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Long-term studies on switchgrass grown on a marginal area in Greece under different varieties and nitrogen fertilization rates

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ABSTRACT

Switchgrass (*Panicum virgatum* L.) is a perennial grass that has been selected as a candidate bioenergy crop for USA in the early 80s, while the research in Europe started a decade later. A long-term study on switchgrass had been carried out (1998–2015) on a marginal area in Greece comparing five varieties (having lowland or upland ecotype) at increasing nitrogen fertilization rates (0, 75 and 150 kg N ha^{-1}). Due to the successful establishment of the plantation quite satisfactory yields were recorded even at the establishment year (8.9 Mg DM ha^{-1}) and the ceiling yields were recorded in the 2nd year and came up to 20 Mg DM ha^{-1}. The under study lowland varieties (Alamo, Kanlow and Pangburn) were more productive compared to the upland varieties (Blackwell and CIR) with mean dry yields 12.37 and 11.39 Mg ha^{-1}, respectively and showed higher resistance to lodging. Among the five under study varieties, Alamo was the best performing giving an average yield of 12.7 Mg DM ha^{-1}, averaged over all treatments and years, while CIR was the least performing producing a corresponding average yield of 10.8 Mg DM ha^{-1}. From the fourth growing season and onwards significantly higher yields were recorded under increasing N fertilization up to 150 kg N ha^{-1} with an average yield of 13.9 Mg DM ha^{-1} (150 kg N/ha) over all varieties and years. The corresponding yields for the other two tested nitrogen rates (0 and 75 kg N/ha) were 10.31 and 11.69 Mg DM ha^{-1}, respectively.

1. Introduction

Switchgrass (*Panicum virgatum* L.) is a C_4 perennial grass with an average lifetime of 15–20 years, native to North America where it occurs naturally from Canada to Mexico. Early in 1970s switchgrass became an important warm-season pasture grass for forage production (Moser and Vogel, 1995). In 1980s, switchgrass has been identified as a candidate energy crop for USA by the department of Energy (DOE) (Wright and Turhollow, 2010) since it could produce significant amounts of lignocellulosic biomass and could be cultivated on marginal croplands. Switchgrass management as bioenergy crop is relatively new (Parrish and Fike, 2005) and at the early stages of switchgrass research as bioenergy crop it was assumed that its agricultural management should be similar to forage management (Sanderson et al., 2006). The research in Europe was initiated in 1990s in UK (Christian et al., 2002; Christian and Riche, 2001) and continued at the end of 1990's in the framework of a European research project named "Switchgrass for Energy" (Elbersen et al., 2004).

The key assets of switchgrass as biomass feedstock are: high net energy production per ha, low production costs (seed establishment), low nutrient requirements, high water-use efficiency, wide geographical adaptation, low ash content, adaptation to marginal soils and increased potential for carbon storage in soil (Christian and Elbersen, 1998; Sanderson et al., 1996; Samson and Omielan, 1992). In the more recent projects in Europe (i.e., OPTIMA; www.optimafp7.eu), the research on switchgrass was focused on marginal and/or less favorable lands for conventional agriculture. It has been reported that at least 1,350,000 ha has been deemed as less favorable for conventional agriculture in Europe (Allen et al., 2014). These lands have been abandoned either due to their low productivity, or are used as grassland and their cultivation with biomass crops-like switchgrass- could diversify and increase the farmers' revenues through the access to new markets like bioenergy and bio-products.

Historically, based on the morphology and the habitat of natural

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switchgrass populations, two main ecotypes have been classified; upland and lowland ones (Porter, 1996). The upland ecotypes typically have shorter tillers compared to the lowland ones and are better adapted to colder and drier habitats, while the lowland ones tend to thrive in warmer and wetter habitats (Porter, 1996). Mullschleger et al. (2010) reported that the lowland ecotypes were able to outperform the upland ones (12.0 ± 5.9 Mg ha^{-1} vs. 8.7 ± 4.2 Mg ha^{-1}) in a study carried out in 39 sites and in 17 states of USA. European research confirms that lowland ecotypes could yield more than upland ones when grown in the pedoclimatic conditions of the South Europe (Alexopoulou et al., 2008, 2015; Monti et al., 2008).

The optimum nitrogen fertilization for switchgrass, when cultivated as bioenergy crop, vary greatly according to the environmental conditions, the N-availability in soil and the harvest frequency and management (Lemus et al., 2009; Mulkey et al., 2006; Thomason et al., 2004; Brejda, 2000). Mitchell and Anderson (2008) stated that nitrogen fertilization is not recommended during the establishment year because it encourages weed growth and increases the competition between switchgrass seedlings and weeds, the establishment cost and finally the economic risk. It is reported that in areas (Western Europe) that switchgrass harvested quite late in winter (after a killing frost) the yield response nitrogen fertilization was quite small even if the crop was grown for many years with no nitrogen fertilization (Sanderson et al., 2012).

The main aim of this study was to compare the productive performance of five switchgrass varieties (lowland and upland ones) at three nitrogen fertilization rates in a long-term field trial carried out for seventeen years on a marginal area located in central Greece.

2. Materials and methods

An experimental field was established on 31 May 1998 at Aliartos plain (latitude 38^0 22′E, longitude 23^0 10′N, altitude 114 a.s.l). "Aliartos field" is located in the *"Forest Nursery of Aliartos"* that belongs to a large plain of about 20 ha derived from the drainage of Kopais Lake at the end of 19th century. The experimental site of switchgrass had been left fallow for almost two decades before the trial establishment. This area used to be cultivated with cereals (durum wheat) with poor yields and thus its cultivation even with subsidies was not economic viable. A soil analysis was carried out before the trial establishment and the results are reported in Table 1. The soil of the experimental field showed a homogeneous profile with a sandy claim loam texture down to a depth of 0.82 m. The deeper soil texture was sandy, probably due to the specific location of the field (bank of the drained lake). The soil had quite low organic matter content and alkaline pH (Table 1). Five switchgrass varieties (three lowland: Alamo, Forestburg, and Kanlow and two upland: Blackwell and Cave-in-Rock) were grown under three increasing fertilization rates (0, 75 and 150 kg N ha^{-1}) (Table 2). The experimental layout was a complete randomized block with three replicates. Each experimental plot covered an area of 48.75 m^2 (6.5 m × 7.5 m), large enough to allow realistic biomass yields determinations. The total area covered by the trial was 2800 m^2. Special attention was given to the soil preparation in order to have a fine texture at the sowing and the trial was seeded at 10 mm depth. The distances between the rows were 0.15 m. Before sowing, the germination capacity of the five under study varieties was measured in order to estimate the appropriate seeding rate at the sowing. Four out of five varieties had almost the same germination capacity (around 60%), while Kanlow seeds had quite low germination capacity (20%). Thus, the seedling rate that was applied for Kanlow was three times higher compared to the applied ones for the other four varieties. The establishment was quite successful and no gaps were detected in the rows and thus the plants were able to compete the weeds when had a height on 15 cm. Due to the fact that switchgrass has a quite low growth rate at the early stages of growth a manual weed control was carried out. The establishment was quite successful and hardly any gaps were detected in the rows. Due to the fact that switchgrass characterized by a low growth rate at the early stages of growth a manual weed control was carried out, while the seedlings when had a height of 15 cm were able to compete successfully the weeds. Thereafter and until the end of the trial there was no need for any kind of weed control.

Table 1
Soil chemical-physical characteristics surveyed at Aliartos (central Greece) before the establishment of switchgrass trial.

Soil characteristics	Soil layers (cm)				
	0–58	58–82	82–92	92–110	110+
Loam (%)	25. 5	25.0	0.3	0.3	S
Sand (%)	62.9	39.6	90.1	91.4	4.7
Clay (%)	11.7	35.5	9.1	8.4	92.1
Organic matter (%)	0.54	0.54	0.674	0.27	0.27
pH	8.00	7.90	8.10	8.50	8.20
N (ppm)	756	574	273	217	154
P_20_5 (ppm)	8.6	5.7	6. 7	6.1	6.4
K_20 (ppm)	2857	1188	375	26	682
Na (ppm)	17.2	18.5	10.1	8.3	362.1
Ca (ppm)	4275	4481	2920	2923	994
Mg (ppm)	4045	5470	1639	1704	1185

Table 2
List of switchgrass varieties tested in the long term experiment (17 years) in Greece (Aliartos).

Variety	Ecotype	Ploidy level	Origin	100 seeds weight (mg)
Alamo	Lowland	Tetraploid	South Texas (28°)	94
Blackwell	Upland	Octaploid	Northern Oklahoma (37°)	142
Cave-in-rock (CIR)	Upland	Octaploid	Southern Illinois (38°)	166
Kanlow	Lowland	Tetraploid	Central Oklahoma (35°)	85
Pangburn	Lowland	Tetraploid	Arkansas (36°)	96

The long-term meteorological data (precipitation, Tmax & Tmin) are presented (mean of all years) in Fig. 1, as recorded by a meteorological station located near-by the switchgrass trial. Aliartos is characterized by a typical southern Mediterranean climate with a mean annual temperature of 18.4 ± 0.6 °C, while the precipitations are mainly concentrated during the winter season (Fig. 1) with a mean value of 490 mm. As it is presented in Fig. 1 the monthly precipitation had large variation among the years. Analyzing the typical growing season of switchgrass under the experimental conditions (i.e., March–October), rainfall amount varied greatly from 62 mm in 2000, up to 419 mm in 2002. In Greece the main growing period of switchgrass is from beginning of April till middle of July including the hottest period in that area characterised by the lowest precipitation (< 10 mm on monthly basis, Fig. 1a). A drip irrigation system was established soon after the sowing of the trial and it was used for both to irrigate the plantation when necessary (from early May till mid-August) and to carry out the nitrogen fertilization from the second year and onwards.

A basic fertilization (NPK 11-15-15, 400 kg of fertilizer) was applied (before sowing) and thereafter on a five years basis prior to the crop regrowth (3/2003, 3/2008 & 3/2013). During the establishment year no additional nitrogen was applied to the trial in order to avoid weed competition. From the second year and onwards a nitrogen fertilization on annual basis was applied through the drip irrigation system, 40–50 days from re-growth. Among the years, the regrowth was varied according to the prevailing climatic conditions but in any case was carried out no later than 20th of March.

During each growing season the following parameters have been measured: number of tillers per square meter (in a marked area of