Panicum Virgatum L. Could be an Alternative Environmental Friendly Feedstock for Energy Production

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Abstract

The investigation of alternative energy sources environmentally friendly is necessary, due to the decrease of fossil fuel reserves, the increased world population needs and the increased CO_2 emissions. During the past two decades, researchers started to investigate the case of producing energy through crop production. Switchgrass is a perennial crop of low input requirements and high biomass production, which could produce high amounts of energy per hectare equivalent to oil. A three years field experiment was conducted in case to examine the effects of four nitrogen - fertilization and two irrigation levels, in two different soils, at two different growing stages (vegetative stage and seed mature) on dry biomass yield, calorific value and ash content of switchgrass Alamo variety. It was found that higher dry yield (27-30 t ha^{-1}) reached on the aquic soil while on the xeric remained at lower levels (14-15 t ha^{-1}). In the case of the average calorific value it was observed a slight increase (from 17 to 17.3 MJ/kg) according only to crop maturation, while in the case of the average ash content crop maturation had the opposite effect (5.4 and 4.5%). Therefore, it is really important to refer that switchgrass cultivation is able to produce 466 GJ ha^{-1} and 1.2 t ha^{-1} ashes which can be used for fertilization and its introduction in future land use systems for an environmentally friendly energy production should be seriously taken into consideration.

Keywords: *Switchgrass, calorific value, ash, biomass, energy*

I. INTRODUCTION

During the last two decades, the depletion of fossil fuel reserves from the daily consumption for heat, electricity and transportation, led to the investigation of renewable energy sources with lower environmental burden from their use. One of the investigated sources is biomass.

Following the adoption of Directive 2003/30/EC, the objective of the European Union (Vamvuka, 2009), is to increase the biomass use and to reduce greenhouse gas emissions (Sims et al., 2003; Berndes & Hansson, 2007). Except the use of agricultural residues, the introduction of plant species of high biomass yield and low input requirements, could fully meet the EU Agricultural policy of low input energy crops with reduced environmental pressure. Plants which can produce high yields under low energy requirements, while sinking large amounts of carbon into the soil, are the perennial ones (Tolbert et al., 2002; Liebig et al., 2005). The most ideal are those who characterized by a high water use efficiency, adaptation to marginal soils, high net energy production per hectare, low ash content and low production costs.

Switchgrass (*Panicum virgatum* L.) is one of these perennial crops and is known since the last century. Switchgrass is a warm-season C4 grass, comprises an important energy crop due to its high productivity and its high adaptability in almost all soil types. Switchgrass has a lifetime of over 15 years, if properly managed and is classified in two ecotypes: i) lowland that are vigorous, tall, thick-stemmed, and adapted to wetter conditions and, ii) upland ecotypes that are shorter, thinner-stemmed, and adapted to drier conditions (Gunter et al., 1996).

Worldwide experiments show that switchgrass is a crop of high biomass productivity, suitability for marginal land quality, low water and nutritional requirements. Since soil plowing takes place only in the first year of establishment, there is a reduced risk of soil erosion (Ma et al., 2000) in the areas of switchgrass cultivation. Recent studies stress the importance of switchgrass high cellulose content for bio-ethanol production and the low ash content in the case of energy production by direct combustion (McLaughlin et al., 1999). Finally, another advantage of switchgrass is that it can be easily integrated into existing farming operations because conventional equipment for seeding, crop management and harvesting may be put in use (Lewandowski et al., 2003; Vogel et al., 2002).

However, switchgrass cultivation must be environmentally acceptable and economically sustainable as to be introduced in agriculture systems. Therefore, high yields of high fuel quality are the key points to make it profitable and suitable for energy conversion. Considerable information on switchgrass yields has been reported mainly from USA (VanLoocke et al., 2012; Sharma et al., 2003; Shield et al., 2012). In EU case switchgrass dry yield has been reported to vary between 6 tons (low fertile soil) up to 25 tons (fertile soil) (Piscioneri et al., 2001; Monti et al., 2004). Contrarily to plenty of studies that have centered on agricultural residues fuel characteristics (Gravalos et al., 2000; Angelini et al., 2009; Everard et al., 2012), only few studies focused on switchgrass biomass quality for energy production (Osowski & Fahlenkamp, 2006; McKendry, 2002).

The objective of this study was to evaluate the calorific value and the ash content from switchgrass biomass in different growing stages under central Greek agro-climatic conditions which is a representative example of the typical Mediterranean climate. More specifically, the variability was monitored as a function of crop mature (harvesting time), nitrogen fertilization levels, irrigation levels and soils of different moisture regime (aquic and xeric).

II. MATERIALS AND METHODS

A. Field experiments and Management

Field experiments were established in two different soil-climatic environments e.g. at Palamas (West Thessaly-Karditsa plain) and at Velestino (East Thessaly-Larissa plain), Central Greece.
Switchgrass (cv. Alamo; lowland ecotype supplied from Colorado USA), was sown in June 2009, using a modern cereal seeding machine, applying 7 kg seed ha^{-1} at a row distance of 12.5 cm. This is slightly more than advised for an ideal crop establishment (5.7 kg ha^{-1}; Elbersen et al., 2004).

Palamas soil is a deep, sandy loam to loam (sand 37-45%, silt 51-43%, clay 12%), moderately fertile (0.9% organic matter content at 40cm depth), characterized by a groundwater table fluctuating from some 2 m below the soil surface (receives artificial drainage) in May, to deeper layers later in summer, and is classified as Aquic Xerofluvent (USDA, 1975). On the other hand, Velestino soil is a clay loam to clay (sand 19-21%, silt 39-41%, clay 38-42%), fertile (organic matter content 1.4-1.8% at 40 cm depth) and was classified as Calcixerollic Xerochrept, according to USDA (1975).

The experimental design was a 2×4 split–plot with four replications (blocks) and eight plots per replication (8 x 4 = 32 plots). Irrigation comprised the main factor [I1 = 0 mm (rainfed), I2 = 250 mm], and N-fertilization comprised the sub-factor (N1 = 0, N2 = 80 N3 = 160 and N4 = 240 kg N ha^{-1}). Plot size was 48 m^2 (6 m width x 8 m length).

Switchgrass was sampled twice (when the plants reached 1 m in height - 92 days after emergence “DAE”, stage of four leaves; upon seed maturation - approximately 190 DAE). There was harvested 1 m^2 per plot in each (destructive) sampling, and each plant was divided into leaves, stems and storage organs. The presented data correspond to 2011 and 2012 experimental years, where switchgrass cultivation was already in the 3rd and 4th growing periods.

B. Laboratory Measurements

The storage organs were weighed and oven-dried at 60^{o}C until equal weights. The dry samples were chopped and grounded. After grinding, samples were placed in a stack of sieves, as to obtain the geometric mean diameter of the sample and geometric standard deviation of particle diameter according to ASAE standard S319.3 (2001). Thereafter, an oxygen bomb calorimeter (Model C5000 Adiabatic Calorimeter, 2004) was used to determine the calorific value of each grind sample.

The determination of ash content was based on ASTM standard D 3174-97 for coal and coke (1998), while the moisture content of the sample was determined according to ASAE Standard S358.2 for forages (2001).

III. RESULTS AND DISCUSSION

A. Weather Conditions

Palamas area is generally characterized by a higher mean air temperature and precipitation during the growing period than Velestino. Specifically, the mean air temperature during summer months (June-August) of 2011 were 25.4 and 26.5 ^{o}C, while summer of 2012 was warmer with mean air temperatures of 27.5 and 31 ^{o}C at Velestino and Palamas, respectively (Fig. 1). Actually, summer of 2012 was the hottest of the last decade, with a particularly long period (almost 3 months) especially at Palamas study site.

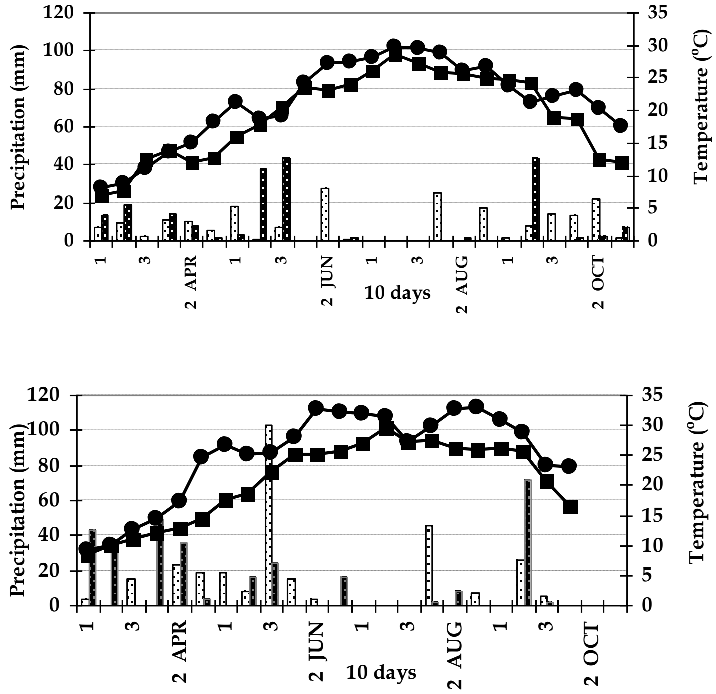

Figure 1. Ten Days Mean Temperature and Precipitation Recorded at the Study Sites (Velestino: Upper Graph; Palamas Lower Graph) During the Growing Seasons of 2011 and 2012 (▒ Precipitation 2011, ▓ Precipitation 2012, —■— Temperature 2011, —●— Temperature 2012).

Precipitation during the growing period (April-September) varied substantially between the two studied sites (Fig. 1). Total precipitation at Palamas, reached 300 mm in both growing periods (295 mm in 2011 and 305 mm in 2012), whereas at Velestino, total precipitation was about 200 mm (203 mm in 2011 and 197 mm in 2012). During the summer period (June-August) of 2012 the recorded precipitation was extremely low (2.6 mm and 26.2 mm for Velestino and Palamas, respectively) compared to the recorded values of 2011 (about 70 mm in both sites). Moreover, the recorded evapotranspiration was almost the same in both years for each site (600 and 770 mm at Palamas and Velestino, respectively; Fig. 2).

Therefore, it could be derived that 2012 was a particularly adverse year for crop growth characterized by warmer and drier weather conditions comparing with the average climate of the site.

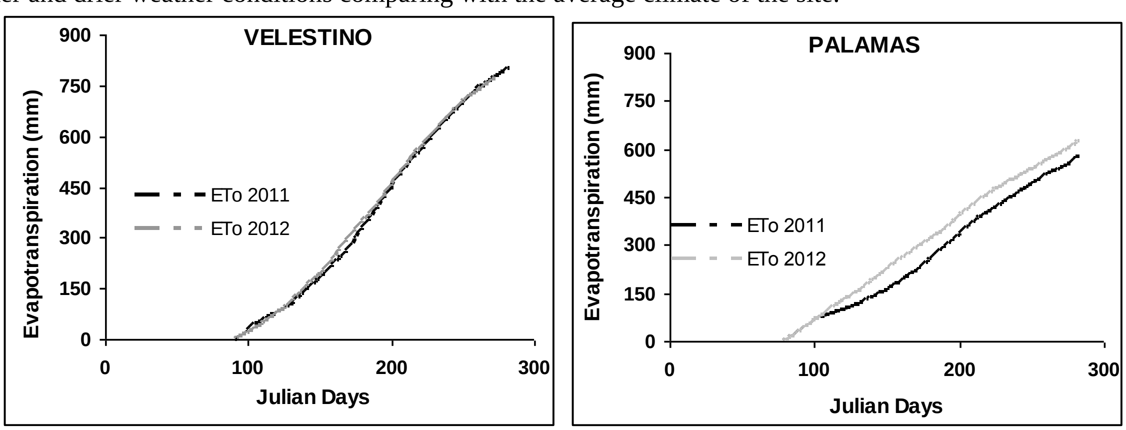

Figure 2. Evapotranspiration (Mm) at the Study Sites During the Growing Seasons of 2011 And 2012.

B. Switchgrass Yield

Switchgrass dry biomass yield was significant affected (P>0.05) by the investigated factors (irrigation and N-fertilization) and their interactions (Table 1). Higher harvested dry yield was found at Palamas experimental site than at Velestino (27.1 and 15.7 t ha^{-1}, respectively). The harvested yield at Palamas site was higher than the reported yields in literature (Lemus et al., 2002) and higher than at Velestino in both harvest stages (stage of 1m height and 4 leaves; stage of seed mature).

The lower yield at Velestino in 2011 (where the crop was in the 2nd growing year) can be explained due to switchgrass perennial characterization with low yield during starting years, when the crop develops its rooting system, whereas it might reach maximum production in the third growing year (Pedroso et al., 2011; Van Esbroeck et al., 1997).

During the 1st sampling, leaves comprised up to 27-30% of the total biomass, whereas the remaining 70-73% was stems. This composition changes with crop age and at the final harvest (seed mature) the partitioning rates of the plant organs were 19-22%, 68-71%, and 10-12% for leaves-, stems-, and flowers of the total biomass, respectively (Giannoulis et al., 2016).

Table 1. Switchgrass Dry Biomass (T Ha^{-1}) As Affected By 2 Irrigation (I1, I2), and 4 N-Fertilization Levels (N1, N2, N3, And N4) In Two Different Sites (Palamas And Velestino) In 2011-2012.

Yield (t ha^{-1})	Palamas				Velestino			
	2011		2012		2011		2012	
	1st Sample	Harvest	1st Sample	Harvest	1st Sample	Harvest	1st Sample	Harvest
Irrigation levels								
I1 (0mm)	11.6	23.2	12.3	19.7 a	6.1 a	8.5 a	7.9	9.1 a
I2 (250 mm)	11.8	26.5	13.6	22.8 b	7.7 b	8.3 b	8.4	14.3 b
$LSD_{0.05}$	ns	ns	ns	1.76	0.15	0.14	ns	2.91
Fertilization levels (kg N ha^{-1})								
N1: 0	9.3 a	22.5	11.4 a	17.8 a	5.7 a	7.5 b	8.1	12.1
N2: 80	10.2 a	26.2	11.0 a	16.4 a	8.0 b	10.0 d	7.8	10.0
N3: 160	13.1 b	27.7	14.7 b	26.6 b	8.1 b	7.1 a	8.0	12.9
N4: 240	14.1 b	22.9	14.7 b	24.2 b	5.8 a	8.9 c	8.6	11.9
$LSD_{0.05}$	1.27	ns	3.09	5.11	0.12	0.10	ns	ns
Interaction (Irrigation * Fertilization)								
I1N1	9.3	19.2	10.5	16.1	5.2 a	7.6 c	7.9	10.6
I1N2	9.3	26.3	10.8	14.4	6.7 d	10.6 g	7.9	8.6
I1N3	12.8	26.1	14.3	16.1	7.1 e	7.7 c	7.5	9.4
I1N4	14.8	21.2	13.5	22.1	5.4 b	8.0 d	8.3	8.1
I2N1	9.2	25.8	12.2	19.5	6.2 c	7.4 b	8.3	13.6
I2N2	11.1	26.1	11.2	18.5	9.3 g	9.5 e	7.7	11.3
I2N3	13.4	29.4	15.1	27.1	9.0 f	6.6 a	8.5	16.3
I2N4	13.3	24.6	15.9	26.3	6.2 c	9.8 f	8.9	15.7
$LSD_{0.05}$	ns	ns	ns	ns	0.18	0.16	ns	3.25
CV %	10.4	33.5	22.2	22.9	1.6	1.9	17.7	17.1

* Duncan criterion: a, b, c, d, e, f, g.

C. Calorific value

In case of calorific value with plant tissue moisture content at 8%, there were found significant differences (P>0.05) only for N-fertilization at Palamas site in 2011 (Table 2). The average calorific value was 17.0 and 16.9 MJ/kg during the 1st sampling (stage of 4 leaves and 1m height) at Palamas and Velestino respectively. At final harvest the above values were slightly increased up to 17.3 and 17.0 MJ/kg at Palamas and Velestino, respectively. Moreover it was found a slightly non significant difference between irrigation levels with the non-irrigated treatment having higher calorific value, regardless the experimental site.

The increasing calorific value due to plant maturation is important as a result of the final received energy per hectare (yield x calorific value) and due to the extra necessary energy for the drying processing of switchgrass biomass (stage of 4 leaves and 1 m height).

It has been reported, that there was found an increase of calorific value by increasing the N-fertilization from 0 to 80 kg ha^{-1} (Kludze et al., 2013), while the calorific value was 18.49 and 18.92 MJ/kg for 0 and 80 kg N ha^{-1}, respectively. The previous values are almost the same with the findings of this study by adding 1.05-1.12 MJ/kg, which are the differences that were found to the samples after the extra drying of the biomass to 0% moisture content.

Table 2. Switchgrass Calorific Value (MJ/Kg) At Two Different Growing Stages (1st Sampling: 1m Height And 4 Leaves, Harvest: Seed Mature) Under 2 Irrigation (I1, I2) And 4 N-Fertilization (N1, N2, N3, And N4) Levels In The Studied Fields Of Palamas And Velstino.

Calorific Value (MJ/kg)	1st Sampling		Harvest			
	Palamas	Velestino	Palamas			Velestino
	2012	2012	2010	2011	2012	2012
Irrigation levels						
I1: 0 mm	17.0	16.9	17.4	17.3	17.2	17.0
I2: 250 mm	17.0	16.8	17.3	17.5	17.1	16.9
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
Fertilization levels (kg N ha^{-1})						
N1 = 0	16.9	16.9	17.4	17.4 b	17.2	16.9
N2 = 80	17.1	16.8	17.3	17.2 a	17.2	16.9
N3 = 160	17.0	16.9	17.4	17.4 b	17.2	17.0
N4 = 240	17.0	16.8	17.3	17.2 a	17.1	17.0
$LSD_{0.05}$	ns	ns	ns	0,1	ns	ns
Interaction (Irrigation * Fertilization)						
I1N1	16.8	16.9	17.3	17.3	17.2	17.0
I1N2	17.0	17.0	17.3	17.2	17.2	17.0
I1N3	17.1	16.8	17.5	17.3	17.2	17.0
I1N4	17.1	16.8	17.4	17.3	17.2	17.1
I2N1	17.0	16.8	17.4	17.3	17.1	16.8
I2N2	17.1	16.7	17.3	17.1	17.1	16.8
I2N3	17.0	16.9	17.4	17.4	17.2	16.9
I2N4	16.9	16.9	17.3	17.2	17.1	17.0
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
CV %	0.5	0.7	0.4	0.2	0.2	0.4

* Duncan criterion: a, b.

Specifically, there was measured the calorific value of each plant storage organ (Table 3) and there was found that there was no significant difference between the calorific values at the 1st sampling (height 1 m and 4 leaves) and at the final harvest (seed maturation). In all cases, regardless treatment and site, the calorific value of switchgrass storage organs in an ascending order were: leaves <stems <floral stems (Table 3). Floral stems had the higher values due to the seed existence and their oil content (17.7 MJ/kg).

It could be concluded that 1 hectare of switchgrass at Velestino produces energy up to 125.6-150.4 GJ at the 1st sampling where biomass needs drying (energy consumption) and 146.0 - 276.6 GJ at the final harvest (where biomass is already dry), depending on the treatment. On the other hand, at Palamas site, 1 hectare produces 176.7-269.8 GJ and 276.9-466.1 GJ depending on the treatment, at the 1st sampling and at the final harvest, respectively.

Table 3. Calorific Value (MJ/Kg) of Switchgrass Storage Organs, at two Different Growing Stages (1st Sampling: 1m Height and 4 Leaves, Harvest: Seed Mature) Under 2 Irrigation (I1, I2) and 4 N-Fertilization (N1, N2, N3, and N4) Levels in the Studied Fields of Palamas and Velstino In 2012.

Ash content (%)	Palamas			Velestino		
	1st Sampling					
	Leaves	Stems	Fl. Stems	Leaves	Stems	Fl. Stems
Irrigation levels						
I1: 0 mm	16.9	17.1	-	16.7	16.9	-
I2: 250 mm	16.9	17.0	-	16.7	16.9	-
$LSD_{0.05}$	ns	ns	-	ns	ns	-

Fertilization levels (kg N ha^{-1})						
N1 = 0	16.6	17.0	-	16.7	16.9	-
N2 = 80	16.9	17.1	-	16.7	16.9	-
N3 = 160	17.1	17.0	-	16.7	17.0	-
N4 = 240	17.0	17.0	-	16.7	16.9	-
$LSD_{0.05}$	ns	ns	-	ns	ns	-
Interaction (Irrigation * Fertilization)						
I1N1	16.4	17.0	-	16.8	17.0	-
I1N2	16.8	17.1	-	16.8	17.0	-
I1N3	17.1	17.1	-	16.6	16.9	-
I1N4	17.2	17.1	-	16.7	16.8	-
I2N1	16.8	17.0	-	16.7	16.9	-
I2N2	17.0	17.1	-	16.6	16.8	-
I2N3	17.0	17.0	-	16.7	17.0	-
I2N4	16.8	17.0	-	16.7	17.0	-
$LSD_{0.05}$	ns	ns	-	ns	ns	-
CV %	1.3	0.2	-	0.5	0.7	-

	Harvest					
	Leaves	Stems	Fl. Stems	Leaves	Stems	Fl. Stems
Irrigation levels						
I1: 0 mm	16.9	17.2	17.7	17.2 a	17.1	-
I2: 250 mm	16.8	17.2	17.7	16.6 b	17.0	17.3
$LSD_{0.05}$	ns	ns	ns	0.15	ns	-
Fertilization levels (kg N ha^{-1})						
N1 = 0	16.8	17.2	17.7	16.8	17.0	17.1
N2 = 80	17.0	17.2	17.7	16.9	17.0	17.2
N3 = 160	16.9	17.2	17.8	16.8	17.0	17.4
N4 = 240	16.8	17.2	17.7	17.0	17.1	17.5
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
Interaction (Irrigation * Fertilization)						
I1N1	16.8	17.2	17.8	17.0	17,1	-
I1N2	17.0	17.2	17.8	17.2	17,0	-
I1N3	16.8	17.3	17.7	17.1	17,0	-
I1N4	17.0	17.2	17.7	17.4	17,0	-
I2N1	16.9	17.2	17.6	16.5	16,9	17.1
I2N2	16.9	17.2	17.5	16.5	16,9	17.2
I2N3	17.0	17.2	17.9	16.6	17,0	17.4
I2N4	16.5	17.1	17.8	16.7	17,1	17.5
$LSD_{0.05}$	ns	ns	ns	ns	ns	-
CV %	1.3	0.2	0.9	0.4	0.3	0.9

* Duncan criterion: a, b. **Fl. Stems: floral stems.

Biomass conversion into forms of energy is an old idea that is receiving increasing attention due to environmental, energy supply and agricultural market condition concerns (McCarl & Schneider, 2001). Several policies and energy consumption related actions have been proposed to limit net GHG emissions. One mechanism that can be used to mitigate GHG emissions is cofiring. Studies for evaluating the feasibility and cost of direct injection cofiring of 10% switchgrass with coal appear promising (Boylan, 2000). It has been reported that switchgrass chemical composition used as a basis for computations of the GHG emissions in % by weight (kg) is: water 11.99, ash 4.61, carbon 42.04, hydrogen 4.97, oxygen 35.44, nitrogen 0.77, and sulfur 0.18.

There is an equation which estimates the higher heating value (HHV) of switchgrass:

$$HHV = 35160C + 116225H - 11090O + 6280N + 10465S$$

Where, HHV is the higher heating value in kJ/kg, and C, H, O, N and S represent the mass fractions on a dry ash free basis for carbon, hydrogen, oxygen, nitrogen and sulfur in the fuel, respectively. Calculated HHV for switchgrass is 16.694 kJ/kg, while the tested HHV for switchgrass, which is employed in this model, is 15.991 kJ/kg (Aerts et al., 1997; Sami et al., 2001), values that are lower than the measured calorific value of this study.

D. Ash content

It is also necessary to know the amount of the produced ash during the processing of biomass burning for heating energy production except the produced energy in the case of green energy production from biomass. For this purpose, in this study was measured the ash content of switchgrass tissue with moisture content at 8% and there were not found significant differences ($P>0.05$), except the case of the 1st sampling in 2012 at Palamas site only for the irrigation factor (Table 4). It was observed a slightly non significant difference in the ash content between the irrigation levels with the non-irrigated treatment showing higher values at Palamas. The average ash content at the 1st sampling was 5.1 and 5.4 %, while at final harvest was 4.2 - 4.3 and 4.5 at Palamas and Velestino, respectively, proving that average values of ash content were decreasing with plant maturation, regardless growing stage, treatment and experimental site.

Table 4. Switchgrass Ash Content (%) at Two Different Growing Stages (1st Sampling: 1m Height and 4 Leaves, Harvest: Seed Mature) Under 2 Irrigation (I1, I2) And 4 N-Fertilization (N1, N2, N3, And N4) Levels In the Studied Fields of Palamas and Velstino.

Ash content (%)	1st Sampling		Harvest			
	Palamas	Velestino	Palamas			Velestino
	2012	2012	2010	2011	2012	2012
Irrigation levels						
I1: 0 mm	4.70 a	5.54	4.18	4.77	4.11	4.23
I2: 250 mm	5.44 b	5.31	3.87	4.01	4.28	4.84
$LSD_{0.05}$	0.43	ns	ns	ns	ns	ns
Fertilization levels (kg N ha^{-1})						
N1 = 0	5.42	5.75	3.98	4.27	4.19	4.40
N2 = 80	4.93	5.47	4.58	4.50	4.13	4.79
N3 = 160	5.22	5.21	3.47	4.24	4.23	4.38
N4 = 240	4.72	5.28	4.08	4.54	4.24	4.55
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
Interaction (Irrigation * Fertilization)						
I1N1	5.14	5.73	4.11	4.42	4.08	4.18
I1N2	4.56	5.23	4.35	5.33	4.41	4.56
I1N3	4.66	5.42	3.80	4.39	4.33	4.29
I1N4	4.45	5.78	4.47	4.93	3.63	3.89
I2N1	5.70	5.76	3.84	4.11	4.30	4.69
I2N2	5.29	5.70	4.81	3.66	3.86	5.02
I2N3	5.78	4.99	3.15	4.09	4.13	4.46
I2N4	4.98	4.78	3.69	4.16	4.85	5.20
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
CV %	3.8	8.2	9.8	10.4	12.9	7.6

* Duncan criterion: a, b,

Specifically, it was found that there was not a significant difference on plant storage organs ash ($P>0.05$) regardless treatment and experimental site, except the case of leaves at Velestino during the final harvest in the irrigation treatment (Table 5). The storage organs with the lower ash content were the stems (about 3-4 %), while leaves had higher ash content (about 8-9 %) regardless harvesting time, treatment or experimental site. In all cases, the descending sequence of switchgrass storage organs is: stems <floral stems <leaves.

Table 5. Ash Content (%) of Switchgrass Storage Organs. at Two Different Growing Stages (1st Sampling: 1m Height and 4 Leaves, Harvest: Seed Mature) Under 2 Irrigation (I1, I2) and 4 N-Fertilization (N1, N2, N3, And N4) Levels in the Studied Fields of Palamas and Velstino.

Ash content (%)	Palamas			Velestino		
	1st Sampling					
	Leaves	Stems	Fl. Stems	Leaves	Stems	Fl. Stems
Irrigation levels						
I1: 0 mm	7.42	3.62 a	-	8.26	4.14	-
I2: 250 mm	7.92	4.45 b	-	7.67	4.10	-
$LSD_{0.05}$	ns	0.666	-	ns	ns	-
Fertilization levels (kg N ha^{-1})						
N1 = 0	8.57	4.13	-	8.17	4.56	-
N2 = 80	7.84	3.77	-	8.05	4.09	-
N3 = 160	6.91	4.53	-	7.64	3.96	-
N4 = 240	7.34	3.69	-	8.00	3.89	-
$LSD_{0.05}$	ns	ns	-	ns	ns	-
Interaction (Irrigation * Fertilization)						
I1N1	8.91	3.59	-	8.47	4.41	-
I1N2	7.52	3.34	-	7.93	3.78	-
I1N3	6.41	3.96	-	7.86	4.13	-
I1N4	6.82	3.57	-	8.79	4.24	-
I2N1	8.23	4.68	-	7.86	4.70	-
I2N2	8.17	4.21	-	8.18	4..40	-
I2N3	7.40	5.10	-	7.42	3.78	-
I2N4	7.87	3.80	-	7.22	3.53	-
$LSD_{0.05}$	ns	ns	-	ns	ns	-
CV %	7.5	7.3	-	6.7	10.3	-
	Harvest					
	Leaves	Stems	Fl. Stems	Leaves	Stems	Fl. Stems
Irrigation levels						
I1: 0 mm	7.80	2.75	4.63	6.53 a	3.08	-
I2: 250 mm	8.08	2.99	4.65	9.29 b	3.29	3.92
$LSD_{0.05}$	ns	ns	ns	1.117	ns	-
Fertilization levels (kg N ha^{-1})						
N1 = 0	7.19	3.00	4.60	8.20	3.10	3.32
N2 = 80	7.83	2.64	5.09	7.91	3.43	2.92
N3 = 160	8.58	2.90	4.26	7.75	3.06	3.68
N4 = 240	8.17	2.94	4.63	7.78	3.17	5.76
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
Interaction (Irrigation * Fertilization)						
I1N1	6.93	2.94	4.38	7.29	2.93	-
I1N2	8.02	2.84	5.07	6.16	3.53	-
I1N3	8.93	2.96	4.48	6.25	3.19	-
I1N4	7.30	2.26	4.60	6.40	2.66	-
I2N1	7.44	3.05	4.82	9.11	3.26	3.32
I2N2	7.63	2.44	5.11	9.65	3.32	2.92
I2N3	8.23	2.83	4.03	9.26	2.92	3.68
I2N4	9.03	3.63	4.65	9.16	3.68	5.76
$LSD_{0.05}$	ns	ns	ns	ns	ns	-
CV %	9.7	19.3	5.6	6.3	13.3	8.7

* Duncan criterion: a, b. **Fl. Stems: floral stems.

It has been reported that switchgrass is an energy crop characterized as a high quality raw material of high volatile content, ranging from 70-85% and relatively low ash content, ranging from 1.8 to 10%, on a dry basis (Vamvuka et al., 2010). It was also reported that stems showed higher volatile and lower ash contents than leaves. Increasing levels of irrigation and fertilization resulted in a small reduction in volatile concentration. However, ash concentration reduced only at later harvest (Christian et al., 2002; Bakker & Elbersen, 2005). In other study, Vamvuka et al. (2010) reported that the ash content ranged from 1.9-2. 4% in stems and 5.6-10.0 % in sheets, while the higher ash content was found in leaves. These results are in agreement with the findings of this study.

Finally, Kludze et al. (2001) reported that ash content further reduces if the final harvest will take place in spring and consistent with previous reports (Ogden et al., 2010; Skrifvars et al., 1998).

CONCLUSIONS

Panicum virgatum L. is a perennial plant of high adaptation and low requirements, producing high biomass yields even under adverse weather conditions.

The responsible plant organs for the total calorific value and the total ash content are stems due to their higher biomass ratio (70% of total biomass). On the other hand, floral-stems are the storage organs with the higher calorific value, probably due to the seed oil content, while leaves have the lower.

Calorific value (8% moisture) slightly increased up to 17.3 MJ/kg at plant maturation while ash content decreased, regardless treatment and experimental site.

Finally, it was calculated that Panicum virgatum L. is able to produce 277-466 GJ ha^{-1} depending on treatment, consisting switchgrass as an important perennial crop of high environmentally friendly energy production and its introduction into future land use systems should be seriously taken into consideration.

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