Opportunities for the production and economics of Virginia fanpetals *(Sida hermaphrodita)*

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Abstract

The main goal of this paper is to analyse the efficiency of the plantlet production of Virginia fanpetals, to make economic calculations for their energetic use and to determine the most favourable plant density. According to the experiments, the cost of a healthy *Sida* plantlet is in the range of 38.4 - 60.6 Euro cents, using the nurse-in-tray technology (NIT). This cost range is much lower than the market prices of the plantlets and the production method is more reliable compared to sowing. In the second year, the dry matter yield originating from *Sida* plantlets was 10.2-11.9 t hectare^{-1} (ha) without fertilization in the different planting densities. However, in the longer term, it is recommended to apply organic manure regardless of spacing. The theoretical market value of *Sida* is generally higher than total unit costs (36 - 60 EUR t^{-1}) in the case of all methods used, except for biogas. The production of *Sida* can be economical for farmers farming in marginal conditions, using locally available organic manure, producing crops with high heat demand, or involved in beekeeping.

Keywords: Sida hermaphrodita, plantlet production, economics, bioenergy

1. Introduction

Global population growth coupled with changes in dietary habits will increase food demand, resulting in a shift in the utilisation of arable land to direct and indirect (meat and dairy production) food production. The production of third generation, i.e., biogeneration crops (e.g. algae) is a possible solution due to the energy use of first and second generation energy crops (maize, sorghum, etc.), as well as their unfavourable impact on food prices, arable land structure, water management and biodiversity [1, 2]. It is one of the main characteristics of these crops that the main objective of their genetic improvement with biotechnological tools is to be able to provide high biomass yields, even on marginal lands [3]. Theoretically, it would be possible to produce 25-30% of the world's liquid fuel demand in marginal areas [4]. Converting conventional crop areas to energy crop production leads to seasonally differentiated land use patterns for conventional crops [5], and field level profitability can also be improved [6]. As energy crops are new to farmers, and thus have certain risks associated with their cultivation, as well with securing both contracts and market prices, for a successful uptake it is vital they provide a reasonable income [7]. According to the analyses of Dombi et al (2014), the most important elements of sustainability are land demand and social impacts (employment, revenue production) [8].

The primary aim of this research is to examine the production technology of Virginia fanpetals based on technical literature sources and the authors' experimental data, as well as an economic analysis of *Sida* production in Hungary. In the experiments extensive

agrotechnical solutions were used – without fertilisation – to analyse the crop nutrition ability of calcareous chernozem soil with low nutrient supply (pH: 7.93±0.025; humus content: 3.14%±0.407, $CaCO_3$: 4.67±0.00, NH_4: 0.15 mg kg^{-1}, NO_3:0.08 mg kg^{-1}, Organic N: 0.14 mg kg^{-1} K_2O: 465.0±7.071, P_2O_5: 24.76±0.692 mg kg^{-1}), for the production of *S. hermaphrodita*. A relatively large spacing was used in small plot experiments in order to try to mitigate the soil depletion caused by crops. Furthermore, the profitability of the novel method was examined, as well. In addition to the various methods of heat energy production, biogas and honey production, as well as CO_2 saving are also taken into consideration.

1.1. Production characteristics

Sida has the potential to be a multi-purpose perennial semi-shrub plant of the temperate climate zone. This species is indigenous in North America, where it is an endangered species [9]. Virginia fanpetals is most effectively propagated vegetatively, as its root section is rich in buds, while sexual propagation is difficult due to the low and protracted germination of seeds, as well as the slow initial growth of the seedling [10-12]. Flowering begins in early summer (early June in Hungary) and it lasts until late October, which is favourable if the crop stand is used as bee pasture. Further favourable characteristics of Virginia fanpetals are that it is less sensitive to pH [13], and it already provides a significant yield in its second year of production [14].

If sexual propagation is used, it is necessary to increase the germination capacity of *Sida*, which is between 10 and 15% in the case of 1-2-year-old seeds [11, 12, 15]. Germination is further complicated by endogenous fungal diseases and the water impermeable coat of the seeds [10, 16, 17]. These considerations make two-step seed priming necessary before sowing, as this method completely eliminates contaminated seeds and the exogenous pathogenic fungal diseases of seeds, resulting in a potential germination percentage above 70% [18].

Sowing can be performed with S071/B KRUK, a one-by-one pneumatic seeder used in maize sowing, which has an appropriate efficiency and a proportion of skips below 22% [19]. However, plant density is not ideal and the percentage of duplicated plants is high. Considering the slow and uneven initial development of *Sida* seedlings, their sensitivity to weeds and potentially to chemical weed control [20], seeding is not reliable, while yield can only be expected following the third year; furthermore, the crop protection activities which need to be performed are quite costly. The required amount of sowing seed is between 2-6 kg per hectare [11].

Plantlet production is potentially favourable from many perspectives:
- The problematic initial increase and the several hundred-fold demand for sowing seed can be eliminated [21].
- Wide row spacing makes it possible to perform inter-row tillage, which is a more favourable method of weed control, considering the aspects of soil protection and the sensitivity of Virginia fanpetals to chemicals, as herbicides which have proved to be effective have an unfavourable impact on the enzyme activity of soils [22, 23]. On the other hand, the biomass yield can be increased with higher planting densities under normal soil conditions in Central Europe (Austria) by using mineral fertilizer [24].
- In addition to using contamination-free propagation material (seed or plantlet) against fungal diseases, chemical weed control can also be provided. However, in dense populations, the number of spray applications needs to be increased to 2-3 occasions

in a given growing season. In the case of wide plant density, the number of spray applications can be reduced to one per year [11].

Based on a comparative analysis, focusing on the biomass yield of 36 different energy crops, it can be concluded that Virginia fanpetals belongs to the upper third of energy crops, with its 15 tons of dry matter yield per hectare [25]. Taking into consideration the fact that it is very suitable for soil remediation and the use of extensive production technology, this yield can be regarded as favourable. Furthermore, other studies have found that Sida biomass production intercropping with legumes and using digestate fertilization under marginal conditions can result in higher biomass production and lower environmental pressure in the temperate zone (Germany) [26, 27]. Studies from Lithuania have reported the advanced effect of liming with N fertilization on the biomass yield of Sida [28, 29].

In comparison with other similar crops which have a high biomass yield (such as willow or miscanthus), *Sida* extracts nutrients from the soil to a proportionately lower extent, since some of these nutrients are returned into the soil by means of the roots and fallen leaves of the crop. Harvesting performed in the proper time results in a low ash content and a relatively low level of extracted mineral substance content [30].

In the case of proper nutrient replenishment, *Sida* provides high biomass yield quantity (6.8-19.6 t absolute dry matter per hectare (DM t ha^{-1})) with a high heating value (17.5-19.9 MJ kg^{-1}) [11, 31-34] (Table 1).

Table 1. *S. hermaphrodita* yields at different fertilisation levels.

Source	Propagation material	Plant density crop m^{-2}	Dry biomass production kg ha^{-1}					Heating value MJ kg^{-1}	N Kg ha^{-1}	P Kg ha^{-1}	K Kg ha^{-1}
			Year 1	Year 2	Year 3	Year 4	Average				
[33]	seeds	25 seeds	2 790	8 360	11 080	11 300	8 382	19.8	100-200	39.3-52.4	83
[32]	seeds	25 seeds	n.d.	11 240	10 760	15 010	12 337	18.8	100	35	83
[32]	root cuttings	4.08	n.d.	15 310	20 750	22 630	19 563	18.7	100	35	83
[11]	seeds	3 kg	n.d.	9 440	14 410	11 930	11 927	17.5-19.5	n.d.	n.d.	n.d.
[11]	seeds	6 kg	n.d.	11 680	15 950	13 820	13 817	17.5-19.6	n.d.	n.d.	n.d.
[11]	seeds	9 kg	n.d.	13 160	15 840	14 500	14 500	17.5-19.7	n.d.	n.d.	n.d.
[11]	root cuttings	3.3	n.d.	6 610	10 030	8 320	8 320	17.5-19.8	n.d.	n.d.	n.d.
[11]	root cuttings	5	n.d.	7 820	13 810	10 820	10 817	17.5-19.9	n.d.	n.d.	n.d.
[11]	root cuttings	10	n.d.	11 010	17 770	14 390	14 390	17.5-19.10	n.d.	n.d.	n.d.
[35]	root cuttings	3.5		11 200	12 200	9 300	10 900	16.5	150	43.6	125
[35]	root cuttings	3.5		9 300	10 900	6 300	8 800	16.9	100	26.4	66.3

If biomass is intended to be used in its green form, the most appropriate timing is determined by the given crop year. Polish examples refer to three harvesting dates [11]. Based on the experiments performed at the University of Lublin, fertilisation has a favourable impact on the growth of green mass up to the application of 400 kg ha^{-1} N active ingredient, even though

it reduces the proportion of certain microelements and amino-acids. The yield of the two harvests ranged between 7.4.-9.53 t ha^{-1} of green mass, depending on the fertiliser dose (N: 100-400 kg ha^{-1}; K$_2$O: 50-150; P$_2$O$_5$: 80 kg) [11]. Based on the research of Jablonowski et al. (2017) conducted in Germany the biomass production method with one harvest yearly for solid fuel has the highest energy balance, accounting for 439 288 MJ ha^{-1}, compared to the more biomass harvesting system used with Sida biomass production [36].

There are several alternatives available for harvesting *Sida*. Mechanisation is the preferred method in the case of harvesting larger areas, as the cost of manual operations is many times higher than the cost of mechanical labour. In addition, harvest of the dried Sida biomass after vegetation allows both a maximum energy yield and a reduced negative impact on the growing plantation, which results in a sustainable supply of Sida biomass over several years [32, 33].

Harvesting is either performed in a single or double cut regime. The former can be carried out with forage harvesters used in maize harvesting [11]. Since the moisture content of the *Sida* stem decreases below 20% by the end of winter [11], the chopped stem can be left on the field.

1.2. The effect of Sida on soil reclamation and waste management

Table 2 summarises the results of soil remediation research. The overwhelming majority of references are therefore of Polish origin, so it seems to be very important to compare them with the experiments of Virginia fanpetals production in Hungary, including results relating to land reclamation and waste management.

Table 2. Results of land reclamation experiments.

Result	Experiment details	Reference
Soil reclamation, soil remediation, phytoremediation. Heavy metal accumulation and uptake	Small plot analysis on acidic fields and areas contaminated with zinc and lead	[37]
	Analysis of Zn, Cu and other heavy metal contamination of land (Cu accumulation: foliage, root system; Zn accumulation: foliage)	[38]
	Testing the cleansing effect of Virginia fanpetals based biochar (absorbent)	[39]
	Accumulation of harmful substances in the soil (mainly in the root zone)	[40]
Biomass production, waste management. Nutrient utilisation and pollutant sequestration: increasing crop yield and macroelement content, improving uptake ability and soil life	Sewage sludge and sewage sludge compost application and their use in agriculture	[41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53]
Increasing yield and waste management, micro-, macroelements and pollutant uptake, increased	Application of sewage sludge compost and brown coal ash from power plants (CaCO3: 1.5 Mg CaO*ha^{-1}; High-calcium brown coal ash: 1.5 Mg CaO*ha^{-1}; municipal sewage sludge compost: 250 kg N*ha^{-1}; their combination and half-dose	[54], [55],

bioassimilation, sewage sludge application, significantly higher P, Mg and S content.	experiments); content analyses	
	Soils saturated with lead and cadmium; application of sewage sludge and brown coal mixture	[56]
Pollutant uptake: accumulation of Co, Fe and N in the stem	Production on 0.5 m thick sewage sludge	[57]
13.8-17.8 DM t ha^{-1} on good quality soil; 6.85-11.3 DM t ha^{-1} on sewage sludge substrate significant heavy metal uptake in the stem	Yield comparison of different production sites: good quality soil and sewage sludge substrate. Analysis of the pollutant uptake of sludge.	[58], [59],
Increasing yield and waste management, micro-, macroelements and pollutant uptake, nutrient replenishment and cost saving, soil life improvement effect; proper alternative, optimum dose: 40 t ha^{-1}	Application of biogas ferment on less favoured, sandy fields (as an alternative of conventional NPK fertilisation);	[60, 61], [62], [63], [64], [65], [66]

1.3. Sida for energy production

According to the measurements of Szemplinski et al. (2014), the heating value of Virginia fanpetals (18.3 MJ kg^{-1}), the energy gained with different technologies (intensive: 1.81 GJ t^{-1}, semi-intensive: 1.53 GJ t^{-1}), as well as their energy efficiency (intensive: 10.2, semi-intensive: 12.6 per dry matter unit: HHV) in the years 2009-2011 [35] exceed the respective values of silo maize or sorghum. At the same time, the average dry matter yield of *Sida* per hectare was much lower than that of both crops (54% lower than maize yield and 23% lower than sorghum yield). With regard to the heating values of Sida, some papers also found an HHV of 18.1 MJ kg1- and an LHV of 16.8 MJ kg-1 [33, 34, 36]. Stolarski et al. (2014) investigated the higher heating value of Sida hermaphrodita and obtained a value of 18.9 MJ kg-1, while Krička et al. (2017) tested an HHV of 17.9 MJ kg-1 [67, 68].

Virginia fanpetals is either directly combusted, or it can be used as an outstanding (supplementary) feedstock for biogas production in accordance with the measurements of Oleszek et al. 2013 [69]. The composition of *Sida* silage fermented for 40 days under mesophilic circumstances in 2010 was the following:
- 26 % dry matter, 91% of which was organic matter
- 39 % carbon, 1.7 % nitrogen, (C/N ratio: 22.4 %), 9.5 % ash
- pH: 5.5

The biogas yield of *Sida* was quite favourable, both in terms of quantity and quality (Table 3), and this yield can be further increased if the proper formula is followed. The C/N ratio is ideal in itself, unlike most animal or vegetable feedstock. The estimated optimum range is 15-30 [70], 20-30 [71, 72] and 25-30 [73].

Table 3. Biogas and methane yield from Virginia mallow in an anaerobic digestion process (2010).

Biogas yield	Methane yield

Ndm^3 kg^{-1} FM	Ndm^3 kg^{-1} DM	Ndm^3 kg^{-1} ODM	Ndm^3 kg^{-1} FM	Ndm^3 kg^{-1} DM	Ndm^3 kg^{-1} ODM
99 (±3)	395 (±11)	435 (±12)	50 (±1.5)	201 (±5.5)	220 (±6)

Source: [69]

The biogas yield of Virginia fanpetals was especially high between days 6 and 12, even reaching 20-60 Nm^3 kg^{-1} DM.

It is important to emphasise that biogas production calls for much higher moisture content in comparison with combustion. For this reason, Virginia fanpetals for biogas production needs to be harvested in July. As no drying costs are incurred it can be regarded as cost saving and there is no dry matter loss which usually occurs at low temperatures.

2. Materials and Methods

2.1. Production technological experiments

The University of Debrecen provided a 10 000 m^2 demonstration garden, half of which was used for mallow and other herbaceous biomass crops and/or ornamental plants, as well as half-wild and field crops used for various purposes. 5m wide and 45m long cultivated strips were established on the plot with similar grass-covered strips in between. According to preliminary plans, 7 cultivated and 7 grassy block were established. The mildly alkaline (7.93 pH±0.025) heavy chernozem soil was rich in humus (3.14%±0.407) and calcium carbonate (4.67±0.00). The land quality was not extreme marginal, but we used a low input and very extensive agrotechnology with a low soil nutrient content.

During planting, three relatively wide spacings were used: 1m x 1m, 1m x 0.75m and 1m x 0.5m (Figure 1/A), to demonstrate that crops are able to compensate for the lower plant density used in the case of wide spacing by producing greater growth and more shoots per stem. Consequently, in this way it is possible to determine the best spacing in areas with similar characteristics.
Harvesting was performed with hand tools. The data for the inner stems were used during the biomass yield calculation.

Figure 1. Plants of the Future Demonstration garden at the University of Debrecen (2010-2015, Hungary)
Source: authors' photos and composition
A: *Sida* plantation (left to right: 1m x 1m, 1m x 0.75m, 1m x 0.5m (Google Earth);
B: 3-year-old *Sida* population;
C: *Sida* population in November;
D: *Sida* sheaves from a 3-year-old population.

2.2. Plantlet production experiments

The technology of plantlet production is described in detail in previously published papers by the authors of this study [18, 74]; therefore, it is not covered in this research. The nurse-in-tray technology consists of using single-space units (595x300x65 mm (Figure 2/A)) instead of applying the cell-tray method (previous experiments) for plantlet production in unused production units. Following the short plantlet production period, plants are overwintered in

so-called planting trenches which were established in accordance with field conditions (Figure 2/C). Later, these plants can be easily removed from the planting trenches (Figure 2/B-E).

Figure 2. Production of *Sida* plantlets with the nurse-in-tray method.
Source: authors' photos and composition
A: establishment of the propagation tray,
B: medium interwoven with roots at the time of plant relocation,
C: trays placed in the planting trench (August 2014),
D: the ultra-dense population in late autumn (November 2014),
E: removing the wintered plants from the planting trench (May 2015),
F: whole overwintered plantlet and cut back plantlet with roots.

The nurse-in-tray plantlet production experiment was carried out on two occasions with seed densities of 30-40, and 50–64 per tray (0.18 m^2) in the spring of 2014 and 2015, respectively (between July 2014 and May 2015). Two seeds were placed in the previously established planting holes (Figure 2/A). Since this latter spacing (64 seeds per tray) was shown to be the most favourable, plantlet costs were calculated in accordance with the results of this experiment (Table 4). The efficiency of each work phase of the nurse-in-tray method and the distribution of costs are shown in Table 4. In this experiment, plantlet production was performed with rented equipment, the cost of which is optional.

Table 4. Calculated costs of the nurse-in-tray method, based on the authors' own data.

Work phase	Personnel costs per 1000 plantlets (EUR)	Material costs per 1000 plantlets (EUR)	Polytunnel rental costs per 1000 plantlets (EUR)	Total cost per 1000 plants with planting (EUR)	Total cost per 1000 plants without planting (EUR)
sowing	7.95	26.17	4.32	38.45	
UD planting	22.11			22.11	
Total	30.06	26.17	4.32	60.56	38.45

UD: ultra-dense planting (252 plantlets per m^2)
Source: authors' own data and calculations

2.3. Economic calculations

The economic calculations focused on the efficiency of each production technology element, as well as the profitability of *Sida* production with a comparative method.

In the analysis of the production technology, planting was compared to seeding, and fertiliser doses were examined in the light of the extra yield obtained. In the calculations the authors' own results deriving from the extensive plantlet technology were used, while other data were provided by the literature source [27]. Hungarian technical literature sources and databases were used to retrieve the economic data related to the cost of fertilisation, mechanical and manual labour, while sowing seed and plantlet prices were obtained from international technical literature sources/databases. Rental fees (as actual or opportunity costs) were calculated using the Hungarian average (Hungarian Statistical Office, 2016), overhead costs (9% of direct costs) are based on sector-level data collection and processing from the Farm

Accountancy Data Network (FADN), Research Institute of Agricultural Economics, Hungary (2016).

In the case of 10,000 and 20,000 plant densities, the yields are the average of the results of the second to the fourth years of the authors' own tests, since the yield of the first year is not relevant in our view, due to the partly balanced population. Costs of planting/sowing were calculated for a 20-year-long life cycle which could be reduced when extensive technology is used. Taxes were not considered as their levels may change significantly depending on the scale and type of operation. Profits from substituted branches as opportunity costs are excluded from our calculations, since they are not accounting costs, and so are not suitable for the calculation of either production costs, nor unit costs, and also because they are hard to predict and depend on plant, year, soil type and technology.

The laboratory heating value was compared to the theoretically expected heating values (which can be estimated with formulas) and the actual heating value was calculated by taking into account the moisture content of the authors' own material sample used in this research. The expected economic value of *Sida* combusted in a stove was obtained by a calculation based on the price of the most frequently used fuels, their typical heating value and stove efficiency. This can be considered as a theoretical market price of *Sida*. Given the fact that *Sida* is a brand new crop it does not have a market price, and so we had no real-world statistics available.

Sida was taken into consideration just as a feedstock for biogas production, as it has become a potential feedstock of biogas plants in operation. The value of natural gas saving was calculated from the expected methane yield, based on literature sources. The stock exchange value of CO_2 saving was also considered. The following basic data were used for the calculations:
- biogas yield of *Sida*: 395 Nm^3 t^{-1} *Sida* DM, of which the quantity of biomethane is 201 Nm^3 t^{-1} *Sida* DM [69],
- moisture content of Sida: 14 % (average value of authors' own measurements)
- CO_2 content of *Sida*: 175 Nm^3 t^{-1} (own estimation)
- CO_2 density: 1.965 kg dm^{-3} [75]
- Stock exchange price of CO_2 saving: 5 EUR t^{-1} CO_2 [76]

For pelletizing and briquetting, Virginia fanpetals was accounted as a supplementary feedstock by using the technical and economic parameters of small-scale equipment in operation (capacity: 100 kg h^{-1}). The extra costs of production were compared to the expected extra revenue. For this reason, the following parameters were used:
- Electricity demand and price: 16.9 kW and 22.2 kW, 0.1 EUR kWh^{-1} [77, 78]
- Personnel costs: 3 people employed for 9 months per year for a monthly salary of 500 EUR
- Other costs: expert evaluation

Sida silage is also suitable for microalgae biomass production based on the work of Dębowski et al. (2017). Microalgae biomass consisting of *Chlorella sp.* and of *Scenedesmus sp.* was co-digested with the silage of Sida in semi-continuous experiments under mesophilic anaerobic conditions. The results showed that mixing of silage of Sida with microalgae biomass ensured a more balanced C/N ratio with less inhibition and digester imbalance [79].

Beekeeping may also potentially result in significant revenue (if biogas is produced, the revenue is lower as a result of the previous harvest), mainly for small-scale producers. The

honey yield was also calculated on the basis of technical literature sources, while for the price Hungarian premium honey prices were considered:

- honey yield: 120   kg ha^{-1} [80]
- price of honey: 10.8   EUR kg^{-1} [81]

3. Theory

Since there is very scarce literature available for *Sida,* limited mainly to Polish sources reporting production-related experiments, the authors of this paper consider it important to communicate the results of the Hungarian field experiments including economic calculations of production costs and the profit attainable in the case of energy utilization. The purpose of this study is to investigate the production technology of Virginia fanpetals based on technical literature sources, evaluate the efficiency of the plantlet production of Virginia fanpetals by using the authors' experimental data and make economic calculations for *Sida* production.

The plant health background of the vegetative plantation of Virginia fanpetals is not entirely known, making it a rather risky process. Cuttings cannot be properly maintained either, as they need to be preserved from drying, fungal infections, early emergence and heat damage at the same time [11]. Consequently, propagation from seed is the safest method of establishing the population. The prime cost of the propagation material is of crucial importance for an economical evaluation of the plant.

Based on the calculations of Balezentiene et al. (2013), *Sida* is one of the most promising crop species in terms of its multi-criteria framework, and as a sustainable choice for energy production [82].

The reason for its high heating value is that its carbon and hydrogen content (47% and 6%, respectively) are basically the same as that of *Miscanthus* ssp. and energy willow, but the nitrogen and ash content (0.2% and 1.8%, respectively), which reduce heating value, are much lower than their respective values [83]. *Sida* is very suitable for biogas production even with its greater moisture content, because its biogas yield is very high (cca. 435 Ndm^3 kg^{-1} ODM) and its C/N ratio is very favourable [83].

The value of *Sida* is greatly dependent on the quality of biomass to be used, the purpose of use and the type of fossil energy source it substitutes. These factors were evaluated with the help of the typical technical parameters and Hungarian economic data for 2015. Our hypothesis is that the high yield and good composition probably make *Sida* a cheap raw material for heat and biogas production and also of potential interest to bee-keepers.

4. Results

4.1. Efficiency of plantlet production methods

197-506 plantlets per m^2 can be produced with the nurse-in-tray method, which corresponds to large-scale plantlet production (427 plantlets per m^2). Based on the land rent, the rental rate for a polytunnel for the production of 1000 plantlets is between 4.30 and 17.00 EUR, depending on the plant density per m^2. A higher density did not reduce germination; on the contrary, the most favourable germination rate was achieved in the case of the highest plant density (Table 5).

Table 5. The efficiency of the NIT method and the rental rate of covered production equipment for the production of 1000 plants using various plant densities per tray.

Number of sowed seeds /tray	Germina-tion rate	Seedling per m^2	Polytunnel rent € per m^2 per month	Plantlet growing time (day)	Rental cost for the production of 1000 plantlets, €
30.00 [1]	59.00	196.67			16.70
40.00 [1]	64.50	286.67		32.00	11.45
50.00 [1]	51.80	287.78	2.19		11.41
64.00 [2]	71.20	506.31		20.00	4.32

[1]: plantlet production in August 2014. [2]: plantlet production in May 2015
Source: authors' own tests and calculations

Based on the calculated data, one person is able to produce 177.0-314.5 viable plantlets per hour, depending on the plant density, which amounts to a labour cost of 7.90-14.12 EUR for the production of 1000 plantlets (Table 6). These calculations are based on the most efficient spacing (64 plantlets per tray). In the experiments the total costs of the nursing of a single, healthy, well developed *S. hermaphrodita* plantlet fluctuated between 38.4 and 60.6 Euro cents.

Table 6. Efficiency of labour, calculated for the NIT method.

Number of sown seeds per tray	Labour efficiency tray h^{-1}	Labour efficiency seed h^{-1}	Loss (%)	Labour efficiency (plantlet h^{-1})	Cost of labour needed for the production of 1000 plantlets, €
30	5.00	300	41.0[a]	177.0	14.12
40	3.75	300	35.5[ab]	193.5	12.92
50	3.00	300	49.2[a]	152.4	16.40
64*	3.50	448.00	29.8[b]	314.5	7.95

Wage: 2.5 € h^{-1}. Different letters mean that there are significant differences between the characteristics measured at the level of $\alpha = 0.05$ based on the TUKEY test.
Source: authors' own data and calculations

4.2. Estimated yield of Sida hermaphrodita

The non-fertilised *Sida* population is expected to give a dry biomass yield ranging between 10 228 kg ha^{-1} (13 300 plants per hectare) and 11 871 kg ha^{-1} (20 000 plants per hectare). It was observed that the soil exhaustion effect of higher plant density (20 000 plants per hectare) became increasingly intensive over time. For double plant density, the average yield was nearly identical in the second and third years, while wide spacing resulted in a more balanced population in subsequent years. In the fourth year, wider spacing resulted in a 9 384 kg ha^{-1} yield, on average (Table 7).

Table 7. Calculated average yield of Virginia fanpetals based on the average weight of inner stems.

Years	2011			2012		
Spacing - thousand plants per ha	10	13.3	20	10	13.3	20
Average weight of inner stems	299.6 ± 56.2	295.2 ± 53.04	195.4 ±034.4	1120.87±93 .3	769.06± 94.4	593.55± 98.4

Average yield kg ha^{-1}	2 996[a,a]	3 926[a,a]	3 909[a,a]	11 208[b,a]	10 229[b,a]	11 871[b,a]
Moisture content %		14.75			18.23	
Years	**2013**			**2014**		
Spacing - thousand plants per ha	10	13.3	20	10	13.3	20
Average mass of inner stems	1076.3±110.8	678.3±237.7	523.1±290.8	938.4± 484.3	426.57± 175.6	358.2± 214.8
Average yield kg ha^{-1}	10 764[b,a]	9 022[b,a]	10 464[b,a]	9 384[c,a]	5 673[c,a]	7 164[c,a]
Moisture content %		12.64			10.53	

Different letters on the left side mean that there are significant differences between the years analysed at the level of a = 0.05, but no significant differences between the different plant density values (right letters) based on the Tukey test.
Source: authors' own experimental data

In order to use *Sida* for combustion purposes, it is necessary to know the higher heating value (HHV) of dry matter, for which an average of three literature data sources were used (Table 8).

Table 8. HHV of *Sida hermaphrodita* / Virginia fanpetals based on technical literature data and theoretical calculations.

	C	H	O	S	N	Ash	HHV (GJ/DM)	Source
							18.75	[33]
%	47	6	44	0.03	0.2	1.8	18.30	[83]
Heating value	16.450	7.080	4.400	0.003	0.004	0.036	**19.10***	[84]
Average							**18.71**	

*: Calculation of HHV based on the content parameters of the latter source and Gaur and Reed's equation (1995) ($HHV = 0.35X_C + 1.18X_H - 0.10X_O + 0.02X_S - 0.10X_N - 0.02X_{ash}$)

The average moisture content of the samples harvested was 14.04% in the four years examined, of which the low heating value at harvesting was calculated as follows: LHV = (HHV x (1-M)) - (P x M), where M: moisture content, P: heat of vaporisation of water, LHV: low heating value, HHV: high heating value) = 16.1 GJ t[-1].

Honey also represents added value, the yield of which could even reach 143 kg t[-1] per hectare during flowering between late June and October, if quality parameters are favourable [80]. The value of this product is 144 EUR/ha based on an average Hungarian market price for acacia honey (10.8 EUR t-1).

4.3. Economic calculations

The extra cost of planting is quite significant (2-3.5 EUR t-1) at a lower plant density and with extensive technology, while its production risk is much lower than that of sowing. In the case of very significant plant density (40 000 plants ha^{-1}) and intensive technology, the difference is negligible in favour of planting (0.6 EUR t-1). The production cost of the more safely planted *Sida* increased to its highest level (3.5 EUR t[-1]) with a lower plant density in extensive conditions and with higher plant density in intensive production circumstances as regards the length of the production period (20 years) (Table 9). Production and unit costs are lowest when using the extensive technology of low plant density with plant sowing; therefore, this technology is recommended. This is especially true in the case of purchased sowing seeds, as the difference in costs between sowing and planting seems to be insignificant due to

the much higher price of market seed. The least recommended version is the middle planting density using semi-intensive technology.

Table 9. Economic differences between planting and sowing in relation to planting density.

	10000 pcs/ha*	20000 pcs/ha*	40000 pcs/ha**
Average yield (t DM ha-1)	9.0	8.4	20
Cost of planting EUR ha-1	1565	2170	3382
Cost of sowing EUR ha-1	929	1828	3625
Fertilization EUR ha-1	0	0	140
Plant protection EUR ha-1	78	156	156
Harvesting EUR ha-1	51.6	51.6	51.6
Rental fee EUR ha-1	145	145	145
Overhead costs EUR ha-1	30	41	60
Total cost of planting EUR ha-1	**383**	**502**	**722**
Total cost of sowing EUR ha-1	**351**	**485**	**734**
Difference (%)	9	4	-2
Difference EUR ha-1 yr-1	32	17	-12
Unit cost of Sida (planting) EUR t-1	**42.6**	**59.6**	**36.1**
Unit cost of Sida (sowing) EUR t-1	**39.1**	**57.6**	**36.7**
Difference EUR t-1	3.5	2.0	-0.6

Source: *authors' own experimental data, ** Borkowska and Molas (2012) [32] production data and authors' own costs

Virginia fanpetals can be combusted or gasified without any further processing if we substitute other energy sources for heating. We considered the burning of *Sida* in a stove which is suitable for burning firewood and can be found a typical village household, and we used its efficiency value for our calculations. The above example produces a value of 67-146 EUR t^{-1}, where the lowest savings occur as a result of substituting straw and the highest are related to pellets (Table 10).

Table 10. Cost of processing the dry biomass of Virginia fanpetals.

	Price (1000 HUF per unit)	Heating value (GJ per unit)	HUF per GJ	EUR per GJ	Stove efficiency compared with fossil fuel	Stove efficiency *Sida*	*Sida* theoretical market price EUR per t
Natural gas (1)	100	34	2 941	9.3	0.9	0.8	**131**
Pellet (2)	71	21	3 381	10.7	0.93	0.8	**146**
Briquette (3)	56	19	2 947	9.4	0.85	0.8	**139**
Straw (4)	15	12	1 250	4.0	0.75	0.8	**67**
Firewood (5)	28	14	2 000	6.3	0.8	0.8	**100**

Sources of basic data: 1: [71], 2:[77]:, 3:[76]:, 4:[85], 5:[86], exchange rate: 315 HUF/EUR (www.mnb.hu)

The value of biogas produced from *Sida* was 55 EUR t^{-1} DM, which can be further increased by the possible sales of CO_2 savings (2 EUR t^{-1} *Sida* DM). In addition, *Sida* can be used with higher moisture content for biogas production.

The factors analysed can be taken into consideration for local use (with no transport costs). At the same time, they are many times higher than the production costs of *Sida* when considering any technology or substituted fuel. Ideally (in the case of combustion by substituting pellets), 2 400 EUR t^{-1} can be realised with direct combustion and intensive technology per hectare, while the respective value of extensive technology was 1 107 EUR t^{-1}, which is higher than that of most field crops produced on high quality land.

The production of compressed products (pellets and briquettes), for which increasing market demand can be observed, calls for significant investment costs of around 12 080-12 400 EUR at a production scale of 100 kg h^{-1} (Table 11).

Table 11. Investment costs for the production of compressed *Sida* products.

	Pellet			Briquette		
	Price (EUR) (1)	Operation time (yr) (2)	Depreciation (EUR)	Price (EUR) (3)	Operation time (yr) (2)	Depreciation (EUR) (4)
Press	1 850	3	617	5 500	3	1 833
Matrix	130	1	130			
Cooling system	3 200	20	160			
Drier	6 000	20	300	6 000	20	300
Shredder	900	10	90	900	10	90
Total cost	12 080		1 297	12 400		2 223

Source: (1): [77] (2): expert opinion, (3): [87] (4): [85]

The extra processing cost of pelleting in 2015 is around 101 EUR t^{-1}, while that of briquetting is 111 EUR t^{-1} per year, in addition to the cost of feedstock production (Table 12). The total cost of producing pellets and biobriquettes from *Sida* (including raw material costs) is 137-161 EUR t-1 and 147-171 EUR t-1, respectively, depending on the production technology used.

Considering the market prices of pellets (215 EUR t^{-1}) and briquettes (178 EUR t^{-1}), profit can still be realised, although at much lower level compared to the local use of Virginia fanpetals. However, the return on invested capital in an optimal case can still be expected within 2-3 years.

Table 12. Compression cost of *S. hermaphrodita* (without feedstock costs).

	Pellet	Briquette
Depreciation, EUR per year	1 297	2 223
Electricity, EUR per year (1)	3 380	4 440
Personnel, EUR per year (2)	13 500	13 500
Other costs, EUR per year (3)	2 000	2 000

Total costs, EUR per year	**20 177**	**22 163**
Production costs (EUR per t)	**101**	**111**

Source (1): 16.9 kW and 22.2 kW, 0.1 EUR/kWh [77, 78] (2): 3 persons, 9 month/year employment, 500 EUR/month salary (3): expert opinion

The main characteristics of S. hermaphrodita are summarised in Table 13, based on our own tests and experiments.

Table 13. The main advantages and disadvantages of industrial scale production of *Sida.*

	Advantage	**Disadvantage**
Industrial scale, cost effective propagation technology	*Sida* plantlet cost was 38.4-60.6 Euro cents with the NIT method. This technology is also easily acceptable in industrial- and *small scale* production, and as a result of this technology the plantation can be established safely.	The plantlet production needs a polytunnel or a greenhouse. The rental fees or investment costs fluctuate depending on the conditions prevailing in a given country.
Plantation establishment	The plantation establishment can be carried out with a traditional planting machine/ transplanter. The maintenance of the plantation also does not require any special machines.	The use of seeds needs further innovative mechanization.
Multipurpose utilization	*Sida* can be used as a biomass plant, a fodder crop and for honey production. The seeds' high crude oil- and protein content make them suitable for food, feed or cosmetic purposes	Further studies are needed.
Post-harvest (Processing)	Because of the low moisture content of the biomass at the end of the season, additional drying is not required if the product is used for combustion.	The costs of post-harvest processing (biogas production, pelleting etc.) considerably reduce the expected profit.
Profitability	Based on our calculations, the expected profit was 63-846 € ha^{-1} (7-94 € t^{-1}) depending on the technology used. Additionally, honey production can produce a profit of 15.40-20.20 € (144 € t^{-1}) per hectare.	
Environmental impacts	In addition to the favourable environmental impacts of biomass plants in general, many literature sources report that *Sida* can recultivate polluted land.	*Sida* has some polyphagous phytopathogen fungi (*Sclerotinia sp., Fusarium sp, Rhizoctonia sp.*), which can survive in the plant's vegetative remains (stems, roots).

Source: authors' composition, based on their own tests and results

5. Discussion

5.1. Efficiency of plantlet production methods

This experiment verified the authors' previous hypothesis that the nurse-in-tray plantlet production and unprotected wintering (Nurse in Tray Method) of Virginia fanpetals with properly pre-treated seeds can be developed into an economical and safe new propagation method. Plantlet production can be performed near large-scale plots with low investment costs (38.4-60.6 Euro cents per plantlet) based on the calculated data. Firstly, there are no heating costs, and this phytotechnique can be easily and appropriately mechanized. Secondly, with this method, it is possible to produce plantlets with a hardened and strong root system. Furthermore, such plantlets can be planted easily with typical planting equipment. In addition, the large-scale transportation of plantlets can be flexibly adjusted and the planting can even be carried out over almost the entire year. The maintenance costs of the so-called UD (ultra-dense) planting are insignificant. The propagation material needed for 1 ha can be produced on a very small plot (70 m^2), while a high plant density prevents weeds from growing.

5.2. Estimated yield of Sida hermaphrodita

In the second year, a yield of 10.2 – 11.8 DM ha^{-1} was achieved without fertilisation by using extensive technology. This value falls within the yield range referred to in bibliographical sources. The soil exhaustion impact of a higher plant density (20 000 plants per hectare) was increasingly noticeable in years following planting. At the same time, the yield obtained with a plant density of 10 000 plants per hectare remained basically unchanged in the three subsequent years. In addition, the wide spacing can make it easier to control weeds mechanically in the early vegetative period of Virginia fanpetals. However, when using extensive technology, organic manure application is recommended in order to provide long-term maintenance. Several studies have highlighted the tolerance of *Sida* to soils contaminated with heavy metals or treated with sewage sludge, so *Sida* can play a significant role in the reclamation of contaminated soils with a high organic matter content. Also, Virginia fanpetals plantations are appropriate locations for disposing of sewage sludge produced in large volumes. With regard to fertilization, the digested manure was obtained from a commercially operating biogas plant using maize silage as feedstock, providing an opportunity for sustainable soil management. Instead of using organic substance mineral fertilizers digested manure may increase the yields and contribute to carbon sequestration in soil, but the high energy consumption for the feedstock production has an overall adverse effect. Moreover, Krzyżaniak et al. (2018) suggest that using fertilizers in general at a rate equivalent to 170 kg ha^{-1} N may not be justified because of a high impact on freshwater eutrophication and acidification [88].

5.3. Economic calculations

The calculated cost of the production of an extra ton of yield with fertilisation is around 13.8 EUR. For this reason, high quality land fertilisation could also be economically justified in the dosage (218 kg ha^{-1} NPK) reported by Borkowska et al. [32], if the other factors of intensive technology are also provided. As is shown in the experiments, the use of local organic manure (mainly wastewater and sewage sludge) is much more justified on marginal land, in order to decrease the pressure on prime cropland for food security reasons.

According to the authors' economic calculations, the production cost of *Sida* over a 20-year life cycle fluctuated between 36 and 60 EUR t^{-1} DM, depending on the production technology used.

For some additional cost, planting made yields much safer with both extensive and semi-intensive technology. At the same time, revenue exceeded production costs in all scenarios, excluding the semi-intensive production of *Sida* technology for biogas production. The expected profits are the following:

- combustion: 70-94 EUR t^{-1}
- biogas: (-)6-(+)18 EUR t^{-1} (+2 EUR t^{-1} CO_2 value)
- pelleting: 54-78 EUR t^{-1}
- briquetting: 7-31 EUR t^{-1}
- honey production: 144 EUR t^{-1} (if it is used for any other purpose)

According to this study, the production cost of Virginia fanpetals was between 36 and 60 EUR t^{-1} in Hungarian economic conditions. Based on Polish data, the structure of the direct production cost of *Sida* can be broken down as follows: seedlings 28.2%; plant protection 1%; chemicals 12.4%, mechanized methods 35.7%; human labour 3.7% [89]. Our experiments are similar, but labour is included in the related working operations, and we considered the rental fee of land – which, at 20-40% is a very significant cost element – as a direct cost.

The profitability of *Sida* plantations is moderate compared to other energy crops, due to the more unfavourable production conditions. In 2009, the total amount of these potential revenues on surveyed plantations of willow amounted to 107 €/ha/year, while for miscanthus the figure was 171-202 €/ha/year and for *Sida hermaphrodita* 79-92 € /ha/year without payments and subsidies in Poland [89].

6. Conclusions

In accordance with the experiments, the cost of nurse-in-tray technology seems to be significantly cheaper, (38.4-60.6 Euro cent) compared to market plantlet prices. In addition, nurse-in-tray technology proved to be more reliable than sowing.

Based on the calculated biomass production of different dense plantations, the soil depletion impact of higher plant densities (13 300 and 20 000 plants per hectare) was increasingly evident; consequently, the biomass production decreased considerably (from 10.2 and 11.9 t ha-1 to 5.6 and 7.2 t ha-1) in the years following planting. At the same time, the yield obtained with a plant density of 10 000 plants per hectare decreased only slightly (11.2 and 9.4 t ha-1) in the three years studied. Accordingly, with extensive technology, a wide plant density is recommended, although land fertilization could also be economically justified at a sufficient dosage and in the appropriate form.

Overall, the agrotechnology applied (production method, plant density and inputs used, in particular fertilization) basically determines the production cost of Sida, while the substituted energy source for heating determines the savings by substituting other energy sources and the capital requirement, and thus producing the economic results. These can result in a production cost difference of up to 20,000 HUF / tonne.

Based on this study's economic calculations, the production costs of *Sida* plantation over a 20 year life cycle are significantly lower than the revenue they produce under Hungarian economic conditions. Planting made the establishment of Virginia fanpetals plantations safer, although it incurs some extra costs. Consequently, the production of Virginia fanpetals can be highly economical for farmers farming marginal land with the application of organic manure and with biogas plants in operation. Another option is crop production with a high heat demand, as well as beekeeping activities.

Acknowledgments

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