Energy Operational Consumption in Switchgrass Energy Crop

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ABSTRACT

Renewable energy sources are assessed thoroughly the last decade in order to be used instead of fossil fuels. One energy source, scientifically interesting, is biomass energy. This type of energy can be extracted of many biomass sources as some types of waste, wood residues from forestry, energy crops, etc. There are many interesting energy crops used for biomass production as biofuels (pellets, chips, biodiesel, etc.). Every energy crop in order to grow up for a given period needs some energy consumption which, in parallel means that provokes some CO_2 emissions during the field operational management. These two factors are very important for evaluation of the sustainability of energy crops.
In this paper, switchgrass is examined as a potential energy crop for biomass production. The field tested regards a 1 ha area, placed in a 1 km distance from the bioenergy facilities. The switchgrass crop, as a perennial crop, is tested for a 10 years period. Especially, in this paper energy consumption during the whole tested period of growth of switchgrass is examined, in order to be evaluated the sustainability of the crop. Energy consumption regards every energy input (direct or indirect) that is inserted during field operations management or from agrochemical material, fuels and other sources. In parallel, the CO_2 emissions due to the field operational management and materials are assessed for the switchgrass crop.

Keywords: Biomass, energy inputs, bioenergy.

1. INTRODUCTION

Last years, research has been developed on energy crops in a series of levels. Energy crops are developed, assessed and optimized in order to achieve lower energy and economic costs during the growing season. There are many scientific approaches regarding energy crops and their energy requirements.
Switchgrass (Panicum virgatum L.) is one quite promising crop that can be considered as a potential energy crop for biomass production. In various researches switchgrass has

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been studied as an energy crop regarding not only the energy requirements (Bassam 2010) but also the probability to optimize some characteristics of the crop regarding the farm practices and other agronomic parameters ((Jessica, et al. 2012), (Piscioneri, et al. 2001) and (Christian, et al. 2001)). Other researchers have studied switchgrass in comparison to other energy crops ((Lewandowski, Scurlock, Lindvall and Christou, 2003) and (Frédéric, et al. 2003)). Given the fact that switchgrass has many beneficial characteristics as a potential energy crop, the majority of the approaches regard the optimization of the crop production process in different aspects, such as fertilization, for example. Though, it is necessary for an energy crop to be assessed within the whole supply chain, i.e. from the establishment in the field till the harvest and transportation of the harvested biomass to the storage-processing facilities.
Here, a whole supply chain assessment of the energy requirements of switchgrass is presented including the stages of establishment, production, harvesting, and transportation in a ten-year exploitation period.

2. SWITCHGRASS AS A POTENTIAL ENERGY CROP

Switchgrass is a warm season, perennial (over 15 years with proper managing) herbaceous grass that is established from seed. It develops rhizomes and its root system is quite deep, often more than 2 m. It grows up to 50-250cm tall depending on the variety and climatic conditions. It makes efficient use of nitrogen and water. Productivity will vary between 6 tonnes dry matter (DM) at low fertile sites up to 25 tones at fertile sites (Christian, et al. 2001).
Switchgrass has many positive characteristics as a potential biomass crop. Some of them are: the high net energy production per hectare, the low production costs, the low nutrient requirements, the low ash content, the high water efficiency, the large range of geographical adaptation, the easy establishment by seed, its cold tolerance after winter hardening, its tolerance in acid conditions and its adaption in wide range of soils even though it grows better in more neutral-pH soils, and the potential for carbon storage in soil ((Piscioneri, et al. 2001), (Christian, et al. 2001), (Bassam 2010) and (Garten, et al. 2010)).
Regarding the crop operations needed, seedbeds are normally prepared using traditional ploughing and secondary cultivation to produce a firm seedbed with a fine-textured surface. During the first growth, it is important for the seedbed to have been weed controlled thoroughly because switchgrass is not competitive during the first establishment phase (Bassam 2010). It is established by seed. The number of plants established can be up to 400 plants per m^2 ((Bassam 2010) and (Christian, et al. 2001)). Regarding fertilization, switchgrass can produce high yield even under limited fertility (75 kg N ha^{-1}) (Wilfred 2008). In the first year no nitrogen should be applied because it is not necessary for the development of the crop and can promote weed growth leading to competition against the new plants. Phosphorus and potassium should be applied if soil availability is low. In later years application of nutrients should be at a level that anticipates rising productivity and also takes into account losses of minerals in

harvested biomass (Christian, et al. 2001). Diseases and no serious pest problems have not been reported in switchgrass in Europe ((Bassam 2010) and (Christian, et al. 2001). There is no technical reason so as the crop not be cut and harvested by traditional grass-harvesting machinery (Bassam 2010). Switchgrass does not perform well when is harvested too frequently. Thus, 1–2 cut harvests per year are usually employed (Wilfred 2008). Switchgrass yield is estimated to vary considerably, from less than 1 ton/ha to almost 40 ton/ha. The most frequently observed yield class across all ecotypes, cultivars, soils, and management practices is between 10 and 12 ton/ha (Hood, Nelson and Powell 2011).

3. ENERGY INPUTS ANALYSIS

The main energy inputs required by the crop of switchgrass in the studied period are shown in Table 1. The main energy factors are machinery and materials (propagation means, herbicides and fertilizers). All these inputs were taken into account in the estimation of the total energy of each farm operation.

TABLE 1: Energy Inputs

Inputs	Energy equivalent (MJ/unit)	Unit	References
Moldboard plough	180	kg	(Kitani, et al. 1999)
Disk-harrow	149	kg	(Kitani, et al. 1999)
Planter	133	kg	(Kitani, et al. 1999)
Mower	110	kg	(Kitani, et al. 1999)
Harvester	116	kg	(Kitani, et al. 1999)
Fertilizer Spreader	129	kg	(Kitani, et al. 1999)
Tractors	138	kg	(Kitani, et al. 1999)
Wagon-trailer	50	kg	(Kitani, et al. 1999)
Diesel fuel	41.2	l	((Wells 2001) and (Barber 2004))
Lubricants	46	l	(Saunders, Barber and Taylor 2006)
Seeds	4	kg	(Kitani, et al. 1999)
Nitrogen (N)	78.1	kg	(Kitani, et al. 1999)
Phosphorus (P_2O_5)	17.4	kg	(Kitani, et al. 1999)
Potassium (K_2O)	13.7	kg	(Kitani, et al. 1999)
Human Power	1.96	h	(Hamedani, Shabani and Rafiee 2011)
Irrigation	0.0098	m^2	(Saunders, Barber and Taylor 2006)

The assessment regards a “unit” field located 1000 m from the base farm and 1000 m from the storage facilities. The field area corresponded to 1 ha. The farm operations that take place for a ten-year period are shown in Table 2.
The fuel energy for diesel was presumed, after a literature review that corresponds to 41.2 MJ/l ((Wells 2001) and (Barber 2004)). The energy content of lubricants calculated based on an average approach from older research, equal to 46 MJ/l

(Saunders, Barber and Taylor 2006). Both of them are taken into account, in every farm operation except irrigation.

TABLE 2: Field Operations per Year

Operations	Years									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Disk-Harrow	√	x	x	x	x	x	x	x	x	x
Fertilizers Spreading	√	√	√	√	√	√	√	√	√	√
Agrochemicals spreading	√	√	x	x	x	x	x	x	x	x
Planting	√	x	x	x	x	x	x	x	x	x
Mower	x	√	√	√	√	√	√	√	√	√
Harvest	x	√	√	√	√	√	√	√	√	√
Transport-Handling	x	√	√	√	√	√	√	√	√	√
Plow	√	x	x	x	x	x	x	x	x	x
Irrigation	√	√	x	x	x	x	x	x	x	x

The operational practice that was followed was the traditional farm operation practice. Farm machinery contributes as energy input, not only through the fuel and lubricant consumption, but also through the embodied energy of each machinery, implement or tractor. This energy includes many parameters as the construction energy of raw materials, the energy of construction of farm machinery, the energy of transport to the final consumer and the energy of repair and maintenance of machinery for their estimated lifetime. By using the energy inputs of machinery, and given their corresponding weights, their estimated lifetime and the operational capacity for each farm operation (see (Wells 2001) and (Alluvione, et al. 2011)), the machinery energy consumption is extracted in MJ/ha.
Regarding fertilization, it was adopted, based on the literature, the following scenario:

- First year: 0 kg N, 200 kg P_2O_5 and 200 kg K_2O per ha.
- Second year: 0 kg N, 200 kg P_2O_5 and 200 kg K_2O per year per ha.
- Third year and further: 75 kg N, 200 kg P_2O_5 and 200 kg K_2O per year per ha.

According to these requirements, it was applied Urea, single superphosphate and potassium chloride, respectively.
Switchgrass requires weed control for the first two years of establishment in order to compete against weeds. It is selected Gliphosate as a quite good herbicide with many positive characteristics with energy content 454 MJ/kg of ai. Switchgrass does not have any requirements in agrochemicals application (herbicide, pesticide, fungicide, etc.) from the third year on.
Switchgrass' typical plant density varies from 350-400 plants per square meter. In our case study, it was selected plant density of 400 plants per m^2. The energy content of the seeds was considered as 4 MJ/kg.
Regarding labor, it was considered that all field operations, both in and out of field (including transport where existed) were performed by man workers. The value of the

energy input (adopted from (Safa, Samarasinghe and Mohssen 2011), (Banaeian and Zangeneh 2011) and (Hamedani, Shabani and Rafiee 2011)) equals to 1.96 MJ / working hour.

The transportation from farm to field and back was taken into account in every field operation. The calculation of energy consumed for this transport varies if the operation that is going to be executed includes material application (fertilizer, agrochemical, etc.) or not. If there is material application, more than one route for transportation should be considered. In the cases that there is no material application, the transport energy is calculated only twice; farm-field-farm. Transport regards, also, the energy inputs during the transport of harvested product from field to biomass storage-processing facilities. This operation is considered to occur every year from the second year on. The energy requirements for transportation are a function of a number of parameters, including the volume of produced biomass, the bulk density of harvested biomass, the total biomass production of the studied field, the transport distance, and the average transport speed.

4. RESULTS

The total energy consumption for all farm operations in a decade corresponds to 112,333 MJ or 112.3 GJ (Table 3). The main energy factors are the fertilizers spreading, the agrochemicals spreading, and the harvesting operations energy consumption 36,564 MJ, 54,081 MJ and 14,872 MJ, respectively.

TABLE 3: Energy requirements per farm operation for a decade

Farm Operation	Energy consumption (MJ)
Disk-harrow	384
Fertilizers Spreading	36564
Agrochemicals Spreading	54081
Planting	350
Harvesting	14872
Mowing	3735
Transport-Handling	991
Plowing	1009
Irrigation	347

In Figure 1, it is shown the proportional per cent energy consumption for the farm operations. Fertilizing has considerable energy requirements equal to 33% of the total energy consumption; agrochemicals spreading energy consumption corresponds to 48% of the total energy input and the harvesting energy content equals to 13%. The other farm operations contribute quite less energetically.

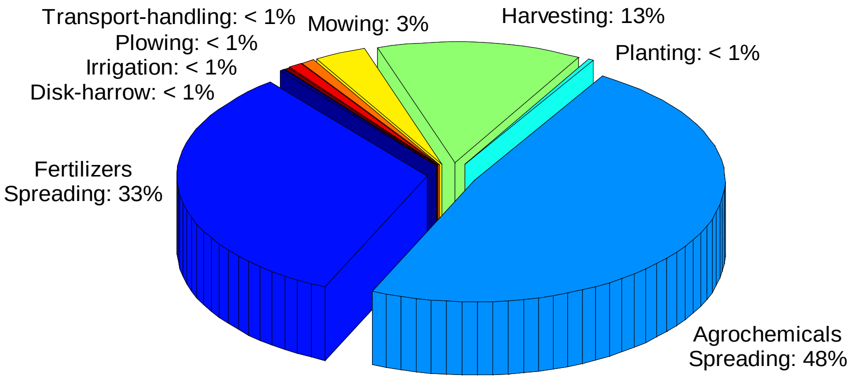

Figure 1: Energy consumption (%) per operation for 1 ha in 1 km from farm and from storage facilities in ten years period

In Figure 2, it is shown the total energy consumption for all in-field and logistics operations that take place in ten years for 1 ha field area located in 10 km distances from farm and from storage facilities. Finally, in Figure 3, the total energy consumption per year (in GJ) for 3 field areas (1 ha, 5 ha and 10 ha) is displayed.

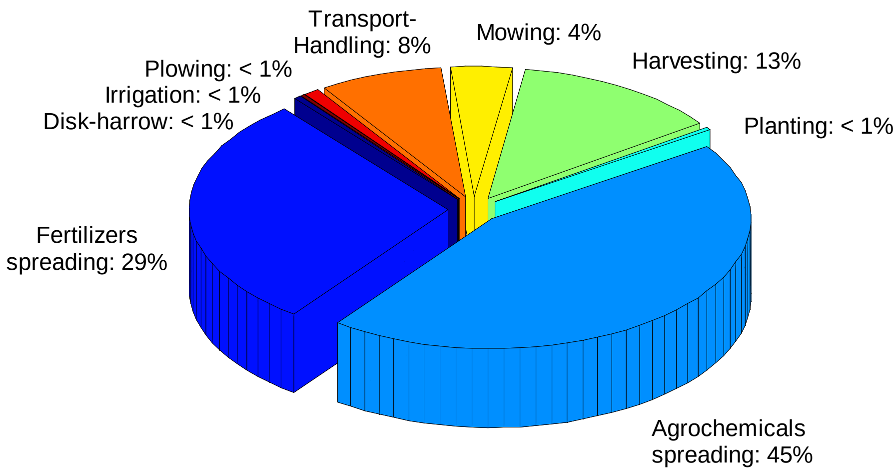

Figure 2: Energy consumption (%) per operation for 1 ha in 10 km from farm and from storage facilities in ten years period.

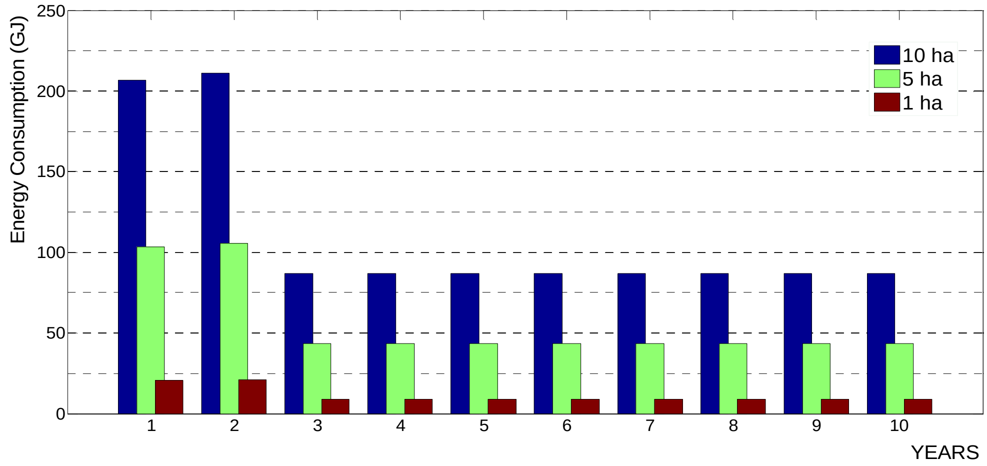

Figure 3: Total energy consumption per year in GJ for 3 different field sizes

5. DISCUSSION

In this paper, switchgrass is assessed as an energy crop regarding the energy inputs that are required for every farm operation during the ten years exploitation period. As it is shown in the results, the main energy factors correspond to fertilization, agrochemicals spreading and harvesting. Concerning fertilization, in this study, it was considered that it is implemented every year. In a further study it can be assessed the effect of lower fertilization in switchgrass crop; in the total biomass yield and the energy inputs. Regarding agrochemicals, they are very important for the first growth of switchgrass but it can be examined more thoroughly the possibility to be applied in lower quantities and the effects of this practice in success of establishment of the crop and in the total biomass yields.

Concluding, this paper is a first approach of the energy requirements in switchgrass crop as a potential biomass source, in a decade. This approach can be improved in order to be even more detailed in every farm operation and targeting to be compared to the energy output of the harvested material.

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