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Biomass and Bioenergy Production of *Arundo donax* L., *Pennisetum purpureum* Schum. and *Pennisetum purpureum* Schumack. × *Pennisetum glaucum* L. in Short Rotation Cropping System in Costa Rica

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Nowadays different alternatives of short-rotation crops have been planted as renewable energy production around the world. The objective of this research was to evaluate biomass and energy production of the first rotation (6 months) of *Arundo donax*, *Pennisetum purpureum* and *Pennisetum purpureum* × *Pennisetum glaucum* propagated by plant and rhizomes in short-rotation crops condition in humid tropical conditions in Costa Rica. These crops were established with spacing of 1 m × 1 m when was established by plant and 1 m × 6 m when was established by rhizomes, in plots of 50 m^2. At six months, within these areas, total height, number of sprouts, biomass production and its respective energy produced were evaluated. The results obtained showed that *P. purpureum* propagated by plant had the lowest ash percentage (13.33%), *A. donax* the lowest moisture content (52.28%) and *P. purpureum* × *P. glaucum* presented the highest calorific value (20218 kJ/kg). *P. purpureum* showed the best yields in biomass production (24.45 ton/ha and 22.52 ton/ha) propagated by rhizome and by plant respectively and therefore these two short-rotation crops were the highest energy produced (470 GJ/ha) after six months.

Keywords: Bioenergy, Tropical Species, Forage, Short-Rotation Plantations, Energetic Potential, Pastures.

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1. INTRODUCTION

Recently, high demand of energy in the world is provided by fossil fuels,[1,2] this has caused an increase in carbon dioxide and other gases that contribute to global warming and environmental and socio-economic problems.[3,4] According to United States Energy and Information Administration (USEIA) projected that, within 20 years the world energy consumption will increase by 50% and the main energy supplier will be fossil fuel.[3]

Due to the need to reduce greenhouse gas emissions and dependence on fossil fuels in the world, biomass for energy emerges as an alternative to produce renewable energy.[2,5,6] Biomass sources include crops, wastes, subproducts and residues from agriculture, food production[7] and forestry, plantation and urban trees.[8] According to Dale et al.[9] and Stoof et al.,[6] biomass is the only renewable raw material that can act in this moment to supplement or displace fuel from petroleum and resolve environmental, social and economic problems.

There are two approaches to produce biomass: (i) biomass from dendro-energetic plantations, which are woody species established at high densities to maximize biomass per unit area.[10] For example, Tenorio et al.[11] reported high energy production from short-rotation energy plantations of *Gmelina arborea* planted in high stand density for one year old in Costa Rica. (ii) On the other hand, biomass from annual and perennial crops, grown specifically for energy production,[5] which consist of plants that persist for several years[12] also known as short-rotation crops. According to Jungers et al.,[13] these bioenergy sources raw materials (woody species and short-rotation crops) have a number of environmental benefits such as carbon sequestration and a reduction of pollution.

Despite these advantages, to develop energy from species is necessary to adequately meet the quality aspects

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of biomass, including moisture content, chemical composition and ash content.[14] Also, when wanting to use a species as bioenergy sources raw materials is important to characterize the species, to know its production capacity and properties.[15–17] Numerous studies have been conducted to evaluate the energetic potential of many woody species and short-rotation crops, which considered energy characteristics as ash content and calorific value, or cropping and industrialization of bioenergy sources raw materials.[18, 19] On the other hand, economic profitability is the most important factor for the adoption of short rotation coppice for energy from biomass, and Hauk et al. found that high economic viability of short rotation coppice.

In Central America, in recent years, an interest for short-rotation plantation (woody species and crops) has emerged for biomass production, such as *Arundo donax*, *Saccharum spontaneum*, *Eucalyptus camaldulensis*, *Gliricidia sepium*, *Leucaena leucocephala* mainly, focused on energetic crops.[21] And Costa Rica was no exception. Currently studies has developed methods to use residues from forest woody species in reforestation,[22] energy evaluation of short-rotation energy plantations of *Gmelina arborea*[11] and recently the evaluation of crops for energetic purposes, which includes *Gynerium sagittatum*, *Phyllostachys aurea*, *Arundo donax*, *Pennisetum purpureum*, *Saccharum* species and *Sorghum bicolor*.[23–25]

For example, León et al.[26] evaluated the performance of 14 clones of cane for energy propose, elephant grass (*Pennisetum purpureum*), and two sugarcane (*Saccharum officinarum*) varieties in the humid tropics of Costa Rica, and eight cane clones for energy propose in the subtropics of Florida. They found that energycane's growth and biomass production were highly variable when comparing clones and they conclude that cane clones for energy propose is a promising feedstock for biomass production and could play an important role as a bioenergy crop when grown in the tropics and subtropics. On the other hand, Tenorio et al.[23] evaluated the energy, physical, and mechanical properties of pellets fabricated from twelve types of agricultural and forestry crops and found high variation in the pellet properties and *Pennisetum purpureum* and *Arundo donax* presented good pellet energy properties.

However, previous studies are based on specific assessments of biomass and not on established test to know true potential of short-rotation crops, this project aims to evaluate biomass production and energetic production, moisture content of the crop, calorific values and ash content from the first rotation for three forage species growing in short-rotation plantation (*Arundo donax*, *Pennisetum purpureum* and *Pennisetum purpureum* × *Pennisetum glaucum*) in humid tropical conditions in Costa Rica. This is to provide one or several forage species with high energetic potential for large scale production of more sustainable fuels.

Although forages species are used as animal feed,[27] this is not displayed as a controversial future problem because crow activity does not present an important development and little areas are utilized for planting this forages species.[28] The Costa Rican government expected that the growth of forages species for energy have a balance with areas planted for animal feed.

2. MATERIAL AND METHODS

2.1. Description on Experimental Test of Bioenergy Crops

To study the short-rotational crops biomass and bioenergy potential a 0.1 hectare trial was established (Fig. 1) in AgrepForestal S.A. company farm, San Carlos, Alajuela (long 10°27′27.0″ N, lat 84°25′35.2″ W). The trial consists of 3 agricultural forage species (*Arundo donax*, *Pennisetum purpureum* and *Pennisetum purpureum* × *Pennisetum glaucum*) with incomplete randomized block design (Fig. 2(a)).

During selection of these crops, climate adaptability, soil conditions and material availability were taken into consideration. Detailed provenance type, plant spacing and propagation techniques used for each species are displayed in Table I. It is not worthy that all crops were planted at a density of 10 thousand plants per ha, each plot had an area of 50 m^2, therefore, plots established with plants had 5 m wide per 10 m long. The trials were established in 2014 at the end of October (rainy season). The crops were harvested at the fourth week of April 2015 after 6 months.

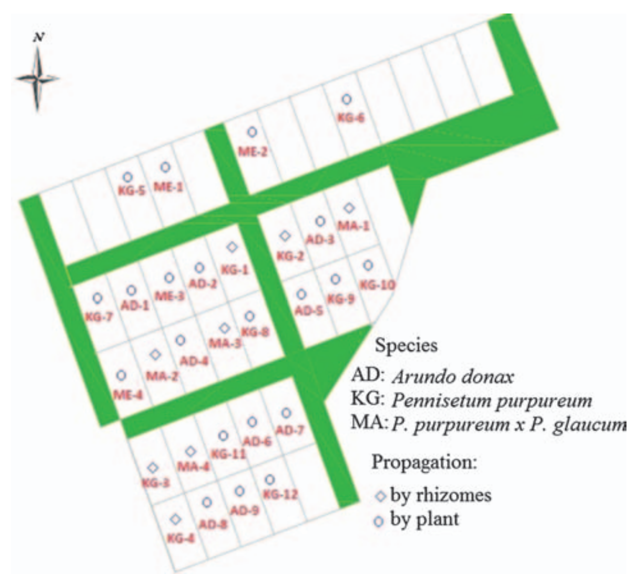

Fig. 1. Experimental design of short-rotation crops plantation of three forage species in Alajuela, Costa Rica.

Fig. 2. Trial of short-rotation crops from three forage species in San Carlos, Costa Rica. Trial initial establishment (A), plantation at harvest time of *Pennisetum purpureum* and *Arundo donax* (B), manual harvest of *Pennisetum purpureum* × *Pennisetum glaucum* (C).

2.2. Sampling and Harvest of Short-Rotation Crops Plantations

A measuring plot of approximately 11.40 m^2 was delimited in area total (50 m^2) for each forage species (Fig. 2(b)). At Six months after establishing the plantation, total height (m) and sprouts per plant and rhizome were measured. And the harvest for total area of trial was performed (Fig. 2(c)). However, the biomass of measuring plots (11.0 m^2) was only weighted and classified per plot.

Subsequently, all the material was chipped and dried to avoid rotting of itself. However, before the material was dried, five samples of about 44 g were taken to determine moisture content of the material.

2.3. Biomass Production and Number of Sprouts

From the weight of total above ground biomass wet (kg) in each measuring plot, its respective effective area (m^2) and moisture content (%) per species, total dry biomass production was calculated (kg/m^2); then, all this was projected in tons and at one hectare surface as observed in Eq. (1):

$$\text{Production (ton}\cdot\text{ha}^{-1}) = \frac{(\text{Green biomass weight} * (1 - \text{Moisture content}/100))}{\text{Ploy area}} * 10 \quad (1)$$

10 = conversion factor of kg/m^2 to ton/ha for dry biomass production.

2.4. Number of Sprouts Per Hectare

At six months, sprouts per plant and per rhizome were counted for each of the test plots, these were classified per species; then, an average calculation of sprouts per effective area of the plot (m^2) was performed, this value is projected to one hectare (Eq. (2)).

$$\text{Number of sprouts per hectare} = \frac{\text{sprouts average}}{\text{plot area (m}^2)} * \frac{10000 \text{ m}^2}{1 \text{ ha}} \quad (2)$$

2.5. Determination of Energetic Properties

2.5.1. Moisture Content (C%)

It was performed following the ASTM D 1762-84 standard,[29] where five samples of the chipped material were taken from each plot classified by species, samples were weighted with a precision balance of 0.01 g and then, placed at 103 °C oven temperature for 24 hours to reweight the sample. This moisture was calculated with Eq. (3):

$$\text{Moisture Content (\%)} = \frac{(\text{Green weight} - \text{Dry weight})}{\text{Green weight}} * 100 \quad (3)$$

2.5.2. Ash Content (Ash%)

Material already dried from each short-rotation crops was grounded to obtain a granulated material (less than 2 mm) and was sieved in 60 and 40 mesh (0.40 and 0.25 mm, respectively). Material between 60–40 mesh was dried to 0% in MC; this was placed with a proportion of 1.5 g in porcelain crucibles with 3 replications and following the procedure indicated in the standard ASTM D 1102-84.[30] Ash content was determined with Eq. (4):

$$\text{Ash (\%)} = \frac{\text{Ash weight}}{\text{Weight of the sample dried in oven}} * 100 \quad (4)$$

2.5.3. Maximum Heat Calorific Value (HCV)

Again from the sieved samples and with moisture content at 0%, three samples of 0.5 g were extracted and placed

Table I. Description of short-rotation crops plantation test for three forage species in Costa Rica.

Species	Common name	Provenance	Spacing	Propagation
Arundo donax	Arundo	AgriBio	1 m × 1 m	Plant
Pennisetum purpureum	King grass	Río San Carlos	1 m × rhizome	Rhizome
Pennisetum purpureum	King grass	Río San Carlos	1 m × 1 m	Plant
Pennisetum purpureum × *Pennisetum glaucum.*	Maralfalfa	Finca San Pedro	1 m × rhizome	Rhizome

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in iron capsules. Then, the iron capsules were subjected to a series of test in the Parr's calorimetric bomb, which involved estimating heat calorific value according to the norm ASTM D-5865.[31]

Samples were compared to a pattern of benzoic acid (C_6H_5COOH), and with data recorded with the calorimetric bomb, proceeding to calculate the calorific value in Eq. (5):

$$HCV = \left(CVAB * \frac{T_i - T_f}{\text{mass sample}} \right) * 4.184 \qquad (5)$$

Where, HCV = Maximum calorific value kJ/kg, CVAB = Calorific value for benzoic acid kcal/kg, T_i = Initial Temperature (°C), T_f = Final Temperature (°C), 4.184 = Conversion factor of kcal a kJ.

2.6. Energy Production and Ash Content Determination

Energy produced was estimated using HCV and the production of total dry biomass for each of the three forage species. This value was quantified with conversion units to calculate total energy produced in GJ/ha. Whereas, ash production (ton/ha) was calculated from production (ton/ha) and ash percentage per species as is shown in Eq. (6):

$$\text{Ash production } (\text{ton} \cdot \text{ha}^{-1}) = \frac{\text{Ash percentage}}{100} * \text{Total dry biomass production} \qquad (6)$$

2.7. Statistical Analysis

A descriptive analysis was performed, where the mean and the variation coefficient were calculated for production in tons per hectare, MC and energetic properties for each forage species. Then, an ANOVA was applied with a level of confidence of 95% to determine the variability in biomass production, MC, ash% and HCV, added to this, the assumptions for normality and homoscedasticity of variance were determined. Additionally, Tukey's mean test was applied to determine if there were significant differences between means among these parameters for three forage species. For the analysis of biomass production and energy produced together with ash% per ha, a square root transformation of the variable was performed to meet the statistical assumptions and determine the best fit variable.

3. RESULTS AND DISCUSSION

3.1. Biomass Production for Three Forage Species at 6 Months

Table II shows biomass production and characteristics for each type of short-rotation crops. Biomass variation was 2.52 ton/ha to 24.45 ton/ha, total height from 1.69 m to 3.12 m, number of plants per hectare 9852 to 10740 and number of rhizome per hectare from 4425 to 4929.

According to biomass production in tons per hectare (Table II), the species with lower production was *Arundo donax* with 2.52 ton/ha which at the same time had the lowest total height. The species with the highest production was *Pennisetum purpureum* planted by rhizome with 24.45 ton/ha; also, among species *Pennisetum purpureum* by plant, *Pennisetum purpureum* by rhizome and *Pennisetum purpureum* × *Pennisetum glaucum* no significant differences were found between means, unlike *Arundo donax* which presented differences.

According to the results obtained from production by biomass (Table II), the species with the highest value was *Pennisetum purpureum* propagated by plant or cutting (24.45 ton/ha) and by rhizome (22.52 ton/ha). However, it is important to note that for rhizome propagation, a higher number of sprouts per hectare were obtained in a lower number of stems planted per hectare compared to the number of plants per hectare, which probably will affect harvesting, since the largest number of sprouts will likely lead to higher energy consumption during harvest.

When comparing production of dry biomass with other researches, the results obtained in this study were similar. For example, Araya-Mora and Bochini[32] conducted a study for *P. purpureum* in Costa Rica in similar climatic condition and found 15.2 ton/ha biomass after 4 months of establishment. Leon et al.[26] reported that a biomass yield of 75 ton/ha for *P. purpureum* growing in tropical weather condition of Costa Rica, yield higher than our research. However, ours yield was reached in less time. Leon et al.[26] harvested this species in 12 months old and the species was harvested in 6 months. Likewise, Rengsirikul et al.[33] reported a yield of 12 ton/ha in the first harvest at three months old during rainy season in Thailand, where climate conditions are very similar to Costa Rica.

Differences found in the production of dry biomass are explained by several studies where harvest age, site conditions, planting time, fertilizer application and precipitation levels are mentioned.[33–35] Also, Araya-Mora and Bochin,[32] explained that as this species age increases, biomass is greater; however, they clarified that at 140 days, dry matter percentage decreased to almost 9% regarding to being cut at 126 days. It is also important to note that the values of dry biomass found by *P. purpureum* are similar to other researches, but it grown under climate conditions of Cuba.[36, 37] These authors reported biomass yield between 20–60 tons/ha in 2 or 3 harvest per year.

Although biomass yield produced for *P. purpureum* can be considered low in this study, there are some researches where it is possible to increase biomass yield for these species. For example Anderson et al.[38] planted selected clones and achieve high productivity, over 40 ton/ha, productivity higher than our productivity. Crespo and Alvarez[37] increased biomass production with the application the fertilizer according to the requirements of the species and nutrient deficiencies in the soil.

Table II. Production for three forage species growing in short-rotation crops conditions in Costa Rica in first rotation (6 months old).

Species of short rotation crops	Propagation	Total height (m)	Number of plants or stems (N/ha)	Number of sprouts (N/ha)	Production (ton/ha)
Arundo donax	Plant	1.69	9852	12977	2.52^{A} (42.72)
Pennisetum purpureum	Rhizome	2.84	4929	62452	24.45^{B} (24.66)
Pennisetum purpureum	Plant	3.12	10740	13656	22.52^{B} (26.59)
Pennisetum purpureum × *Pennisetum glaucum*	Rhizome	2.71	4425	97376	20.31^{B} (17.08)

Notes: *Values in parentheses correspond to the coefficient of variation. The different letters for each parameter represent statistical differences among short-rotation crops species (significance of 95%).

Moreover, in the species *Arundo donax* a very low production of biomass was observed (Table II) compared to the other species, which makes this species unprofitable in the first harvest at 6 months old. However, this production must be valued. Dragoni et al.[35] explains that this species, during the first months of being planted, presents low number of sprouts by plant, since it is concentrated in the growth below the ground, in the anchoring of roots mainly to sustain the newly formed air biomass.

Aundo donax is a species widely studied for production of energy in many countries around the world from tropical to subtropical climate.[39] Corno et al.[39] reported a wide variability in biomass yield is reported for this species, finding variations for a first harvest of 1.3 to 6.0 ton/ha, which includes 2.52 ton/ha produced in the present study. Then as stated above, the low biomass yield of *Arundo donax* is normal for first harvest, but it is expected that the increased biomass for 2 or 3 harvest or aging of plantation.[40]

Another negative aspect that helped low *Arundo donax* biomass yield is propagation used in the tests. This plant is not possible propagate by seeds, then asexual vegetative reproduction is used.[41] Two types of vegetative reproduction are frequently used:

(i) rooting at the nodes and
(ii) the cane fragments.[41]

The last method is more effective for biomass yield because cane produce propagules characterized by the presence of developed below- and above-ground structures that allow a very high percentage of plant establishment (∼100%) and the successive development of vigorous plants, right from the first year of plantation.[42] On contrary, rooting at the notes, as used this research, the plant or plantation establishment will reach large time,[42] therefore lower biomass yield is produced in the first months.

The species with the highest number of sprouts per hectare, was *Pennisetum purpureum* × *Pennisetum glaucum* (maralfalfa) with 97376, which also had the lowest number of rhizomes per hectare with 4425. Likewise, *Arundo donax* had the lowest number of sprouts and the lowest number of plants, both were per hectare with 12977 and 9852 respectively. The sprouts quantity for *P. purpureum* and *Arundo donax* agreed with the values reported for Costa Rica,[26,32] Thailand[33] and Cuba.[36,37]

Regarding to MC by species and propagation, is *Arundo donax* the one with the lowest MC values, with 52.28% (Table III). This data is consistent with a study done by Pari et al.,[43] which variation was of 43–59%. Moreover, it is observed that genres of *Pennisetum* obtained similar values in MC or higher than the species *Arundo donax*; which will probably lead to a higher energy consumption during the process of drying.

High MC in the species *P. purpureum*, is explained in a study done by Takara and Khanal.[32] These authors performed measurements on moisture from the establishment, with measures every two months during a year and found high humidity, caused by variation in precipitation and the great need of the plant to absorb moisture to sustain its growth.

The moisture in the biomass of perennial grasses is focused in some studies,[44] because it are related to the energy consumed for drying or biomass efficiency.[45] Tahir et al.[46] reported that moisture increase with frequency caused the feedstock to have an higher moisture content. The harvest of perennial grasses with short rotation is characterized by high humidity presented in the biomass,[44,47] which is confirmed in the grasses used in this study.

3.2. Energetic Properties for Three Forage Species at 6 Months

MC range was from 52.28% to 66.94%, ash content varied from 6.51% to 9.64% and HCVc from 19204.99 kJ/kg to 20218.32 kJ/kg. The species *Pennisetum purpureum* by rhizome and plant together with *Pennisetum purpureum* × *Pennisetum glaucum* had no differences between means, unlike *Arundo donax* which is different to these three only in MC and was also the lowest with 52.28% regarding *Pennisetum purpureum* and *Pennisetum purpureum* × *Pennisetum glaucum*.

For ash% and HCV, the species *Arundo donax* obtained 6.51% and 19 505.40 kJ/kg respectively. *Pennisetum purpureum* by rhizome was 9.64% in ash and 19204.99 kJ/kg in HCV, *Pennisetum purpureum* by plant 8.40% in the first parameter and 19582.79 kJ/kg in the second parameter, and finally *Pennisetum purpureum* × *Pennisetumglaucum* 8.93% in ashes and 20218.32 kJ/kg in HCV. These two energetic parameters had no statistical differences between the (Table III).

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Table III. Energetic properties for three forage crops growing in short-rotation crops conditions in Costa Rica in first rotation (6 months old).

Species of short rotation crops	Propagation	Moisture content (%)	Heat calorific value (kJ/kg)	Ash content (%)
Arundo donax	Plant	52.28^{A} (8.51)	19505.40^{A} (3.37)	6.51^{A} (21.88)
Pennisetum purpureum	Rhizome	62.16^{B} (8.68)	19204.99^{A} (4.08)	9.64^{B} (19.85)
Pennisetum purpureum	Plant	62.51^{B} (7.09)	19582.79^{A} (4.12)	8.40^{AB} (26.67)
Pennisetum purpureum × *Pennisetum glaucum.*	Rhizom	66.94^{B} (3.73)	20218.32^{A} (3.17)	8.63^{A} (13.64)

Notes: *Values in parentheses correspond to the coefficient of variation. The different letters for each parameter represent statistical differences among short-rotation crops species crops (significance of 95%).

In case of HCV for three short-rotation species, values varied from 19200 kJ/kg to 20218 kJ/kg (Table III); these were consistent with the species of fast-growing plantations established in Costa Rica.[19] When comparing the values for genres of *Pennisetum sp* and *Arundo donax* with other studies, shows that are slightly higher than those reported by Tenorio et al.,[23] which vary from 15000 kJ/kg to 18400 kJ/kg. HCV could be indirectly influenced by the time the harvest was carried, the amount of rainfall, genetics of the species, number of repetitions, taking temperatures and weights and not by contrast, density of the plantation or fertilization.[49,50]

Regarding ash% (Table III), the percentage obtained were similar to reported by Tenorio et al.,[23] where found for *Arundo donax* an average of 10.5% and *Pennisetum purpureum* of 7.5%. However, another study in Thailand, where several methodologies for collecting and processing of the material were developed for species of *Pennisetum sp*., obtaining values from 0.6% to 16.1%.[48] These authors[48] explained that this may be due to the location of the plantation, weather, season of harvest, method of harvest, soil conditions, plant age, genetics, plant maintenance, amount of rainfall, particle size and even the number of repetitions of the experiment, causing that ash percentage vary.

The values of HCV and ash% obtained in the present study (Table III) agreed with other studies. These two energy parameter values are comparable with reported for Costa Rica,[26,32] Thailand[33] and Cuba.[36,37] And the range of values presented Corno et al.[39] for *A. donax* in different regions around the world including HCV values and ash% obtained in this study.

3.3. Energy Produced for Three Forage Species at 6 Months in Short Rotation Condition

According to the energy produced for three forage species per hectare (Table IV), it was observed that there is a distribution from 49.02 GJ/ha to 470.16 GJ/ha and ash production vary from 0.35 ton/ha to 3.64 ton/ha.

Among the *Pennisetum sp.* species, values obtained were statistically equal, *Pennisetum purpureum* by rhizome had 3.64 ton/ha of ash content and an energy produced of 470.16 GJ/ha, *Pennisetum purpureum* by plant 2.97 ton/ha in ashes and 441.29 GJ/ha in energy, and *Pennisetum purpureum* × *Pennisetum glaucum* 3.35 ton/ha and 411.45 GJ/ha, in ashes and energy respectively. In case of *Arundo donax* with an ash content of 0.17 ton/ha and energy produced of 49.02 GJ/ha where it was observed that these values were significantly different to the other species of *Pennisetum purpureum* × *Pennisetum glaucum*.

As for energy produced (Table IV), although the species *Pennisetum purpureum* × *ennisetum glaucum* had the largest number of HCV and ash% compared to the other species (Table III), when the estimation of energy produced was done, which included the production obtained from each species (Table II), *Pennisetum purpureum* was the species propagated both rhizome and plant, which presents the highest value for energy produced with 470 GJ/ha and 441 GJ/ha respectively; reflecting that energy per species was directly reflected by the production obtained per hectare. However, these values should be considered with caution because production is influenced by the dry and rainy season.[51]

The results obtained from biomass and energy yield (Tables III and IV) for first harvest are typical. The plant generally concentrates their growing to establish and develop roots in the first period this type of grasses.[47] Then it is expected lower biomass and energy yield.[44] However, different studies have shown an increasing in biomass yield with increasing of quantity of harvest.[46,47] Therefore, we hope that *Arundo donax* and *Pennisetum purpureum* will increase biomass and energy yield with age increases. In this way, it will be possible to have better productivity in the yield of biomass crops in Costa Rica.

Table IV. Energy produced in three forage species per hectare growing in short-rotation crops conditions in Costa Rica in first rotation (6 months old).

Species of short rotation crops	Propagation	Ash content (ton/ha)	Energy produced (GJ/ha^{-1})
Arundo donax	Plant	0.17^{A} (62.94)	49.02^{A} (42.85)
Pennisetum purpureum	Rhizome	2.29^{B} (37.39)	470.16^{B} (26.29)
Pennisetum purpureum	Plant	1.91^{B} (33.37)	441.29^{B} (27.08)
Pennisetum purpureum × Pennisetum glaucum	Rhizome	1.81^{B} (10.58)	411.75^{B} (19.64)

Notes: *Values in parentheses correspond to the coefficient of variation. The different letters for each parameter represent statistical differences among short-rotation crops species (significance of 95%).

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4. CONCLUSIONS

1. The major production by biomass was for the species *Pennisetum purpureum* planted by both rhizome (24.45 ton/ha) and plant (22.52 ton/ha) compared to the other species that had production of 2.52 ton/ha for *Arundo donax* and 20.31 ton/ha for *Pennisetum purpureum* × *Pennisetum glaucum.*
2. In the energetic properties, *Pennisetum purpureum* propagated by plant, has the lowest ash percentage with 13.33%; *Arundo donax* had the lowest moisture content with 52.28% and *Pennisetum purpureum* × *Pennisetum glaucum* obtained the highest calorific value with 20218 kJ/kg.
3. As for energy produced, all had variations; however, is *Pennisetum purpureum* propagated in both rhizome and plant, which obtained the highest value closed to 470 GJ/ha after 6 months of being planted.
4. The results of the present study confirmed that *Pennisetum* species and *Arundo donax* are a promising feedstock for biomass production with adequate energy properties at six months old (first rotation) and could play an important role as a bioenergy crops. Although the results are coming from experimental trial, they can be explored to larger areas for industrial use. Then they must be re-evaluated their productivity, and especially, crop systems must be developed for these crops in the humid tropical environment.

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