# SIDATIM: ASSESSING THE POTENTIAL OF NEW BIOMASS CROPS AND VALUABLE TIMBER TREES IN AGROFORESTRY SYSTEMS

Paris P[4*], Augusti A[4], Burgess P[5], Bury M[6], Chiocchini F[4], Cumplido-Marin L[5], Facciotto G[3], Chiarabaglio PM[3], Graves A[5], Lauteri M[4], Leonardi L[4], Martens R[2], Morhart C[1], Rossi AE[3], Tarchi M[7], Nahm M[1]

(1) Albert-Ludwigs-University, Freiburg, Germany (2) 3N Centre of Experts-Lower Saxony Network for Renewable Resources, Werlte, Germany (3) Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA) - Research Centre for Forestry and Wood Casale M, Italy (4) CNR-Institute of Agro-environmental and Forest Biology, Porano, Italy (5) Cranfield University, Cranfield, UK (6) West Pomeranian University of Technology, Szczecin, Poland (7) W2 Agency, Osimo, Italy

*Corresponding author: piero.paris@ibaf.cnr.it


## Abstract

The SidaTim project is investigating new pathways for biomass production for a circular bio-based economy. Part of the project activities are focused on two new bioenergy crops, *Sida hermaphrodita* and *Siphium perfoliatum*, both perennial herbaceous crops, not native to Europe. Sida can produce both biomass for biogas, when freshly harvested with leaves, and “woody” biomass during the dormant season with a moisture content lower than 30%. Silphium can be used as an alternative biogas feedstock to maize, with a water use efficiency higher than the latter in dry seasons. A network of experimental plots was established in 2016 and 2017 in Poland, Germany, the UK, and Italy, comparing Sida and Silphium to maize and *Salicaceae* short rotation coppice. Preliminary results from experimental plots are presented here, along with ecophysiology measurements and biodiversity test. Research activity is being continued concerning the two novel crops on yield, ecology, biodiversity impacts, and their economic integration into agroforestry systems.


**Keywords**: combustion biomass; biodiversity; biogas; drought adaptation; *Sida hermaphrodita*; *Silphium perfoliatum*

## Introduction

Current production methods of producing wood from forests and of crops from agriculture are unlikely to meet the multiple demands put on biomass for food, feed, bioenergy, timber, fibres, and bioplastics within a future circular bio-economy (Morhart et al. 2014). For example, the principal feedstock for much biogas production in Europe is maize (*Zea mays*), which can cover more than 50% of agricultural land in some regions, leading to ecological degradation. Fast growing tree plantations are often not financially attractive to farmers because of their low profitability and lack of flexibility in response to market variation. Hence, new land use



iomass for the address these issues, with more efficient use of environmental resources and management inputs, whilst providing ecosystem services. New multipurpose biomass crops, which can be easily adapted to standard farm management and market variation, are also required in a future circular bio-economy. The FACCE SURPLUS sponsored project SidaTim (www.sidatim.eu/en) aims to strengthen the circular bio-economy by researching and promoting new land use concepts that comprise innovative multipurpose plant species and novel agricultural management approaches. SidaTim consists of two research pillars (RP). RP1 is assessing the performance of *Sida hermaphrodita* (Sida), a promising multipurpose plant that has received little attention until recently. Potential uses of Sida include: energy provision through both direct combustion of the stem biomass (up to 15 Mg dry matter (dm) ha$^{-1}$ year$^{-1}$ with a moisture rate at harvest <30%) and biogas production from the stems and leaves (up to 25 Mg dm ha$^{-1}$ per year with two harvests; Jablonowski et al. 2017); pollinator food, and use as a material for fibre products, and particle and insulation boards (Nahm and Morhart 2018). Along with Sida, *Silphium perfoliatum* (Silphium) is also being investigated as a promising feedstock for biogas production (Bauböck et al. 2014). It is a perennial plant native to temperate Northern America. Silphium is particularly suitable as an energy crop owing to its low maintenance requirements (lasting up to 15 years without replanting) and high biomass and thus, biogas yields. Additionally, Silphium is an important source of food for pollinating insects (Gansberger et al. 2015).

RP2 is advancing knowledge about the production of valuable timber on agricultural land, particularly along field boundaries. The final objective of the project is to merge the two RPs by assessing and modelling the economic and ecological potential of growing Sida in combination with valuable timber trees. The present contribution focuses on RP1. It presents the preliminary findings obtained by the project so far on: i) Sida and Silphium growth in a network of experimental plots in Europe; ii) eco-physiological characteristics of Sida, and; iii) the ecological values of Sida and Silphium, using a Biological Soil Quality Index.

## Experimental plots

Five experimental plots were established by the project in: Poland (53.20°N; 14.58°E), Germany (52.85°N; 7.67°E), the UK (52.07°N; -0.63°E), northern (45.13°N; 8.51°E) and central Italy (41.95°N; 14,78°E). Climate conditions range from sea-continental-warm humid in Poland, to temperate oceanic in Germany and the UK, and to humid-subtropical in Italy. Plots were established in both 2016 and 2017 due to procurement challenges. Experimental designs consist of randomized blocks, for comparing two Sida provenances (Sida 1 and 2, grown from parent stocks in northern and southern Germany, respectively) and one Silphium provenance with two planting methods (sowing and seedling transplanting) and two harvesting methods (for biogas and biomass production). Sida and Silphium seedlings were planted at 44,000 plants $ha^{-1}$. In some experimental areas the novel crops were compared to reference crops such as maize and short rotation willow coppice (SRC).

In Lipnik, Poland, the average annual temperature was 8.5°C, with an annual precipitation of 555 mm, which peaks in summer. The soil texture was sandy (72% sand) with an acid pH. Two experimental fields were established in 2016. The reference crop is Salix SRC with 44,000 plants $ha^{-1}$.

In the UK, an experimental area was established in the early part of 2017 near Silsoe, Bedfordshire. The soil was ploughed and harrowed in March 2017, and fenced during May 2017. Silphium and Sida were then planted during June-July 2017 .The Silphium plants, both those planted as seedlings and those sown directly from seed, grew well forming rosettes, and finished 2017 having reached growth stage 3, according to the general BBCH-scale (Jablonowski et al. 2017).

In Germany, at the experimental area of Werlte, the average temperature is 9°C, with the annual precipitation of 768 mm with a summer peak. Soil texture is sandy (76% sand) and acidic (pH = 5.6). The experimental field for the project SidaTim was established in 2016. In this site the reference crop is Silphium planted in 2010 (the oldest Silphium test field in Germany with an annual average yield of 13.1 dm $ha^{-1}$).

In northern Italy, in the experimental field of Casale the average annual temperature was 12.5°C, with an annual precipitation of 784 mm and a dry period in July. The soil texture was sandy loam with a pH of 7.8-8.0. Experimental plots were established in spring to summer 2016. The reference bioenergy crop was poplar SRC (10,000 cuttings $ha^{-1}$), with two different harvesting cycles (one and two year). During the growth phase of 2016, Sida1 and 2 were harvested once for biogas and biomass.

In central Italy, in the experimental area of Montenero the average temperature was 17.5°C, with an annual precipitation of 364 mm and a dry period from May to September (monthly reference evapotranspiration varies between 110-150 mm and precipitation is about 23 mm per month). Soil texture was clayey (44% clay) with an alkaline pH. Experimental plots were established during spring and summer in 2017. A sowing treatment was not used for Sida and Silphium, as during preliminary testing, its inefficacy for the local site and seasonal conditions had become evident. The reference bioenergy crop was silage maize, sown at a density of 84,000 seeds $ha^{-1}$.

## Preliminary results of experimental plots

In Poland, during the growth phase in 2016-17, Sida and Silphium were harvested once: for biogas, the average yield was 3.1 Mg dm $ha^{-1}$, with the highest yield being for Sida1 of 4.5 Mg dm $ha^{-1}$ without any marked difference between seed or seedling planting methods. In 2017, two harvests for biogas were taken in June and October. Sida1 produced 14.4 Mg dm $ha^{-1}$, and Silphium produced 25.6 Mg dm $ha^{-1}$.

In the UK, the Sida plants that had been established using seedlings grew well, and reached growth stages 3-7. However, the sown Sida plants generally failed to grow, possibly as sowing had been later than is ideal. Those that did grow reached only growth stage 1. In November 2017 a white fungal infection, probably *Sclerotinia sclerotiorum* was noticed on those Sida plants that had been established as seedlings. Yield results have been recorded and the results are currently being analyzed.

In Germany, marked differences were found between the two planting methods (5.7 vs 13.7 Mg dm $ha^{-1}$ for seed and seedling, respectively), with an annual yield for the first growing season reaching a maximum yield of 16 Mg dm $ha^{-1}$ for Sida2.

In northern Italy, for biomass (January 2017), the average annual yield was 1.9 Mg dm $ha^{-1}$, with a marked difference in yields between the seed and seedling planting methods (0.54 and 3.20 Mg dm $ha^{-1}$ $year^{-1}$, respectively). In 2017, two biogas harvests were taken in July and October. When planted as seedlings, Sida1 produced 11.2 Mg dm $ha^{-1}$, and Silphium 14.4 Mg dm $ha^{-1}$. The yield difference between seedling and seed treatments was very large particularly for Sida. Poplar yield, in a two year cycle, was estimated to be 33.4 Mg dm $ha^{-1}$ after the first two growing seasons, and for a one year cycle it was estimated to be 5.7 Mg dm $ha^{-1}$ in the second year. For Sida and Silphium harvested for biomass production, the yield was 7.1 and 10.3 Mg dm $ha^{-1}$ $year^{-1}$ in October 2017.

For the experimental plots in central Italy, so far, data for biogas production are available, with Sida1 being harvested in late August 2017 after 90 days of cultivation, producing 4.6 Mg dm $ha^{-1}$, while the maize yield was 18.4 Mg dm $ha^{-1}$. Drip irrigation was used for both crops, with 225 and 340 mm being applied to Sida1 and maize respectively. A first estimation of the irrigation use efficiency is 23 and 54 kg dm $(ha\ mm)^{-1}$ for Sida1 and maize respectively. Further collection of data and data analysis are in progress.

## Ecophysiological performance of Sida

A greenhouse experiment was set up during the summer 2016 at CNR-IBAF in Porano, Italy, to characterise the ecophysiological performance of Sida under drought stress.

Sida seedlings were transplanted in 25 l pots on the 16th of June, adopting two planting densities, 1 or 2 seedlings per pot, in order to evaluate the effects of plant competition. After one month, water stress was applied by an 80% reduction of irrigation. Photosynthesis and predawn leaf water potential ($\Psi_{PD}$) were measured after one week from drought imposition. After two weeks from drought imposition, the total above ground biomass was collected to measure plant productivity and carbon (C) and nitrogen (N) contents and isotope compositions.

Control plants showed a mean assimilation rate (*A*) of about 15 µmol $CO_2$ $m^{-2}$ $s^{-1}$. On average, water stress decreased *A* by about 18% compared to control, despite a decrease in stomatal conductance ($g_s$) of about 72% and a decrease of around 54% in $\Psi_{PD}$. These figures were similar for both plant densities, indicating a similar increment of intrinsic water-use efficiency. When considering single plant biomass, control plant yields were about 60.0 g for the low density treatment vs 37.8 g for the high density treatment. When considering control plant biomass on a pot basis, the high density treatment showed a value as high as 75.7 g. Drought stress caused a decrease in dry matter production of 38 and 53% for low and high density treatments, respectively. Nevertheless, in the drought treatment, the amount of biomass produced on a pot basis was about 36 g, irrespective of the plant density.

The C and N contents in Sida leaves did not show any remarkable variation, irrespective of plant density and watering treatment. On the contrary, carbon isotope composition measured on leaf material showed enriched values in drought conditions compared to control ones. As expected, this result is associated to lower *A* rates, owing to the negative effect of water shortage on $g_s$. Our results indicate that drought effectively decreases Sida productivity. However, increasing plant density did not cause further biomass decrease under drought. Finally, it is noteworthy that, in control conditions, increasing plant density is associated with a higher productivity.

## Biodiversity

The Biological Soil Quality Index (BSQ) is based on the evaluation of the community of soil arthropods in the first 10 cm of the soil: these invertebrates are particularly sensitive to soil quality and therefore to human activities (Andrews et al. 2002). In the experimental field in Casale, during the second year, three soil samples about 1 kg were collected for Sida1 and 2, Silphium, poplar and, as a reference, in an agricultural crop (maize) and in a natural forest near to the experimental field. The soil samples of the four sampling sessions were subjected to dynamic extraction of arthropods. In order to calculate BSQ, the eco-morphological indices were assigned to each arthropod extracted. The results obtained show that Sida, Silphium and poplar have a very similar BSQ, while that of maize is slightly lower, and that of natural forest has the highest value. The results of the fourth sampling session indicate that maize has the lowest value (55) whereas Silphium, Sida and poplar are a little higher (respectively 69, 80 and 91). All the data obtained in the cultivated land were much lower compared to natural forest where the index reached a value of 173.

## Preliminary conclusions

Given the necessity to replace fossil fuels with renewable energy sources, it seems likely that the interest in Sida and Silphium will increase further, as they combine high biomass productivity with ecologically valuable effects when grown in appropriate climate conditions. It will be interesting to evaluate the biomass productivity of these plants in the coming years, as it is known that both Sida and Silphium productivity increases considerably after the first years of growth (Gansberger et al. 2015; Nahm and Morhart 2018).

At present, however, different important research gaps need to be addressed in addition to collecting further data on yield productivity, thermophysical properties, and the management cost of the examined plant species. For example, Sida and Silphium are neophytes in Europe, and it is of crucial importance to assess their competitive and invasive potentials, as well as their susceptibility to *Sclerotinia sclerotiorum.*

## Acknowledgements

SidaTim Project has received funding from the European Union's Horizon 2020, grant agreement No 652615 (FACCE-JPI). Funding is provide to each partner by national agencies (see https://www.sidatim.eu/en/)

## References

Andrews SS, Karlen DL, Mitchell JP (2002) A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agric Ecosyst Environ 90: 25-45.

Bauböck R, Karpenstein-Machan M and Kappas M (2014) Computing the biomass potentials for maize and two alternative energy crops, triticale and cup plant, with the crop model BioSTAR in the region of Hannover (Germany). Environ Sci Europe 26: 19-31.

Gansberger M, Montgomery LFR, Liebhard P (2015). Botanical characteristics, crop management and potential of *Silphium perfoliatum* L. as a renewable resource for biogas production: A review. Ind Crop Prod 63: 362–372.

Jablonowski ND, Kollmann T, Nabel M, Damm T, Klose H, Muller M, Blasing M, Seebold S, Krafft S, Kuperjans I, Dahmen M, Schurr U (2017) Valorization of Sida (*Sida hermaphrodita*) biomass for multiple energy purposes. GCB Bioenergy 9: 202-214.

Morhart CD, Douglas GC, Dupraz C, Graves AR, Nahm M, Paris P, Sater UH, Sheppard J, Spiecker H (2014) Alley coppice—a new system with ancient roots. Ann For Sci 71: 527-542.

Nahm M, Morhart C (2018) Virginia mallow (*Sida hermaphrodita* (L.) Rusby) as perennial multipurpose crop: Biomass yields, energetic valorization, utilization potentials, and management perspectives. GCB Bioenergy, doi: 10.1111/gcbb.12501.