Seed potential and germination dynamic of *Abutilon theophrasti* in subsequent crops

Samenpotential und Auflaufdynamik von Abutilon theophrasti in Folgefrüchten

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Abstract

Abutilon theophrasti (Medic.) is native in China or India and primarily known in Germany as a weed in sugar beets. Due to the increased demand for renewable raw materials, *A. theophrasti* as a fibre plant could be of particular interest to the automotive industry in Germany. The possibilities and potential of cultivation of *A.theophrasti* in Germany are still under investigation. However, the high production of persistent seeds could be a problem in cultivation. The emergence of the seeds in the following growing season can lead to yield loss in the subsequent crop. In order to investigate and quantify the seed potential in the soil and the dynamics of germination of *A. theophrasti*, field trials were carried out in 2015 and 2016, where winter wheat (*Triticum aestivum*) and sorghum (*Sorghum bicolor*) were cultivated after *A. theophrasti*, in 2017 followed by maize (*Zea mays*).

The seed potential in the soil and the number of emergent plants was continuously determined. After harvest of *A. theophrasti*, a soil seed bank of over 10,000 seeds m^{-2} in 2015 and 6,000 seeds m^{-2} in 2016 was determined. Within 2 years after the cultivation of *A. theophrasti* and winter wheat the number of seeds in the soil decreased by 77 to 82%. But 1 year after cultivation of *A. theophrasti* and subsequent crop still 1,973 to 3,096 seeds m^{-2} in the soil were present. The dynamics of germination showed that the majority of the seeds in the soil only emerge before sowing sorghum and after harvest of sorghum or winter wheat. The comparison of *A. theophrasti* with *Camelina sativa* as a pre-crop showed that there were no significant differences in yield of sorghum or winter wheat.

Keywords: *Abutilon theophrasti,* crop rotation, population dynamics, preceding crop, soil seed bank

Zusammenfassung

Abutilon theophrasti (Medik.) stammt ursprünglich aus China oder Indien und ist in Deutschland vor allem als Unkraut auf Rübenäckern bekannt. Durch die gestiegene Nachfrage nach nachwachsenden Rohstoffen könnte *A. theophrasti* als Faserpflanze in Deutschland vor allem für die Automobilindustrie von Interesse sein. Die Möglichkeiten und das Potential des Anbaus von *A. theophrasti* in Deutschland werden derzeit noch untersucht. Allerdings könnte die hohe Produktion persistenter Samen ein Problem beim Anbau von *A. theophrasti* darstellen. Das Auflaufen der Samen in der folgenden Vegetationsperiode kann zu Ertragseinbußen der Folgefrucht führen.

Um das Samenpotential im Boden und die Auflaufdynamik von *A. theophrasti* genauer zu untersuchen und zu quantifizieren, wurden im Jahr 2015 und 2016 Feldversuche angelegt, bei denen nach *A. theophrasti* Winterweizen (*Triticum aestivum*) und Sorghum-Hirse (*Sorghum bicolor*) angebaut wurden, 2017 folgte Mais (*Zea mays*).

Das Samenpotentials im Boden und die Anzahl auflaufender Pflanzen wurde kontinuierlich bonitiert. Nach der Ernte von *A. theophrasti* wurde ein Samenvorrat von über 10.000 Samen m^{-2} im Jahr 2015 und 6.000 Samen m^{-2} im Jahr 2016 ermittelt. Innerhalb von 2 Jahren nach dem Anbau von *Abutilon theophrasti* und anschließendem Winterweizen wird die Anzahl der Samen im Boden um 77 bis 82 % verringert. Allerdings waren noch immer 1.973 bis 3.096 Samen m^{-2} im Boden. Die Dynamik der Keimung zeigte, dass die Mehrheit der Samen im Boden nur vor der Aussaat von Sorghum und nach der Ernte von Sorghum oder Winterweizen auflaufen. Im Vergleich von *A. theophrasti* zu *Camelina sativa* als Vorfrucht zeigten sich keine signifikanten Unterschiede im Ertrag von Sorghum oder Winterweizen.

Stichwörter: *Abutilon theophrasti*, Fruchtfolge, Populationsdynamik, Samenbank, Vorfrucht

Introduction

Velvetleaf, *Abutilon theophrasti* (Medik.), is known in Germany as a weed in sugar beets. Originally, the plant is from China or India and belongs to the family of Malvaceae (Li, 1970; Spencer, 1984;

MITICH, 1991). Since 2,000 B.C. *A. theophrasti* has been cultivated as a fibre plant. The bast fibre is used to make e.g. ropes, cordages, bags, coarse cloth or fishing nets (SPENCER, 1984). The seeds of *A. theophrasti* were brought along to America by the early settlers. As a base of agricultural development *A. theophrasti* should be used for fibres. Over time cotton (*Gossypium hirsutum*) and hemp (*Cannabis sativa*) replace fibres of *A. theophrasti* (SPENCER, 1984). The plant probably came to Europe via imports of maize and soybeans as animal feed from America (MEINLSCHMIDT, 2005). Through the digestion process of the animals, seeds are not damaged and can be applied to the fields via liquid manure or dung (MEINLSCHMIDT, 2005).

With increasing demand for renewable raw materials, the demand for plant fibres for the automotive industry increase (NABI SAHEB and JOG, 1999; MOHANTY et al., 2002; DIEPENBROCK et al., 2016). They are processed as fibre composite materials for the production of interior components. As an alternative or supplement to the currently used fibres of hemp and kenaf (*Hibiscus cannabinus*), fibres of *A. theophrasti* could gain more importance. The possibilities and the potential of cultivation of *A. theophrasti* in Germany are still under investigation. One problem by cultivation of this species may be the high production of persistent seeds (SPENCER, 1984). Due to several mechanisms of dormancy only a part of the seeds in the soil germinates (EGLEY and CHANDLER, 1978; WARWICK, BLACK, 1988). Because seeds are persistent they can also germinate in subsequent crops. Especially in spring crops *A. theophrasti* is one of the most important weeds (SPENCER, 1984). Decisive for a reduction in yield are, however, weed density and the stage of development of the crop (SATTIN et al., 1992). So, plants with a slow development of youth, such as sugar beets, are subject to a higher competition pressure. Therefore, a high competiveness, especially in the first days after emergence, is important in order to suppress weeds in the reduction of yield (SATTIN et al., 1992). The potential of *A. theophrasti* as a competing plant in following crops becomes clearer when considering the seeds produced. With a number of an average of 34 seeds per capsule and an average of 50 mature capsules per plant, a single plant can produce about 1,700 mature seeds.

In predicting crop yield loss it is crucial to understand the interactions between crop and volunteers. Therefore, this research was conducted to determine population dynamics and seed potential of *A. theophrasti* within two and three rotational crops (*Triticum aestivum*, *Sorghum bicolor*, *Zea mays*), respectively. Furthermore, the impact of *A. theophrasti* to yields of following rotational crops was determined.

Materials and Methods

Field trials

Field experiments were initiated in 2015 and 2016 on two sites at Bingen in southwest Germany (49°95´11´´N, 7°92´71´´E; 100 m altitude). The soils are both characterized as sandy loam with a pH varying between 6.4 and 6.7. Precipitation and average air temperature was 351 mm, 11.7 °C in 2015 and 560 mm, 11 °C in 2016, respectively (weather station Bingen-Gaulsheim (88 m altitude); (DLR-RNH, 2017)).

The experimental design on both sites in 2015 and 2016 was identical, respectively. The trials were a 2-year crop rotation systems including *Abutilon theophrasti* (ABUTH), *Camelina sativa* (CAM), *Sorghum bicolor* (SORVU), and *Triticum aestivum* (TRZAW). After cultivation of *A. theophrasti* in the first year of trial, either sorghum or winter wheat was cultivated. As a reference *Camelina sativa* was also cultivated before sorghum and winter wheat. In 2017, *Zea mays* (ZEAMA) were cultivated after winter wheat.

All trials were arranged as a randomised block design with 4 replicates. Plot size was 18 m^2 in the experiment started in 2015 and 24 m^2 in the experiment started in 2016. In 2016 mixed fertilizer was applied before sowing *A. theophrasti* (16.03.2016) at a rate of 100-100-50 (NPK) kg ha^{-1}. Due to high mineral nitrogen in the soil, no fertilizer was applied in 2015.

The seedbed was prepared by a rotary harrow before sowing.

The examined 'cultivar' of *A. theophrasti* comes from the company 'Herbiseed' in the UK (New Farm, Mire Lane, West End, Twyford, England RG10 0NJ) and was sown in the first year of trial with a single grain seeder (0.5 m row distance) on 20.03.2015 and an experimental drilling machine (inter-row spacing 0.15 m) on 11.04.2016 with a density of 50 seeds m^{-2}. *Camelina sativa* (cultivar Ligena) was sown with a density of 600 seeds m^{-2} on 19.03.2015 and on 17.03.2016, respectively.

For weed control in *A. theophrasti* a combination of metamitrone (700 g kg^{-1}) and ethofumesate (151 g l^{-1}) + phenmedipham (75 g l^{-1}) + desmedipham (25 g l^{-1}) at rate of 1 l ha^{-1} each (200 l ha^{-1} water) was applied up to 3 times during April and May. In plots of camelina napropamid (450 g l^{-1}) was applied preemergence at a rate of 2 l ha^{-1}. Surviving weeds were removed by hand.

A. theophrasti was harvested with an experimental harvester. The upper third of *A. theophrasti* which contains most of the capsules was harvested on 28.09.2015 and 29.09.2016. The rest of the plants were mulched. *Camelina sativa* was also harvested with an experimental harvester on 10.07.2015 and 26.07.2016, respectively.

In subsequent year, sorghum was sown after seedbed was prepared by rotary harrow on 09.05.2016 and 05.05.2017 with an experimental drilling machine (density 35 seeds m^{-2}; cultivar Iggloo). Winter wheat was sown on 05.10.2015 and 12.10.2016 (320 seeds m^{-2}; cultivar JB Asano/Julius), respectively.

Before sowing of sorghum glyphosate (360 g l^{-1}) at a rate of 3 l ha^{-1} was used to prevent germinated weed. For weed control during vegetation period of *Sorghum bicolor* bromoxynil (200 g l^{-1}) and terbuthylazine (300 g l^{-1}) at rate of 1.5 and 3 l ha^{-1} (01.06.2016, 22.06.2016) was used. In winter wheat fluroxypyr (200 g l^{-1}) at rate of 0.9 l ha^{-1} and 2.4-D (500 g l^{-1}) at a rate of 1.5 l ha^{-1} (21.04.2016) and 2017 pyroxsulam (68.3 g kg^{-1}) + florasulam (22.8 g kg^{-1}) at rate of 240 g ha^{-1} were used.

Sorghum and winter wheat were harvested with an experimental harvester in July (27.07.2016, 18.07.2017) and September (29.09.2016, 25.09. 2017), respectively.

In 2017 maize was cultivated on the experimental fields after winter wheat (experiment 2015). Seedbed was prepared by a rotary harrow and sown on 18.04.2017. For weed control mesotrione (100 g l^{-1}) at a rate of 1.5 l ha^{-1} was used two times (22.05.2017, 08.06.2017).

Soil samples and dynamics of germination

The first soil samples were taken after emergence of winter wheat (November 2015/2016) and repeated in spring-time (March 2016/2017) and following autumn (August and November 2016/September 2017). All soil samples were taken by an auger (Ø 2.2 cm) up to 30 cm to determine the amount of remaining seeds of *A. theophrasti* in the soil seed bank. Each plot was sampled 18 times. Seeds were separated from the soil by washing and sieving (3 sieves: mesh width 3.55 mm, 2 mm and 1.4 mm).

To determine the dynamic of germination all *A. theophrasti* plants (cotyledon stage) emerged per plot were determined. First data collection was carried out on 20.04.2016 and 29.03.2017. The number of emerged plants was counted every 3 weeks.

Statistical analysis

The statistical evaluation was carried out with R statistics (version 3.3.1 (2016-06-21)). Following the tests for normality and homogeneity of variances an analysis of variances (ANOVA) was conducted for crop yield. Differences were identified at $p \leq 0.05$. The significant differences between the treatments were calculated with Tukey HSD test ($\alpha = 0.05$) and differences were shown with different letters.

Results

Seed potential

After harvest of *A. theophrasti* the first soil samples were taken in November 2015. The soil seed bank in all plots was clearly above 10,000 seeds m^{-2} (Fig. 1). The number of seeds in the soil has been reduced over the winter by 40% in plots cultivated with winter wheat and by 28% in plots not cultivated (sorghum sown in May). After one year (August/November 2016), the soil seed bank has already been reduced by 77% and 76%, respectively. So, after harvest of winter wheat there were still 2,960 seeds m^{-2} in the soil (August 2016). Soil samples in November 2016 showed still 2,630 seeds m^{-2} in plots of sorghum. After the plots were sampled once again in June, there were 2,448 seeds m^{-2} in plots of sorghum and 2,265 seeds m^{-2} in plots of winter wheat (Fig. 1). Therefore, 2 years after cultivation of *A. theophrasti* seed potential in the soil has reduced by 77 and 82%, respectively.

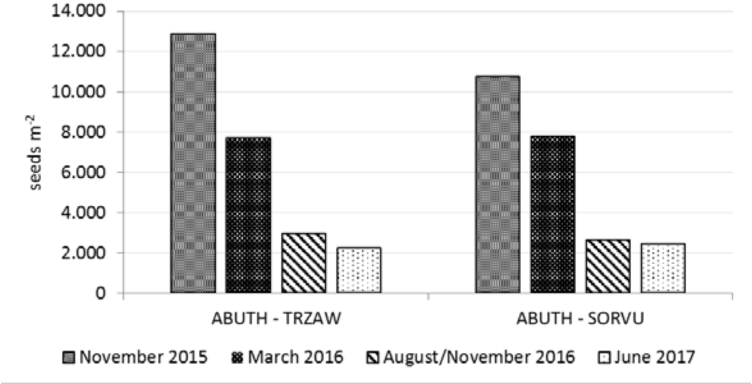

Fig. 1 Soil seed bank after harvest of *Abutilon theophrasti* (first trial start: 2015) over 2 years and 2 different rotational crops (*Triticum aestivum* = TRZAW; *Sorghum bicolor* = SORVU).

Abb. 1 *Samenvorrat im Boden nach der Ernte von* Abutilon theophrasti *(erster Versuch, Start: 2015) über 2 Jahre in 2 verschiedenen Fruchtfolgekulturen (*Triticum aestivum = *TRZAW;* Sorghum bicolor = *SORVU).*

Similar results are also shown for the experiment started in 2016. However, the soil seed bank after harvest of *A. theophrasti* in the first year was about 6,000 seeds m^{-2} which is clearly smaller than soil seed bank in 2015 (cf. Fig. 1 and 2). So, the reduction of seeds over winter was lower - 28 and 13% (Fig. 2). In September 2017 soil seed bank was reduced by 50 and 67%, respectively. In plots of winter wheat were still 3,096 seeds m^{-2}, and in plots of sorghum 1,973 seeds m^{-2} were present in the soil.

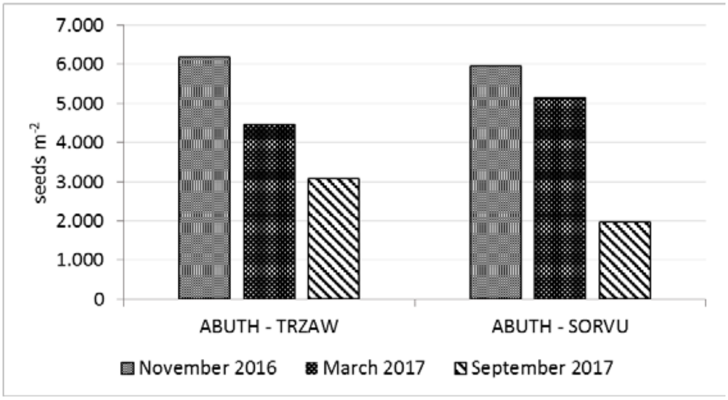

Fig. 2 Soil seed bank after harvest of *Abutilon theophrasti* (second trial start: 2016) over 1 year and 2 different rotational crops (*Triticum aestivum* = TRZAW; *Sorghum bicolor* = SORVU).

Abb. 2 *Samenvorrat im Boden nach der Ernte von* Abutilon theophrasti *(zweiter Versuch, Start: 2016) über 1 Jahr in 2 verschiedenen Fruchtfolgekulturen (*Triticum aestivum = *TRZAW;* Sorghum bicolor = *SORVU).*

Germination dynamic

While germination of *A. theophrasti* was low in spring 2016 in plots of winter wheat, in plots which were not cultivated over winter until sorghum was sown on 09.05.2016 a large number of *A. theophrasti* emerged (Fig. 3). The density of germinated *A. theophrasti* decreased with emergence and growth of sorghum. In plots of winter wheat, some *A. theophrasti* emerged once winter wheat matured. After winter wheat was harvested in July 2016 an increase of velvetleaf germination was observed, while the number of germinated *A. theophrasti* in sorghum decreased. During the following winter no viable *A. theophrasti* plants were observed. In 2017 maize was cultivated on the experimental field. Thus, *A. theophrasti* germinated in all plots until maize was sown (18.04.2017). In spring 2017 there were still 170 plants m^{-2} in plots of sorghum and 235 plants m^{-2} in plots of wheat. However, over the vegetation period of maize the density of germinated *A. theophrasti* decreased very quickly (Fig. 3).

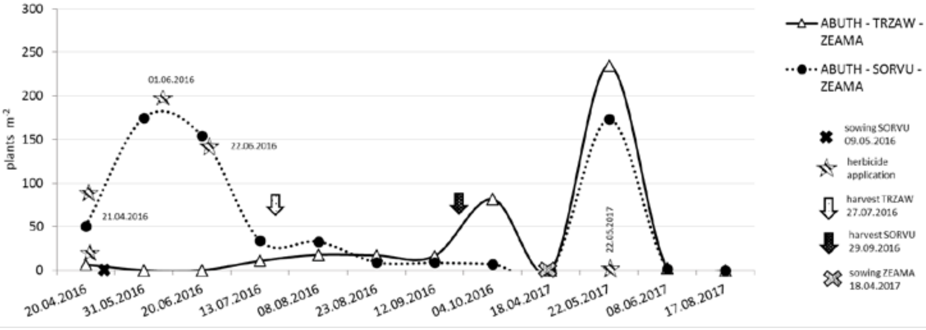

Fig. 3 Germination dynamics of *Abutilon theophrasti* in 3 different rotational crops (*Triticum aestivum* = TRZAW; *Sorghum bicolor* = SORVU; *Zea mays* = ZEAMA) over a period of 2 years (experiment started in 2015).

Abb. 3 *Auflaufdynamik von* Abutilon theophrasti *in 3 verschiedenen Fruchtfolgekulturen (*Triticum aestivum = *TRZAW;* Sorghum bicolor = *SORVU;* Zea mays = *ZEAMA) über 2 Jahre (Versuchsbeginn 2015).*

Similar to the findings of the first experiment, the second experiment (started in 2016) showed that a large proportion of the seeds were found in spring 2017 in the plots cultivated with sorghum (Fig. 4). The growth of sorghum reduced the number of emergent *A. theophrasti* plants.

In plots cultivated with wheat most of the plants did not grow until wheat was harvested. After harvest, about 95 seeds m^{-2} germinated (18.07.-09.08.2017) in plots of winter wheat stubbles. In September 2017 there were still 55 plants m^{-2} in these plots while plots of sorghum showed only 3 plants m^{-2} (Fig. 4).

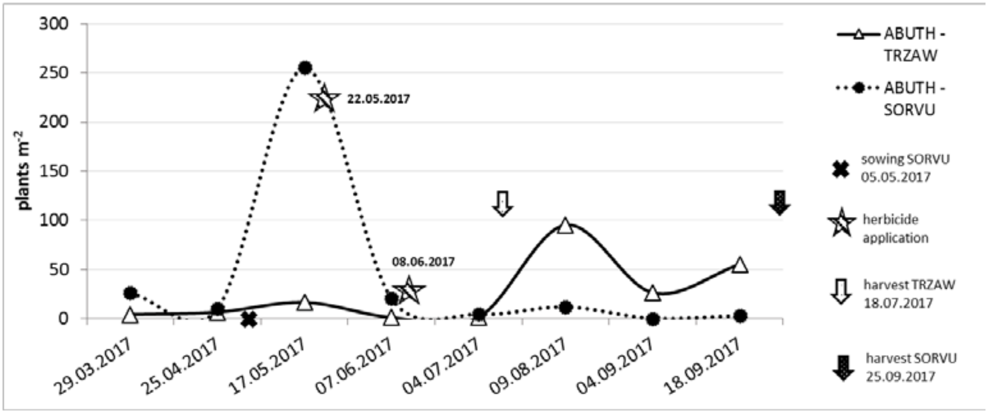

Fig. 4 Germination dynamics of *Abutilon theophrasti* in 2 different rotational crops (*Triticum aestivum* = TRZAW; *Sorghum bicolor* = SORVU) over a period of 1 year (experiment started 2016).

Abb. 4 *Auflaufdynamik von* Abutilon theophrasti *in 2 verschiedenen Fruchtfolgekulturen (*Triticum aestivum = *TRZAW;* Sorghum bicolor = *SORVU) über 1 Jahr (Versuchsbeginn 2016).*

Crop yield

The yield of sorghum showed no statistical significant differences between the different pre-crops (CAM or ABUTH) within a year (Fig. 5). In 2016 yield of sorghum after *Camelina sativa* was about 7 t ha^{-1} while the yield after *A. theophrasti* was slightly lower (6.1t ha^{-1}). In 2017, the yield after *A. theophrasti* was also slightly lower.

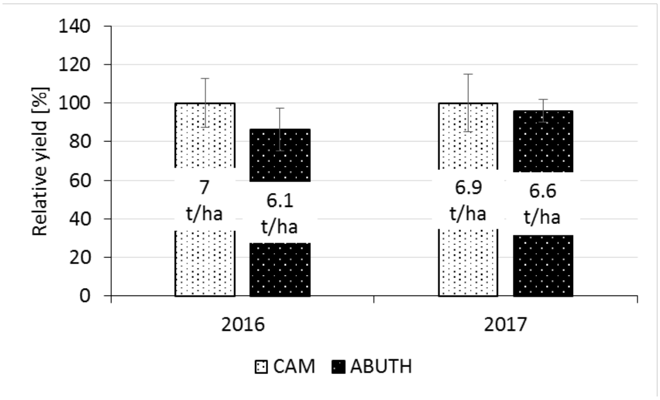

Fig. 5 Relative yield of *Sorghum bicolor* from 2 trial years, cultivated after *Abutilon theophrasti* (ABUTH) and *Camelina sativa* (CAM), respectively (100% sorghum grain yield after pre-crop *Camelina sativa*).

Abb. 5 *Relative Kornerträge aus 2 Versuchsjahren von* Sorghum*, angebaut nach* Abutilon theophrasti *(ABUTH) bzw.* Camelina sativa *(CAM) (jeweils in Bezug auf den Ertrag von* Sorghum *nach der Vorfrucht* Camelina sativa*).*

The yield of winter wheat also showed no significant differences between *Camelina sativa* and *A. theophrasti* as a pre-crop in 2016 (Fig. 6). Other results were shown in 2017 where the yield of wheat after *A. theophrasti* was significantly higher by 24% (5.9 t ha^{-1}) than the yield of wheat after *Camelina sativa* (4.7 t ha^{-1}).

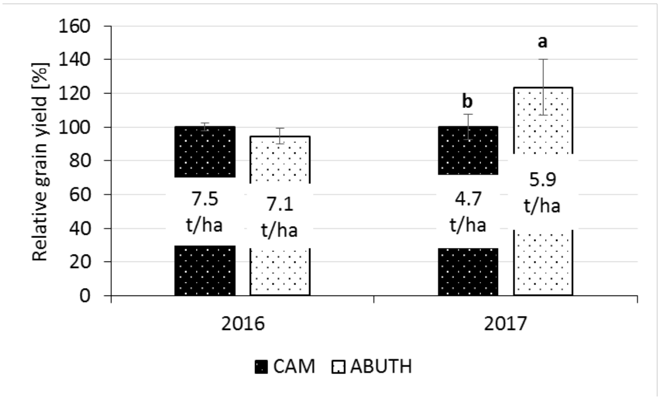

Fig. 6 Relative grain yield of winter wheat from 2 trial years, cultivated after *Abutilon theophrasti* (ABUTH) and *Camelina sativa* (CAM), respectively (100% sorghum grain yield after pre-crop *Camelina sativa*); different letters within each year indicate significant differences among treatment means according to Tukey HSD test ($p < 0.05$).

***Abb. 6** Relative Weizenerträge aus 2 Versuchsjahren, angebaut nach* Abutilon theophrasti *bzw.* Camelina sativa *(CAM) (jeweils in Bezug auf den Ertrag von* Sorghum *nach der Vorfrucht* Camelina sativa*); unterschiedliche Buchstaben innerhalb eines Jahres zeigen signifikante Unterschiede zwischen den Mittelwerten der Varianten nach Tukey HSD ($p < 0,05$).*

Discussion

The number of *Abutilon theophrasti* seeds in the soil showed the potential of *A. theophrasti* as a competing plant in following crops. Despite the fact that in 2016 there were only half as many seeds in the soil as 2015, there are still 6,000 seeds m^{-2}. The lower seed intake in 2016 after harvesting *A. theophrasti* could be due to various weather conditions during the vegetation period. In 2015 precipitation was very low, so all capsules were dry and had been matured before harvest. Due to a higher water supply in 2016, the maturation of the capsules within a plant was very inhomogeneous.

Soil seed bank was reduced over 2 years. The reduction of seeds in soil may have 3 reasons. On the one hand the activity of predators plays a role, but also physiological aging and exhaustion of reserves through respiration can cause the reduction of seeds in the soil. The most frequent cause, however, is the germination of seeds at depth in the soil or germination at unfavourable times of the year (for example winter months) (MOHLER, 2001). And it is also reduced by germination during the vegetation period of the subsequent crop. Cause of coverage in plots of winter wheat *A. theophrasti* volunteers first appeared with maturing of winter wheat when more light at the soil surface stimulated *A. theophrasti* seeds to germinate. In plots of sorghum most of the *A. theophrasti* seeds germinated in spring because sorghum was sown in May. And even after harvest of winter wheat or sorghum *A. theophrasti* germinated. Therefore *A. theophrasti* could be controlled best by appropriate tillage.

Since volunteers often lead to problems in following crops, which are often associated with yield loss, crop yield was also an important parameter in these experiments. In plots of *Camelina sativa* no volunteers showed up, so yield should not be affected. Germination of *A. theophrasti* was high during May till June in plots of sorghum. But further development and further germination of *A. theophrasti* could be prevented by herbicide applications. Therefore yields of sorghum after *Camelina sativa* or *A. theophrasti* do not differ widely. As the dynamics of germination of *A. theophrasti* in winter wheat showed, there are hardly volunteers during vegetation period of winter wheat. Therefore there are also no differences in yield between different pre-crops in 2016. The lower yield of winter wheat in 2017 in plots of *Camelina sativa* cannot be explained. However, previous results for sorghum and winter wheat showed that velvetleaf could be controlled and does not cause yield losses. The herbicide applications especially in sorghum showed good effects. On the one hand herbicide applications were intended to prevent germinated plants from growing further. On the other hand this guaranteed that no new seed entry takes place and only newly germinated plants are counted (for the evaluation of the germination dynamics).

If *A. theophrasti* could not be controlled by herbicides or tillage the remaining seed bank in the soil could become a problem. HARTZLER (1996) investigated the population dynamics of *A. theophrasti* in soybean (*Glycine max*). He showed that within 1 year the population of 0.4 plants m^{-2} of *A. theophrasti* can result in emergence of 145 plants m^{-2} in the following year. And after 4 years still 35 plants m^{-2} emerged. Therefore, an increase in *A. theophrasti* density could result in increased weed management and much more seeds remaining in the soil.

Consequently, further experiments with different cropping systems over a longer period of time and further investigations on seed production of velvetleaf have to follow, before *A. theophrasti* can be integrated as fibre plant into European crop rotations.

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