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Yield and quality of bast fibre from *Abutilon theophrasti* (Medic.) in southwest Germany depending on the site and fibre extraction method

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ABSTRACT

Natural fibres are environmentally friendly and therefore often used in the automotive industry as an alternative to glass or mineral fibres. In order to meet the demands of natural fibres for the European automotive market, mainly flax and hemp are cultivated in Europe, but the import of other fibres, like kenaf, is also necessary. To increase the possibilities of fibre use and to reduce the dependency of fibre import, additional fibre plants from European countries could be a solution. An alternative fibre crop with fibre properties described as suitable for high value fibrous applications, could be *Abutilon theophrasti* (velvetleaf). However, there are no European studies about the cultivation of velvetleaf published. Besides cultivation, economically and ecologically acceptable fibre extraction methods are essential for successful implementation of velvetleaf in Europe.

Field trials at three different sites are carried out and, in addition, the effect of water shortage on biomass and fibre yield is investigated. Furthermore, four different fibre extraction methods, known for other fibre plants (chemical and mechanical extraction, water and dew retting) are investigated concerning linear density, breaking tenacity and tensile elongation at break.

Over the two experimental years and three different sites, velvetleaf biomass yield varied between 5.2 and 12.8 t ha^{-1} dry matter (DM), and the fibre yield ranged from 0.7 to 2.4 t ha^{-1} DM. Additional irrigation significantly increased the fibre yield in 2016 by 29%.

Among the different methods for fibre extraction, water retting and chemical extraction by 4% sodium hydroxide solution showed the lowest values of linear density (57 and 58 dtex, respectively). Over all extraction methods, the linear density ranged from 53 to 115 dtex. The highest breaking tenacity was determined for chemical extraction by 0.4% sodium hydroxide solution (52.4 cN tex^{-1}) and water retting (50 cN tex^{-1}).

Generally, cultivation and fibre extraction of velvetleaf are possible under the conditions in southwest Germany. Due to the different fibre characteristics of velvetleaf compared to flax, hemp, and kenaf, this plant should be assessed in future research for its applicability as a renewable resource for industrial fibres.

1. Introduction

In recent years, the use of natural fibres has increased (Barth and Carus, 2015; Carus et al., 2015; European Commission, 2017). In contrast to their synthetic opponents (i.e. glass fibres), natural fibres are renewable, reduce costs and CO_2, and are less dependent on imported mineral oil sources (Holbery and Houston, 2006). Besides, natural fibres offer a low mass density compared to glass fibres (Türk, 2014). Most of the manufactured applications are therefore used in the automotive industry (Barth and Carus, 2015; Carus and Partanen, 2016).

In the European Union flax (*Linum usitatissimum*), hemp (*Cannabis sativa*), and cotton (*Gossypium hirsutum* L.) are currently cultivated as fibre crops (European Commission, 2017). While flax and hemp are mainly grown in France, cotton is cultivated mainly in Greece (European Commission, 2017). However, the cultivation of cotton is geographically limited (Türk, 2014), fibres are used for textile purposes, and only recycled cotton fibres are used in the automotive industry (Carus et al., 2015). Currently, fibres of flax, hemp, and kenaf (*Hibiscus cannabinus*) are used for the production of composites for interior applications (Carus et al., 2015; Holbery and Houston, 2006). Due to fibre quality of flax, a large proportion of flax production is aimed at the production of long fibres for the textile industry (Barth and Carus, 2015). Therefore, only the remaining short fibres could be used and are also depending on the demand of the linen fashion market

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(Barth and Carus, 2015). In contrast, fibres of hemp and kenaf are used mostly for technical purposes, which explain the increase in market share in the European automotive industry in the last years (Barth and Carus, 2015; Carus et al., 2015). While hemp can be grown in Europe, kenaf is mainly grown in India, China and Bangladesh (Karus and Kaup, 2002; Petrini et al., 1994) and have to be imported to Germany. The local production and processing, however, of renewable raw materials is associated added value for the country. In addition, reducing the cost of import, the focus is also on optimising the characteristics of the end product, which are mostly due to the fibre properties. However, this is not possible in Europe with current fibre resources. Consequently, new fibre crops, which can be grown in Europe, might be a useful expansion. Therefore, this paper addresses the possibility of cultivation of *Abutilon theophrasti* (velvetleaf) as a fibre plant in Germany.

Velvetleaf is suitable for fibre production and originates from China or India, where it is still used as a fibre plant (Li, 1970; Mitich, 1991; Spencer, 1984) for the production of ropes, cordage, bags, coarse cloth, fishing nets or paper (Spencer, 1984). It is an annual plant belonging to the family *Malvaceae*. There is nothing known about the cultivation and the yield to be achieve of velvetleaf in Central Europe. However, it is described as a weed that is able to adjust its whole development to different habitat conditions (Sattin et al., 1992). This suggests good amount of yield compared to other fibre plants even under less than optimal conditions. At the same time, the fibre properties should not vary greatly. So far, the fibre properties of velvetleaf are described to be similar to other common natural bast fibres (Reddy and Yang, 2008). Consequently, velvetleaf fibres may provide new properties that might be useful for technical purposes. Besides the question, if velvetleaf can be grown in central Europe, there are still no studies on fibre properties of velvetleaf depending on the extraction method. It is hypothesise, that the extraction method influences the fibre properties. For technical as well as economically reason the fibre extraction has to be optimised.

The aim of this study is to examine the yield and fibre quality level at different sites and, in addition, the effect of water shortage on the biomass and fibre yield. The suitability for cultivation and the yield in Germany/Central Europe is discussed, in addition to the evaluation of the optimal fibre extraction method for velvetleaf.

2. Material and methods

2.1. Field trials

Field trials were established at three sites at Bingen in southwest Germany (49°95′11′́N, 7°92′71′́E; 100 m altitude) for two years (2015, 2016). Long-term (1981–2010) average temperature and precipitation at the Bingen-Gaulsheim weather station (88 m altitude; approx. 3.8 km from the experimental field) was 10.5 °C and 546 mm, respectively (DLR-RNH, 2017). The average annual temperature was 11.7 °C in 2015 and 11 °C in 2016, and annual precipitation was 351 mm in 2015 and 560 mm in 2016; temperature and precipitation variations are depicted in Fig. 1 (DLR-RNH, 2017). Precipitation during the vegetation period (April to September) in 2016 was more than twice as high as precipitation between April and September in 2015 (18.4 °C and 127.1 mm in 2015, 17.1 °C and 261.5 mm in 2016).

Table 1
Site parameters for the three sites used for field trials in 2015 and 2016.

sites	E1	E2	E3
Year	2015	2016	2016
Location	Bingen am Rhein	Bingen am Rhein	Bingen am Rhein
Type of soil	loamy sand	sandy loam	sandy loam
N_{min} (kg ha^{-1})	57	144	55
Soil pH ($CaCl_2$)	6.8	7.3	6.9

All three sites are located close together (distance of 200–1000 m), but there were differences between the characteristics of the soil properties (Table 1). The phosphate content was elevated in both experimental years at sites E1 and E2. However, the potassium content was at an optimal level.

To investigate differences in biomass and fibre yield, velvetleaf was cultivated at three different sites, with and without irrigation. The experiment was set up as a randomised block design with four replicates, with a plot size of 8 × 1.5 m (12 m^2) and inter-row spacing 0.15 m. The seedbed was prepared by a rotary harrow. Seeding of velvetleaf, genotype “Herbiseed” (Co. New Farm, Mire Lane, West End, Twyford, England RG10 0NJ), was carried out with an experimental drilling machine on 22 April in 2015 (E1) and on 11 April in 2016 (E2 and E3) with a density of 90 seeds m^{-2}. At two-leaf stage the plants were thinned by hand to 30 plants m^{-2}. The additional irrigation was carried out by drip irrigation. The irrigation period was five to six days (each about eight hours) from July till the beginning of August providing three L m^{-2} h^{-1}, adjusted to plant needs to avoid drought stress. Floppy leaves were used as the indicator for water needs.

In 2015 nitrogen was applied at site E1 at the two-leaf stage in the form of calcium ammonium nitrate at a rate of 83 kg N ha^{-1} added to the mineral soil N of 57 kg N ha^{-1} (measured on 19 March 2015). Because of the high mineral nitrogen content in the soil (144 kg N ha^{-1}) in March 2016, no additional fertilizer was applied at E2. In 2016 a mixed mineral fertilizer was applied on site E3 before sowing (16 March 2016) at a rate of 100-100-50 (N-P-K) kg ha^{-1}. 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 for chemical weed control three times during April and May (all sites in both experimental years). Furthermore, no action against diseases had to be taken.

The plants were harvested with a brush saw approximately 5 cm above the soil surface on 14 September 2015 (E1) and 09 September 2016 (E2 and E3). At this time, most of the seeds had matured. To

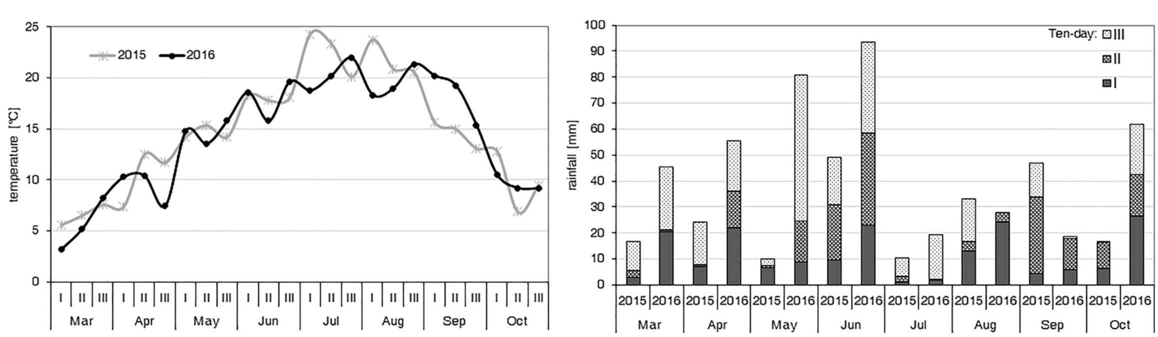

Fig. 1. Mean temperature in °C (A) and sum of rainfall in mm (B) in ten-day periods (I, II, and III) during the growing season (April to September) of *A. theophrasti* in 2015 and 2016 at the experimental sites. Data was obtained from the Bingen-Gaulsheim weather station (88 m altitude; approx. 3.8 km from the experimental fields) (DLR-RNH, 2017).

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