) Biomass production in switchgrass across the United States: database and determinants of yield. Agronomy Journal Vol 102, p.1158-1168

[15] Smeets E.M.W, Lewandowski I.M., Faaij A.P.C. (2009) The economical and environmental performance of miscanthus and switchgrass production and supply chains in a European setting. Renewabe and Sustainable Energy Reviews. 13 p 1230-1245.

[16] Karp A. and Shield I. (2008) Bioenergy from plants and the sustainable yield challenge. New Phytologist. 179: 15-32.

[17] Christian, D.G. ; Riche, A.B (1999). Establishing fuel specifications of non-wood biomass crops. IACR-Rothamsted. IX, 64, p 11

[18] Heaton E.A., Flavell R.B., Mascia P.N., Thomas S.R., Dohleman F.G. & Long S.P. (2008) Herbaceous energy crop development: recent progress and future prospects. Current Opinion in Biotechnology 19:202-209.

[19] EEA Technical report. Estimating the environmentally compatible bioenergy potential from agriculture. No 12/2007 ISSN 1725-2237.

[20] Neeta S., Biomass/Biowaste/Bioenergy, EU- India Partnering Initiative, Speaker and Discussant in the Conference on "India-EU and Member States Partnership for a Strategic Roadmap in Research and Innovation 11-12 November 2010, Delhi, India