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Field Trials Indicating the Potential of *Abutilon Theophrasti* (Medic.) As A New Fiber Crop in Southwest Germany

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Abstract

Natural fibre based composites are being used more frequently in the automotive industry because of their positive characteristics. Fibres currently used and mostly imported to Europe do not sufficiently meet all the demands for natural fibres. As a new fibre plant velvetleaf (*Abutilon theophrasti)* has been taken into consideration. However, there is no knowledge about the cultivation of velvetleaf in Europe.

Four field trials in southwest Germany were set up to investigate the potential of fibre yield in a temperate climate. The factors crop density, nitrogen fertilization, accessions, and different harvesting dates were tested.

Across all experiments fibre yield ranged from 0.4 to 1.5 t ha^{-1} dry matter. The highest yields were achieved with a crop density of 30 plants m^{-2}, and with N fertilization of 100-150 kg N ha^{-1} for the accession 'Herbiseed'. For highest fibre yield, the date of harvest should be at the beginning of maturity.

This study provides first insights into possibility and variation of cultivating velvetleaf and suggests adequate fibre yield when cultivated in proper plant density and appropriate accession. However, before the plant can be implemented as a new crop, more research on fibre quality and breeding activity to improve agronomic factors is required.

Indexing terms/Keywords: Biomass, Fibre Yield, Natural Fibres, Plant Height, Velvetleaf

Subject Classification: Industrial crops

Type (Method/Approach): Field experiments with four different factors for determining the potential of fibre yield

Introduction

Natural fibres which may improve the environmental quality of technical products attract public attention. Due to their biodegradability, natural fibres are considered environmentally friendly [1] and they can be used for textile purpose as well as for industrial use. Especially the automotive industry uses bio-based fibre composites more frequently [2–5]. With regard to the directive of the European Parliament and Council on end-of-life vehicles [6], which prescribe reuse and recycling of 95% for vehicles build from 2015 onwards, the use of bio-based composites is therefore a necessity. Typical fibre plants used for the production of composites are flax (*Linum usitatissimum*), hemp (*Cannabis sativa*), kenaf (*Hibiscus cannabinus*), and cotton (*Gossypium hirsutum*) which are currently not or not mainly cultivated in Germany but partly in different European countries [7] or elsewhere in the world. For the automotive industry the consistent quality of the fibres and also economic aspects are of special interest. The cultivation of fibre plants in the country where they are used, reduces high ecological and economical costs. However, cultivation is geographically limited depending on the fibre plant and their specific requirements. Furthermore, mostly one type of fibre cannot meet all the requirements of the automotive industry. Therefore, fibres from different fibre plants are blended to achieve a multitude of end products with varying properties [8]. The European automotive industry already used a total volume of 80,000 t of wood (38%) and natural fibres for the production of composites in 2012 [9]. With increasing interest and further research and development, an increased amount of natural fibres will be used in the future [9]. The establishment of a new fibre plant in Germany could be a solution to meet the demand with regard to the improvement and variation of the properties of the end product as well as to reduce the dependency on fibre imports.

Abutilon theophrasti (velvetleaf) could be such an alternative. Velvetleaf is an annual plant belonging to the family of Malvaceae, which can reach a height of up to 4 m under optimal growing conditions [10]. The origin of the plant is China or India, where it is traditionally used as a fibre plant [10–12]. However, findings of carbonized seeds in Hungary make the origin questionable [13]. In Germany, velvetleaf is considered a weedy neophyte on many arable fields. The seeds first came to Europe, especially Germany, with imported animal feed [14,15]. The plant is described as having a good ability to adapt to different habitats [16]. Furthermore, velvetleaf could grow on several types of soil [17] which might suggest it could also grow on marginal land [11,18] and thus might not have to compete with food production. However, velvetleaf is not yet cultivated in central Europe. First studies by the authors [19] showed the general potential for cultivation. Fibre yield of velvetleaf similar to that of flax can be achieved, and also the fibre properties turned out to be of appropriate quality. There is still information missing on how agronomic factors affect fibre yield, and thus how to increase the fibre yield and quality under Central European conditions.

As known from other plants, for example kenaf, increasing crop density increases plant height [20]. Taller plants (in connection with small stem diameter) would lead to an increase in primary fibres and thus increase the stability of the plant [21]. The first hypothesis is that higher plant density results in taller plants, and consequently in higher fibre yield. Furthermore, other fibre plants, like hemp [22,23] and kenaf [20,24], show a positive response to the application of nitrogen. Thus, the second hypothesis states that higher availability of nitrogen leads to taller plants and therefore higher fibre yield. Additionally, the choice of accession is always crucial. In contrast to plants used for fibre production [25], the volunteer plants in Germany are short in height and produce many branches. The ideal type, however, would be a plant with an erect stem and no branching. Another precondition for high fibre yield might be the optimum date of harvest. It is hypothesized that fibre production of the plant is completed when maturity of the seeds begins. The aim of the study is for the first time to vary and test different agronomic factors influencing the production of velvetleaf in a field experiment in a temperate climate obtaining a high fibre yield.

Field trials at three different sites in three years (2015-2017) were conducted in Bingen/Rhein (Germany). Four different factors were examined: plant density, nitrogen fertilization, accessions, and the date of harvest. All trials were analysed for plant height, biomass yield, and fibre yield.

Materials and Methods

Experimental fields

Field trials were set up in Bingen/Rhein in southwest Germany (49°95´11´´N, 7°92´71´´E; 100 m altitude) in 2015, 2016, and 2017. In each year all trials were conducted on another field (F1, F2, F3) in the same location. The fields varied in soil properties, particularly in the content of soil mineral nitrogen (Tab. 1). The phosphate content was at a raised level at F1 and F2 (25 and 24 mg 100 g soil^{-1}). On site F3 phosphate content was at a medium level (11 mg 100 g soil^{-1}).

Table 1. Location, type of soil, mineral soil N contents and soil pH value of the three fields used for trials in 2015, 2016, and 2017.

field	F1	F2	F3
year	2015	2016	2017
location	Bingen/Rhein	Bingen/Rhein	Bingen/Rhein
type of soil	loamy sand	sandy loam	sandy loam
N_{min} (kg ha^{-1})	57	144	33
analysed	19.03.2015	10.03.2016	02.03.2017
soil pH ($CaCl_2$)	6.8	7.3	7.0

Long-term (1981-2010) average temperature and precipitation was 10.5 °C and 546 mm, respectively [26]. The average annual temperature for the experimental sites was 11.7 °C in 2015, 11 °C in 2016, and 11.2 °C in 2017. The annual precipitation was 351 mm in 2015, 560 mm in 2016, and 496 mm in 2017. The course of mean temperature and total precipitation for all experimental years is depicted in Fig. 1. Compared with temperatures during the growing season (March/April to September) in 2016 and 2017, the average temperature was higher in 2015 (on average 18.4 °C in 2015 vs. 17.1 and 16.8 °C in 2016 and 2017, respectively). The daily minimum temperature during growing season ranged from -4.4 °C in April 2017 to -0.1 °C in April 2015, while the maximum temperature varied from 36.3 °C in June 2017 and August 2016 to 40.1 °C in July 2015. Precipitation in the growing season 2015 was lower (127 mm) than in 2016 and 2017 (251 and 262 mm, respectively; Fig. 1).

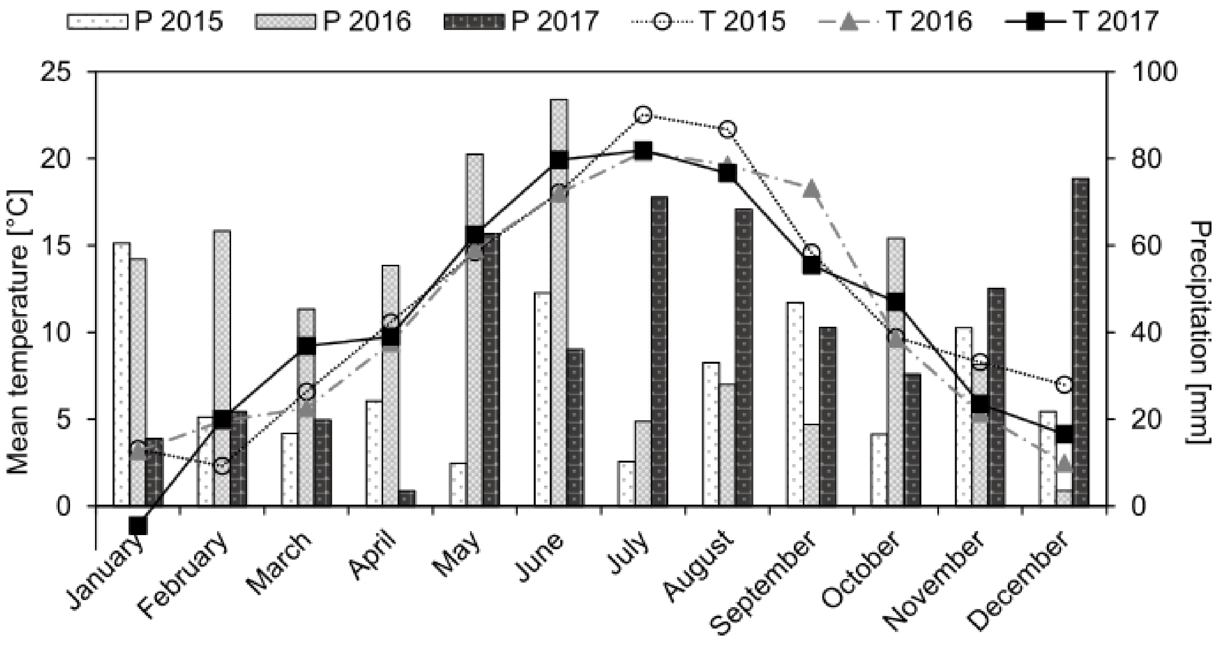


Figure 1. Mean temperature (T, °C) and precipitation (P, mm) per month in the years 2015, 2016 and 2017 in Bingen/Rhein. Data was obtained from the Bingen-Gaulsheim weather station (88 m altitude; approx. 3.8 km from the experimental fields; [26]).

Experimental Setup

Four trials were set up, each of them in a one-factorial randomised block design with four replicates. Experimental factors were (1) crop density (10, 15, 20, 30, 40 plants m^{-2}), (2) fertilization (0, 50, 100, 150 kg N ha^{-1} (incl. N_{min})), (3) accession, and (4) date of harvest (August – October). The used accession of velvetleaf for trials 1, 2, and 4 was obtained from the company Herbiseed in the UK (New Farm, Mire Lane, West End, Twyford, England RG10 0NJ) and is called 'Herbiseed' in the following. Other accessions of velvetleaf were provided by University of Hohenheim, Institute of Weed Science (360b) which comprise seed samples from China (3), Korea (3), Germany (39), and the Czech Republic (42; field samples). Due to the low number of seeds, the seeds of the different accessions were germinated in the greenhouse and were transplanted in small plots (1x1.5 m) at 2-4 leaf stage on site F1 in 2015. For further investigation of accessions six populations (H1- Steinbrück/Lower Saxony; H2- Kriepitz/Saxony; H3- Cunnersdorf/Saxony; H4- Wesseling/North Rhine-Westphalia; H5- Jiřice/Czech Republic; H6- Weilerswist/North Rhine-Westphalia; H7- England) with different plant habitus and fibre yield were chosen. During maturity, seeds of these accessions were collected and used for the field trial conducted in 2016 and 2017.

The plot size was 8 x 1.5 m (12 m^2) with an inter-row spacing of 0.15 m, except trial 4 (0.5 m row spacing). In trial 4 the inter-row spacing was 0.5 m to improve the accessibility to follow the ripening process in the field on a single plant basis. Seeding was performed by a plot drill with a seed rate twice as high as the final plant density. At two-leaf stage the plants of trials 2 and 4 were thinned by hand to 20 plants m^{-2}, and in trial 1 to the intended plant density. In trial 3 in 2016, plants were not directly sown in the field due to the low number of seeds. Plantlets were raised in the greenhouse and transplanted in the field with a density of 25 plants m^{-2} (due to planting machine). Seeds from these plants were collected and used for machine sowing in trial 3 in 2017 (25 plants m^{-2}).

The different treatments, sowing dates, and the dates of harvest for all the experiments conducted over the three years are depict in Tab. 2.

Table 2. Treatments, sowing dates and dates of harvest of the four experiments over two and three years for investigation of yield properties of *Abutilon theophrasti*, respectively.

	Trial 1	Trial 2	Trial 3	Trial 4
factor	plant density [m^{-2}]	nitrogen fertilization [kg N ha^{-1}]	accessions	harvesting time
levels	10, 15, 20, 30, 40	0, 50, 100, 150	H1, H2, H3, H4, H5, H6, H7 (Herbiseed)	end of August to beginning of October, about every two weeks
Sowing time	20.03.2015, 11.04.2016, 27.03.2017	20.03.2015, 10.04.2017	04.04.2016 (planted), 27.03.2017	20.03.2015, 11.04.2016, 10.04.2017
Harvesting time	22.09.2015, 13.09.2016, 11.09.2017	14.09.2015, 13.09.2017	12.09.2016, 13.09.2017	25.08., 07.09., 24.09., 05.10.2015; 26.08., 09.09., 23.09., 07.10.2016; 29.08., 13.09., 02.10., 16.10.2017

Nitrogen fertilizer was applied at two leaf stage and after thinning of the plants in 2015 and 2017 in form of calcium ammonium nitrate (CAN) in trials 1, 3, and 4. The total nitrogen application in these trials was 130 kg N ha^{-1} including mineral soil N (57 and 33 kg N ha^{-1} in 2015 and 2017, respectively).

For chemical weed control a combination of Metamitron (700 g kg^{-1}) and Ethofumesat (151 g L^{-1}) + Phenmedipham (75 g L^{-1}) + Desmedipham (25 g L^{-1}) at a rate of 1 L ha^{-1} each (200 L ha^{-1} water) was applied up to three times during April and May (for all experiments in all experimental years). Surviving weeds were removed manually. Relevant pests or diseases did not occur in all three years.

In trial 1, in addition to the different plant densities, a plant density of 30 plants m^{-2} with and without additional irrigation was trialled. This was done plot specific (randomized) by drip irrigation at five to six days (each about eight hours) in a period from July till August. Adjusted to the plants needs to avoid drought stress, three L m^{-2} h^{-1} were provided.

Plant height was determined before harvest (stage maturity) by measuring 5 randomly selected plants per plot (measured from the soil surface to highest point of the plant).

At the stage when most parts of the plants had reached maturity (BBCH 89; [27]), they were harvested with a brush saw approximately 5 cm above the soil surface (date of harvest in Tab. 1). To determine the total aboveground biomass, all plants per plot were weighted. Samples of each plot were taken for dry matter (DM) and fibre content determination. Samples were dried for 24 h at 105 °C in a drying oven to determine dry matter. The fibre yield was calculated by biomass yield (stem, branches with leaves and capsules) and fibre content. Fibre content was achieved by chemical fibre extraction in 2015 and 2016 (not analysed in 2017). The method is based on the fibre extraction method of Reddy and Yang [28] and Sankari [29]. After harvest, a total of 20 stems per plot were selected randomly, leafs and capsules were cut off and all stems were cut into pieces of 20 cm in length. After the stems of each sample were mixed up, two randomly chosen samples of 110 g each were taken, and oven dried at 60 °C for 24 h to determine the dry matter. In order to obtain the bark after drying, the stems were boiled in tap water for one hour. Afterwards the bark and the fibres included therein could be removed manually from the stem and yielded approximately 20 to 30 g of bark DM after drying for 24 h at 60 °C. Subsequently, the bark was boiled in 0.4% sodium hydroxide solution (NaOH) for 45 minutes to obtain the pure fibres. To remove any remaining NaOH solution and most of the dissolved substances after boiling, the material was washed with a jet of tap water and washed in a washing machine afterwards (30 °C, 500 r min^{-1}). The samples were washed in small laundry bags (25 cm x 40 cm) with a mesh width of 3 mm to separate the samples during the washing process. After washing in the washing machine, pure fibres were obtained and dried at 60 °C for 24 h to determine the fibre DM.

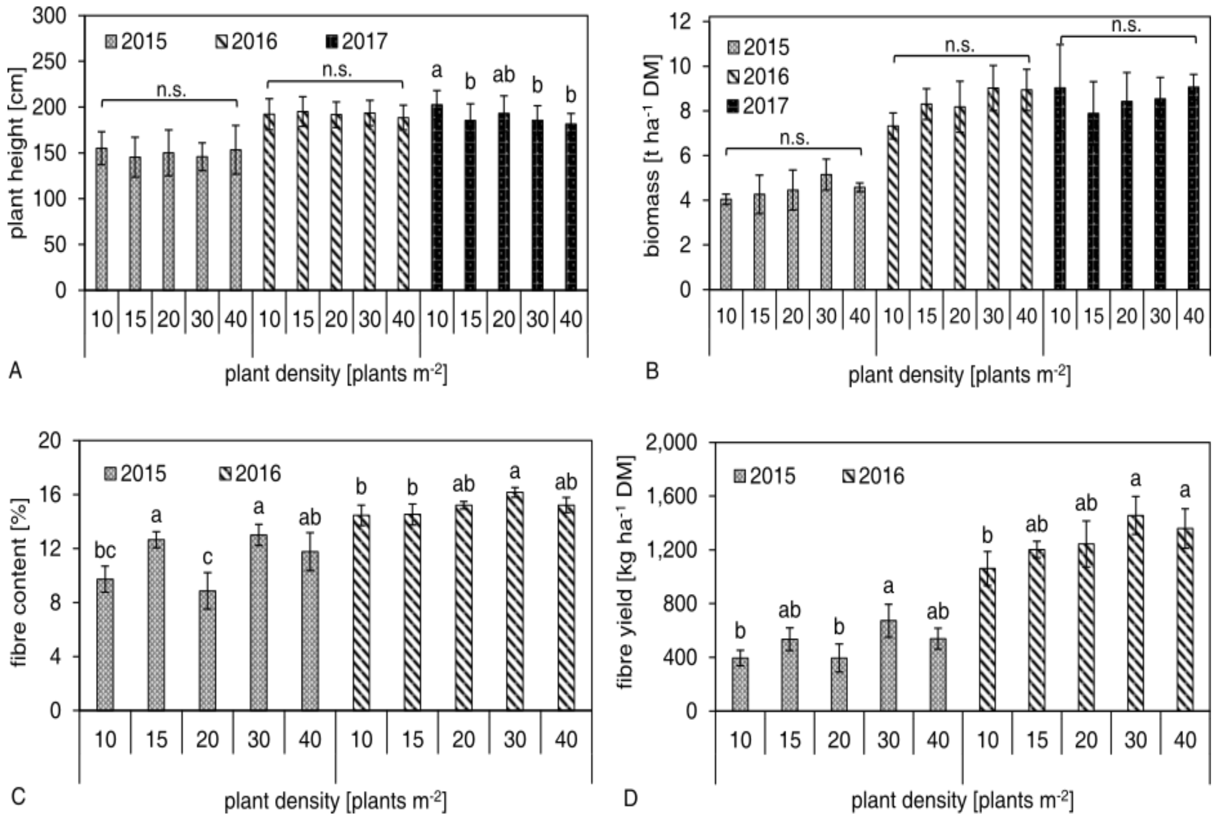
Statistics

Data were analysed by the statistical analysis software R statistics (version 3.3.1 (2016-06-21)). Each of the four trials was analysed separately. Following the tests for normality and homogeneity of variances, an analysis of variances was conducted. Differences were identified at $p \leq 0.05$. The significant differences between the treatments were calculated with Tukey HSD test ($\alpha = 0.05$). Different letters showed significant differences within each experimental year.

Results

Influence of plant density on morphology and yield of velvetleaf Plant height of velvetleaf varied between 145 and 202 cm across all experimental years and plant densities (Fig. 2 A). In 2015 plant height was lower compared to plant height in 2016 and 2017. There were no statistically significant differences between different plant densities in 2015 and also 2016. In 2017 plant height was significantly highest (203 cm) if plant density was at 10 plants m^{-2}. Furthermore, the biomass achieved was lowest in 2015 (average 4.49 t ha^{-1} DM; Fig. 2 B). Significant differences in biomass yield depending on plant density could not be detected. Biomass yield in 2015 and 2016 was highest for a plant density of 30 plants m^{-2} (5.15 and 9.02 t ha^{-1} DM, respectively), and in 2017 for 40 plants m^{-2} (9.06 t ha^{-1} DM). Linked to this, the significantly highest fibre content was determined for a plant density of 30 plants m^{-2} in 2015 and also in 2016 (Fig. 2 C). Therefore, the highest fibre yield in both experimental years was produced with a plant density of 30 plants m^{-2} (Fig. 2 D). Fibre yield clearly varied between the years. In 2015 the highest fibre yield was about 673 kg ha^{-1} and 1,456 kg ha^{-1} in 2016, respectively.

Figure 2. (A) Plant height (cm), (B) biomass yield (t ha^{-1} dry matter, DM), (C) fibre content (%), and (D) fibre yield (kg ha^{-1} DM) of *Abutilon theophrasti* depending on plant density (plants m^{-2}) for three experimental years (2015-2017); Error bars depict standard deviation; different letters within each year indicate significant differences among treatment means according to Tukey HSD test ($p < 0.05$); n.s.: not significant at the probability level of $p < 0.05$; Bingen/Rhein, Germany.



Effect of Nitrogen Fertilizer on Velvetleaf

There were no significant effects in 2015 for plant height, plant biomass, fibre content, and fibre yield (Fig 3 A-D). In 2015 plant height and biomass yield did not differ much. Over both experimental years, plant height varied between 138 and 234 cm, and biomass yield of 4 up to 10.2 t ha^{-1} were achieved. In 2017, increased nitrogen levels resulted in increased plant height (Fig. 3 A) and plant biomass (Fig. 3 B). Plants reached highest height of 234 cm at an N level of 150 kg N ha^{-1} (incl. mineral soil N), and aboveground biomass of 10.2 t ha^{-1}.

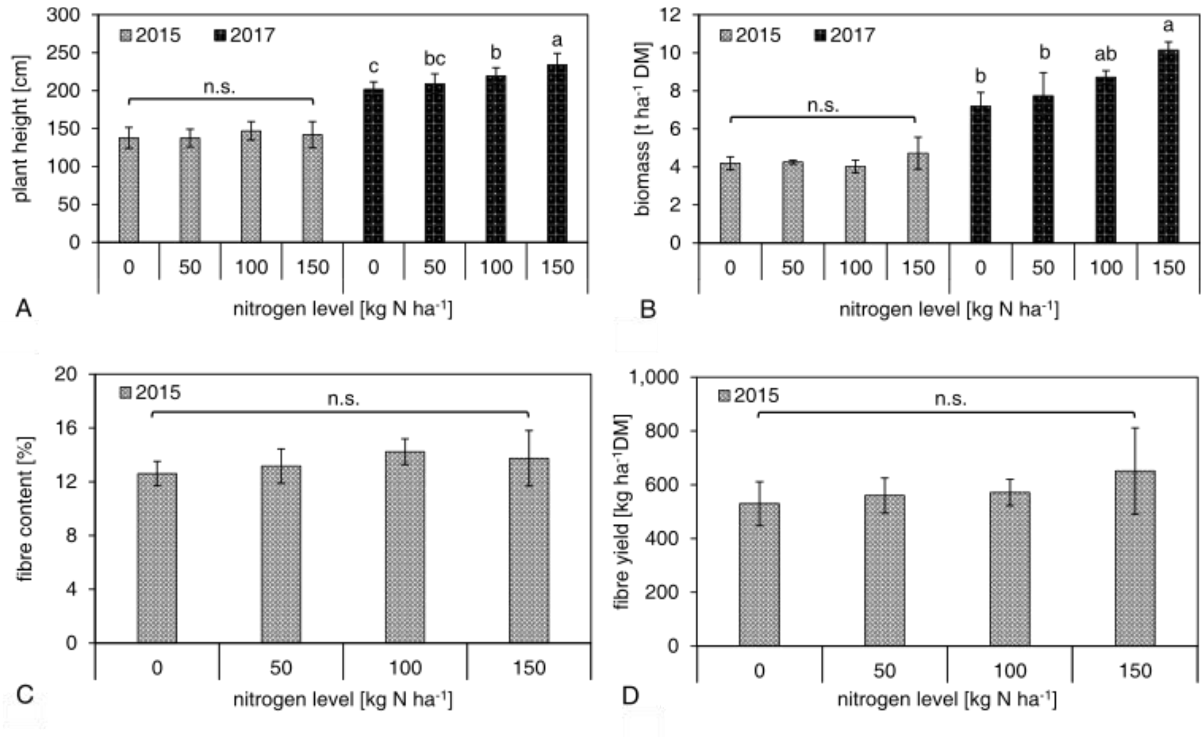


Figure 3. (A) Plant height (cm), (B) biomass yield (t ha^{-1} dry matter, DM), (C) fibre content (%), and (D) fibre yield (kg ha^{-1} DM) of *Abutilon theophrasti* depending on nitrogen level (kg N ha^{-1}) for different experimental years (2015, 2017); Error bars depict standard deviation; different letters within each year indicate significant differences among treatment means according to Tukey HSD test ($p < 0.05$); n.s.: not significant at the probability level of $p < 0.05$; Bingen/Rhein, Germany.

Velvetleaf Accessions

The tested accessions of velvetleaf differed in all tested characteristics except fibre content. Accession H5 had the shortest plants among all accessions tested in both experimental years (Fig. 4 A). This accession also had strong branching and a high number of seed-filled capsules (data not shown). Plant height was highest in accessions H6 and H7 in 2016 (202 and 197 cm), and also for H7 in 2017 (188 cm). This is also reflected in the biomass yield in both experimental years where H7 showed high yield in 2016 and the significantly highest yield in 2017 (11.8 and 8.4 t ha^{-1} DM, respectively; Fig. 4 B). The highest yield in 2016 was shown by the accession H1 (12.1 t ha^{-1} DM). The biomass yield for accession H5 was 39% lower (2016). Also accession H3 showed significant low biomass yields of 8.0 and 6.4 t ha^{-1} DM in 2016 and 2017, respectively. In 2017 differences in biomass yield were smaller than those in 2016, so biomass yield of accession H3 was 2.1 t ha^{-1} DM below the highest (H7, 8.4 t ha^{-1} DM).

The fibre content was approximately 12 % in all accessions (determined only in 2016; Fig. 4 C). Therefore, the same significant differences as for biomass yield (2016) were obtained for fibre yield in 2016 (Fig. 4 D). The fibre yield ranged between 879 and 1,515 kg ha^{-1} DM (H5 and H7, respectively).

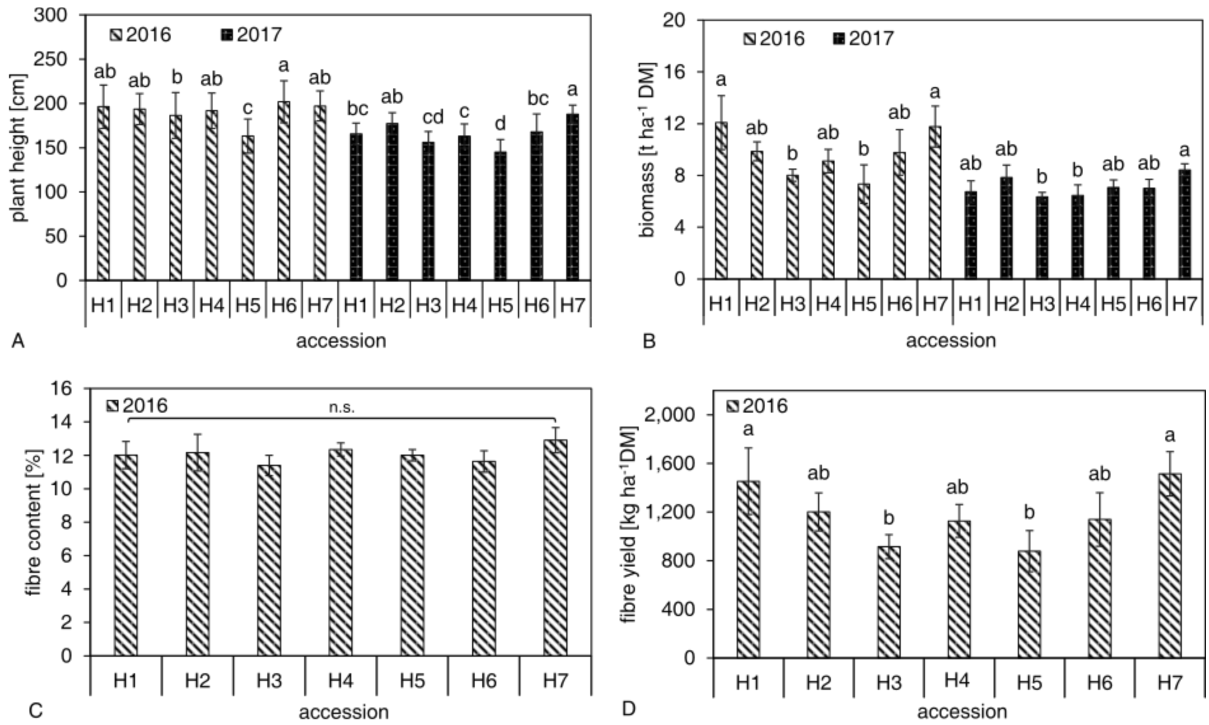


Figure 4. (A) Plant height (cm), (B) biomass yield (t ha^{-1} dry matter, DM), (C) fibre content (%), and (D) fibre yield (kg ha^{-1} DM) of *Abutilon theophrasti* depending on the accession (H1-6 from University of Hohenheim; H7 from Co. Herbiseed) for different experimental years (2016, 2017); Error bars depict standard deviation; different letters within each year indicate significant differences among treatment means according to Tukey HSD test ($p < 0.05$)); n.s.: not significant at the probability level of $p < 0.05$; Bingen/Rhein, Germany.

Influence of Harvest Date on Velvetleaf Yield

Depending on the date of harvest, biomass yield was lowest in 2015 and highest in 2017 (Fig.5 A). In each year, biomass yield was highest at ripeness of the plants (BBCH 89; 05.10.2015 (199 days after sowing (DAS)), 09.09.2016 (151 DAS), 29.08.2017 (141 DAS)). Only in 2017 the biomass yield varied significantly between the harvesting dates, and decreased with delay of harvest.

Same as for biomass yield, highest fibre content was detected on harvest date 05.10.2015 (14.5 %) and 09.09.2016 (16 %; Fig. 5 B). At these dates nearly all plants per plot were matured and in stage of ripeness (BBCH 89; matured capsules and seeds). Due to lower biomass yield in 2015 compared to biomass yield in 2016, the fibre yield in 2016 was more than double compared to 2015. Very similar to biomass yield, the highest fibre yield could be achieved at stage of ripeness (Fig. 5 C).

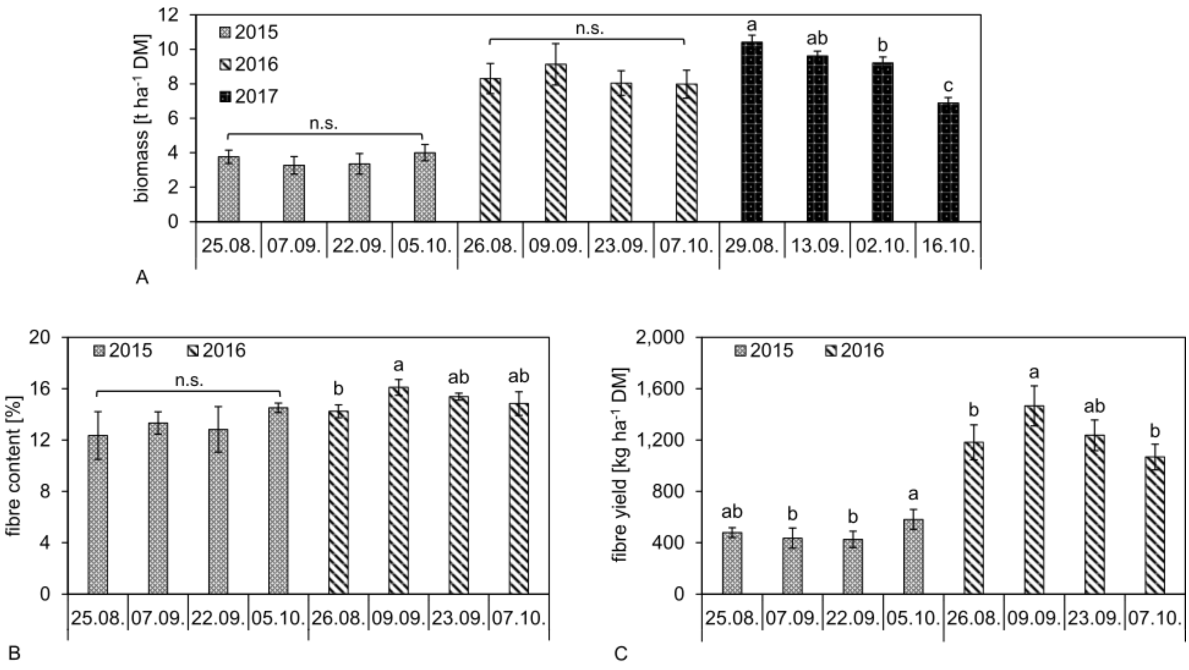


Figure 5. (A) Biomass yield (t ha^{-1} dry matter, DM), (B) fibre content (%), and (C) fibre yield (kg ha^{-1} DM) of *Abutilon theophrasti* depending on date of harvest for different experimental years (2015, 2016, 2017); Error bars depict standard deviation; different letters within each year indicate significant differences among treatment means according to Tukey HSD test ($p < 0.05$); n.s.: not significant at the probability level of $p < 0.05$; Bingen/Rhein, Germany.

Discussion

In addition to environmental conditions, the yield of agricultural crops is also influenced by agricultural parameters. By adapting several of these parameters, the highest yield of the crop can be determined, considering the location. The cultivation of velvetleaf in Europe has not yet been considered, because this plant is mainly known as a weedy neophyte. However, as a fibre plant velvetleaf supplies bast fibres, which, due to their quality, are very well suited for technical use [28]. The establishment of a new fibre plant in Europe might lead to the advantage of being less dependent on fibre imports on the one hand, and on the other hand new fibres could be used to improve the properties of the end products. However, it is crucial that sufficient amounts of fibres can be produced. Since velvetleaf is not yet cultivated in Europe, nothing is known about the yield potential. The investigation of different agricultural parameters and their influence on the yield parameters could provide information about the potential of velvetleaf as a fibre plant in Europe.

Agronomic Aspects For Cultivation of Velvetleaf

Overall fibre yield of velvetleaf (1.5 t ha^{-1} DM) is comparable with the fibre yield of hemp cultivated in Finland (1.3 t ha^{-1} DM; [29]. However, hemp grown in Germany yields about 2.6 t ha^{-1} without additional fertilization [22]. Fibre yield of flax cultivated in Germany is ranging from about 1.8 up to 2.7 t ha^{-1}, depending on the cultivar [30]. Yield of velvetleaf is clearly below the level of yield of fibre plants currently cultivated in Germany. However, there are no trials in Europe which compared the fibre yield of different bast fibre plants including velvetleaf grown on the same site directly.

In this study plant density of velvetleaf did not have a significant effect on plant height. This is similar to findings of Vrbnicanin et al. [31]. Unlike Werner et al. [32] and Bailey et al. [33] who stated increasing plant height with increasing plant density for velvetleaf, in our study in 2017 plant height decreased with increasing plant density. Similar to these results studies of hemp in Europe also showed that plant height decreased with increasing plant density [23,34–37]. Media villa and Bassetti [23] explain this by greater availability of water and nutrition as well as light for plants cultivated in low plant density, and therefore better growing conditions. Under this presumption, biomass yield would also have to decrease with increasing plant density, but this does not apply to velvetleaf biomass yield as it slightly increases with increasing plant density. Presumably, biomass yield could be compensated with a higher number of plants at higher plant density. In addition to biomass yield, fibre content is another crucial parameter that determines fibre yield. Depending on increasing plant density, fibre content increased (especially in 2016). Same results are also detected for hemp for which high fibre yield also depend on high plant density [34,36].

The effect of nitrogen fertilization on fibre yield of velvetleaf could not confirmed without doubts. Fibre plants such as hemp [23,35] and kenaf [20,24] generally show a positive yield response to increasing nitrogen fertilization. Experiments with kenaf conducted in Greece [38] and hemp conducted in Germany [22] showed increasing plant height with increasing nitrogen fertilization. Due to the associated high biomass yield, also the fibre yield of hemp was high [22]. The same results are achieved for velvetleaf in the present study. However, the effect of nitrogen fertilization on plant height and biomass yield was clearly significant in 2017 compared to experimental year 2015: Due to low precipitation in 2015 the plants might not be able to utilise the offered fertilizer. Therefore, also the fibre content was affected slightly and might not be directly influenced by nitrogen itself. Furthermore, the experiment has to be replicated to be able to make a statement whether fibre yield is significantly influenced by the content of nitrogen or not.

Considering the accession there are two types described by Kurokawa et al. [25]. They classify two different phenotypes of velvetleaf. On the one hand there is the crop type: fibre plants with erect stem and a small number of branches, and on the other hand the wild type, which is characterised by low plant height and many branches. In addition, experiments of Kurokawa et al. [25] also showed a strong weedy nature of some of the tested accessions which could lead to problems in the following rotational crop. Spencer [10] stated high yield loss due to the occurrence of velvetleaf in soybeans. The accessions 1 to 6 of this study are all field samples (from Germany and the Czech Republic), so it can be assumed that all of these are related to the wild type. However, only the accession H5 (from Czech Republic) showed clearly phenotypic characteristics of the wild typ. For future fibre production plants related to the crop type are requested. Therefore, it is necessary to focus on this characteristic in the selection for future breeding. Especially the production of seeds has to be controlled, because the amount of produced seed hinders the integration of velvetleaf into existing crop rotations. The seeds are viable in the soil for about 50 years [39] and therefore could cause high yield loss because of volunteers over a prolonged period of time.

The hypothesis of highest fibre yield at the beginning of seed maturity was proved. However, due to different environmental effects during the experimental years maturation was at different time periods after sowing. In 2015 precipitation was low, and therefore development of the plants was delayed, so maturation begun 199 days after sowing whereas maturation in 2016 already began 151 and in 2017 141 days after sowing. According to this, biomass yield, fibre content and fibre yield were highest at this time. Similar results are also reported for hemp, where growth of the stem was slowed after flowering and therefore the content of bark was reduced until the end of vegetation [40]. In addition, Struik et al. [41] showed an increase of cellulose yield from day of sowing until the end of vegetation (140 days after sowing) for hemp, which is comparable with increasing fibre content of velvetleaf detected in the present study.

Risk of Weed Infestation of European Cropping Systems

A. theophrasti is known as a neophyte and occurs as a weed in some agricultural crops, especially in spring crops. In the United States it causes high yield loss in soybean, maize, and cotton [10]. Due to this, weed density and the stage of development of the crop are key for a possible reduction of yield [16]. So, the pressure of competition is much higher for plants with a slow development in their youth. In Europe velvetleaf is, therefore, most common to occur in the cultivation of sugar beets. However, in order to prevent yield loss, weed control is a major aspect especially in the first days after emergence [16]. Besides the competitive character, the high production of dormant seeds is another critical property of velvetleaf [39,42]. Those are viable in the soil for up to 50 years [39]. Furthermore, they are able to emerge during the whole vegetation period of the cultivated crop which could make weed control difficult. Here, especially the further seed intake of matured plants in the soil seed bank is critical.

Additional filed trials in Germany showed that volunteer velvetleaf occurs in subsequent spring crops like *Sorghum bicolour*, but not in winter cereals [43]. However, in most spring crops velvetleaf can be a serious weed, but can be highly efficiently controlled with herbicides in most cases. This can be confirmed by velvetleaf occurrence in the last 18 years [14]. In Germany velvetleaf only causes problems regarding weed control in sugar beet growing areas. From this point of view velvetleaf can be integrated in many crop rotations without increasing risks for weed control, but there are limitations.

Conclusions

As for other crops, yield of velvetleaf depend on crop management. In addition to the optimal plant density, the appropriate fertilization and the optimal harvest date, and the choice of variety (accession) is important. Along with this, the biggest problem in regard to integrating velvetleaf into existing cop rotations is the appearance of volunteers in subsequent crops. As far as this is concerned special breeding is necessary to reduce the input of seeds into the soil seedbank. Today the fibre yield of velvetleaf cannot compete with other fibre plants already cultivated in Germany. However, fibre properties may differ compared to other crops. Consequently, velvetleaf as a new fibre plant in Europe should be taken into consideration.

Data Availability (excluding Review articles)

Readers do not have access to the data underlying the findings of the study.

Conflicts of Interest

There are no conflicts existing.

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