ADAPTIONS OF HARVESTING METHODS AND CONCEPTS IN ORDER TO REDUCE WEEDS ON AGRICULTURAL FIELDS AND TO GAIN POTENTIALLY A SO FAR UNEXPLOITED BIOMASS FEEDSTOCK

C. Glasner[1]*, C. Andreasen[2], C. Vieregge[3], A. Dikiy[4], J. Fenselau[1], Z. Bitarafan[2], E. Shumilina[4]
[1]Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Osterfelder Str. 3, 46047 Oberhausen, Germany, phone: +49-208-8598-1133, fax: +49-208-8598-1295, christoph.glasner@umsicht.fraunhofer.de
[2]University of Copenhagen, Department of Plant and Environmental Sciences, Crop Sciences, Højbakkegaard Allé 13, DK-2630 Taastrup, Denmark, phone: +45-35333453, fax: +45-35333478, can@plen.ku.dk
[3]CLAAS Selbstfahrende Erntemaschinen GmbH, Muehlenwinkel 1, 33428 Harsewinkel, Germany, phone: +49-5247-12-2050, fax: +49-5247-12-1786, christopher.vieregge@claas.com
[4]Norwegian University of Science and Technology, Department of Biotechnology and Food Science, Sem Sælands vei 6/8 Trondheim, NO-7491, Norway, phone: +47-73597863, fax: +47-73591283, alex.dikiy@biotech.ntnu.no

ABSTRACT: Within the international project Sweedhart different measures and concepts are investigated to reduce weeds on agricultural fields without using herbicides. During harvesting three main fractions are produced – grain, chaff with weed seeds and straw. Conventional combine harvesters return the chaff and weed seeds to the fields and the seeds become a problem in future growth seasons. In Sweedhart, the effect of removing chaff from the field and utilize it energetically and/or materially is investigated. The possibility to kill the weed seeds in the chaff fraction thermally directly in the combine harvester before it is returned to the field is investigated as well. All measures intend achieving a reduced weed pressure on the field in the following growth seasons. Field tests were carried out in 2016 and 2017 to assess the concepts. While the long-term effect of reducing weed by the proposed measures remains object to future evaluation, the basic principles have been approved successfully. Applicable thermal treatment parameters were defined and an energetic utilization pathway including applicable pelletizing conditions for chaff was worked out. The project shows that chaff containing weed seeds can be converted into an unexploited biomass feedstock.
Keywords: agricultural residues, biomass, environmental impact, feedstock, harvesting, strategies

1 INTRODUCTION

Weeds are one of the most devastating constraints for agricultural plant production worldwide. Herbicide resistant weeds have become a growing problem in agriculture and international trade and traffic have contributed to the spread of seeds and plant parts and resulted in increasing problems with invasive weeds [1, 2]. The possibilities to develop new effective herbicides seem to be exhausted. No new mode of actions in plants for herbicides have been discovered since the 1980s (F2-HPPD inhibitors where the last), and many herbicides have been banned due to risks of unwanted side effects.

The extensive use of herbicides has resulted in increasing public concerns and lead to further restrictions for herbicide use in Europe. Consequently, this favors the weed flora and threatens our food security and the livelihood of farmers [3]. The situation calls for new integrated weed management approaches to avoid increasing weed problems in the future and new methods need to be developed to replace and supplement present methods.

Furthermore, there is a need to reduce CO_2 emission and to create a bio-based economy in order to reduce the negative effect of human activities on climate. Therefore, there is a demand for utilizing agricultural biomass without affecting food security. During harvesting a separation of harvested material takes place directly on the harvester. Grains are separated and collected in a tank. Two more fractions are generated – straw and chaff.

The straw is separated and chopped or laid down on the field in rows to enable an efficient drying of the straw. After drying, these rows are collected and compacted into straw bales. The chaff fraction consists of the remaining harvested materials which are light plant residues containing weed seeds. The chaff is uncontrollably blown back onto the field as an unused fraction, spreading also the weed seeds homogeneously on the field (Fig. 1).

Figure 1: Output of straw (middle) and chaff (below straw and sides) (© Fraunhofer UMSICHT)

Chaff represents a significant and unexploited amount of biomass, and a removal rate of 0.33 is considered as acceptable without influencing the soil balance negatively [4]. Spelt chaff has a heating value of 15.1 – 16.8 MJ/kg [5, 6] (e.g. wood pellets 16.3 MJ/kg) and may contain a variety of bioactive compounds. The exploitation of this source would therefore increase the sustainability of agriculture and add other value chains.

In the EU-28, around $152 \cdot 10^6$ t/a wheat and spelt corn are harvested annually [7]. Although the distribution of grain, straw and chaff yield varies, especially between different crops [8], we estimated the distribution of the harvested material to be approx. 50 % grain, 25 % straw and 25 % chaff. This leads to a total biomass potential for chaff of about $38 \cdot 10^6$ t/a. Taking into account a sustainable removal rate of 0.33 and the lowest calorific value, the theoretical energetic potential is almost 200 PJ/a. Thus, a large amount of the energy demand of a farm for heating, grain drying and power could be covered (e.g. the energy demand for drying of 1 t grain is between 1.1 to 1.8 MWh/t [9]). On farm level, farmers would be enabled to use a self-generated cheap and renewable fuel contributing significantly to reduce CO_2 emissions. Surely, there are some constraints in using chaff as energy source and making it available without losing all positive effects by immense logistics costs resulting from low bulk densities. Possible mitigation strategies and alternatives are investigated in Sweedhart.

Other alternative concepts for harvest weed seed control (HWSC) propose a mechanical destruction of weed seeds during harvesting [10], narrow-windrow burning of chaff and straw [11] and chaff tramlining [12].

The limitations of these concepts are that chaff as additional biomass feedstock is lost. These concepts have only been proven in Australian cropping systems. The adoption to European conditions is still outstanding. The proposed methods of Sweedhart promise to have additional benefits compared to the existing ones and will be evaluated with regard to their weed reduction effects and with regard to being more cost efficient harvesting practices.

2 CONCEPT DEVELOPMENT

The project Sweedhart - "Separation of weeds during harvesting and hygienisation to enhance crop productivity in the long term" focus on the above-mentioned problems and potentials. The aim is to reduce weed infestation and the need of herbicide application in favor of alternative processes. Therefore, several concepts are investigated that on the one hand will inactivate viable weed seeds and on the other hand will make chaff containing weed seeds available for further utilization. The technological concepts of Sweedhart are separated into three pillars. Figure 2 gives a rough overview about all investigated process chains. Each pillar is described more thoroughly in the following.

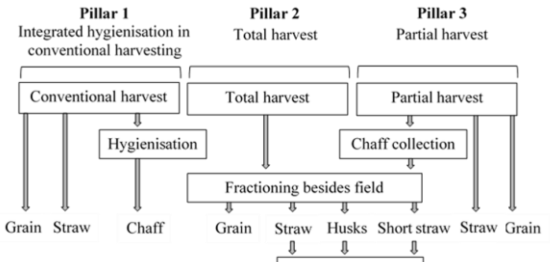

Figure 2: Overview about investigated process chains and possibilities during harvesting

Sweedhart investigates the proposed concepts in terms of applicability, sustainability and added value generation. The final objective is a catalogue of measures to reduce the weed pollution on the fields and strategies to implement preferred measures that will be published probably in April 2019. This paper summarizes intermediate results.

2.1 Pillar 1: Integrated hygienisation in conventional harvesting

In pillar 1 the conventional harvesting method is not changed. The harvesting process and the distribution of chaff and straw on the field remains as it is, but the possibility to damage the weed seeds thermally is investigated. The heat source from the exhaust gas of the combine harvester is used. Here, the chaff fraction that contains all harvested seeds needs to be brought into contact with the heat. This can happen by direct and indirect heat transfer. Afterwards the chaff shall be returned to the field as during conventional harvesting. In contrast to the concepts of pillar 2 and 3 this does not make an unexploited biomass feedstock available, but the problem with herbicide resistant and other weeds is tackled by this measure.

In Sweedhart, tests have been carried out to evaluate the applicability of this concept in terms of possible throughput and general proof of concept [13, 14].

2.2 Pillar 2: Total harvest

Total harvest means that everything is harvested from the field including grains, straw and chaff without leaving any material on the field and to store it in a tank on the combine harvester or to transfer it to an accompanying trailer. The idea to remove the chaff and thus the harvested weed seeds has already been proposed in the past [15, 16]. The total harvest only applies when the field fertility allows removing everything without affecting the soil balance. This depends on crop sequences. The harvested material will not be separated on the harvester as usual. Moreover, a fractionation besides the field becomes necessary. This will be the main focus of Sweedhart.

The usability of the single fractions in terms of energetic, material and feed use will be evaluated.

Therefore, tests with existing pilot units investigated the energetic applicability. The material and feed use is investigated by analytical methods and depends on the composition of the material. This measure can raise a big biomass potential that is unused so far.

In the end of the project (April 2019), a conclusion will be provided that shows possible utilization pathways of the agricultural side streams. A cost-benefit analysis compared to conventional harvesting will be given, too.

2.3 Pillar 3: Partial harvest

The main characteristic of this pillar is that only a partial harvest takes place. This means that an intelligent handling of chaff is investigated in order to use it as a fraction for further use (energy, material and feed) while simultaneously reducing the weed seed concentration on the field. Three different partial harvesting methods have been and will be evaluated:

- Collection of chaff during harvesting by continuous overloading.
- Controlled placing of chaff on the straw rows to prevent a homogeneous distribution of weed seeds. Subsequently the swath can be collected and used besides the field. A usage as proposed in pillar 2 is envisaged (compare Fig. 2).
- Compacting of straw-chaff into bales for further use. A usage as proposed in pillar 2 is envisaged (compare Fig. 2).

3 MATERIAL AND METHODS

3.1 Wheat chaff

So far, all investigations were done with material from winter wheat fields. The combine harvester company CLAAS Selbstfahrende Erntemaschinen GmbH collected the material in Germany in 2015. It was stored sealed until the experiments in 2016 and 2017. The chaff consisted of husks with a length of 0.8 mm and of straw with pieces of 1 to 20 cm length. The bulk density was 34 g/L and the water content 7.5 %.

3.2 Field tests

In 2016 and 2017 field tests in winter wheat fields where done in the Elbmarsch region in Germany. During the field tests, two measures have been extensively investigated:

- Placing chaff on the straw swath with subsequent baling
- Partial harvest by continuously overloading chaff onto an accompanying trailer

The used combine harvester was modified in a way that allows a precise handling of chaff in contrast to the normal blow out of chaff. This mechanism allowed placing chaff in a controlled manner directly on the straw swath. Afterwards the swath mixture of straw and chaff was collected and baled in order to simulate conventional harvesting practices. In defined areas, the weed seeds that fell onto the ground were counted and the effectiveness to bring weed seeds into the bales was evaluated.

The same modified combine harvester was used to transfer the chaff directly onto an accompanying trailer instead of blowing it back onto the field. The general feasibility of this measure was tested and data was collected in order to carry out a cost-benefit analysis.

3.3 Hygienisation conditions

In order to find applicable hygienisation conditions to kill or damage viable weed seeds, preliminary simulations and laboratory experiments were done. The intention was to define parameters to ensure the feasibility of a principle implementation on a combine harvester. The possible effect of exhaust gas is object of ongoing research.

3.3.1 Simulation

The temperature profile inside a seed after heat exposure has been determined by the computational fluid dynamics software COMSOL Multiphysics®. A temperature of at least 80 °C at the core was targeted.

This temperature is characterized as the lethal temperature for weed seeds [17]. The mechanisms radiation and convection of heat were analyzed. The seed was approximated as a cylinder with a height of 2 mm and a diameter of 1 mm. The simulation of the convective heat treatment was carried out with two different gas velocities, representing the minimum (=0.08 m/s) and maximum (=8.8 m/s) possible limit within a combine harvester. The results of the simulations are displayed in Table I. Figure 3 shows an example of the temperature distribution within the seed. Here, the applied conditions led to a core temperature of 69.8 °C after 2 s at 250 °C outside temperature. The results gave only a first indication of possible parameters. Transferring these results to real conditions the effects of varying seed sizes, moisture content and different heat transfer velocities have to be taken into account.

Table I: Required exposition times in [s] for hygienisation based on a core temperature of the seed of 80 °C

Temperature	Radiation	Convection (v=0.08 m/s)	Convection (v=8.8 m/s)
100 °C	(*)	10.3 s	3.2 s
150 °C	26.7 s	4.7 s	1.7 s
200 °C	14.5 s	3.2 s	1.3 s
250 °C	9.1 s	2.4 s	1.1 s
300 °C	6.2 s	2.0 s	0.9 s
400 °C	3.5 s	1.5 s	0.8 s

(*) The simulation was conducted for 60 seconds. For the simulation with radiative heat at 100 °C the core of the model seed did not reach the demanded temperature of 80 °C.

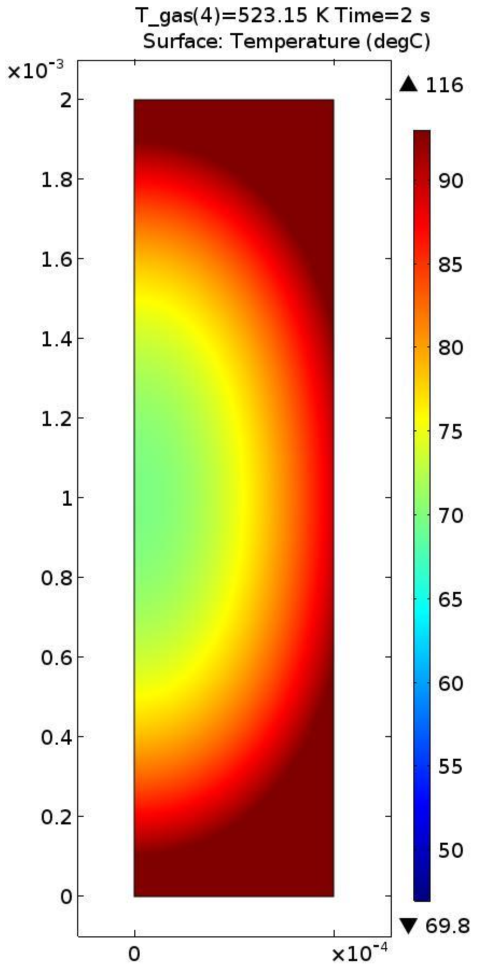

Figure 3: Temperature profile (= right y-axis in °C) of a seed (2 mm height = left y-axis and 1 mm diameter = x-axis starting with the middle of the seed) after 2 seconds heat exposure at 250 °C

3.3.2 Hygienisation experiments

Because of the simulation, the hygienisation experiments have been made for temperatures between 100 °C and 400 °C and for exposition times between 0 s and 60 s. Model seeds such as tomato and cress have been used to evaluate the single effect of radiative or convective heat. These preliminary tests were used to refine the test unit and the parameter range.

Based on the preliminary tests, the experiments with different weed seeds have been refined to a parameter range of 50 °C to 250 °C and exposition times of 2 s to 20 s. The design and conduction of the experiments has been published by Andreasen et al. [13].

3.4 Germination experiments

3.4.1. Germination experiments with model seeds

The seeds from the indirect and direct heat treatment as well as untreated comparison samples were lined out on potting compost. The temperature was about 22 °C. For the examination of the germination ability, a plant propagator, which is an indoor plant growing apparatus, was used in combination with Jiffy® pellets consisting of peat. For steady watering a capillary reservoir mat consisting of fleece was placed below the pots. Each Jiffy® pellet were soaked with 75 ml tepid water. The procedure of soaking took about 5 minutes. The remaining water was drained off. The mesh on the upper side could be opened easily and the counted seeds could be placed in the Jiffy®.

According to the German regulation for biological waste (in German: “BioAbfV”) the destruction of the seed can be ascertained if the seed does not sprout after a duration of 21 days. In the laboratory, the plant propagator had a light exposition of 12 h per day. During the growing period, the Jiffy® pellets were kept moist but waterlogging was avoided. Seeds were regarded as germinated if the root or the shoot was visible. After 21 days in which no seeds sprouted, the inactivation was proofed and the germination test was completed [18].

A germination test for the untreated seeds was performed to have a baseline for comparing the thermally treated seeds. The initial germination indicates how many seeds there were able to sprout before the heat treatment.

Cress seeds had germination percentages between 92-100 % and tomato seeds between 87-96 %.

An example of the results of the germination tests can be seen in Figure 4. In the first line the Jiffy® with the untreated samples were placed. The next two lines are the results of heat treatment with convection at 200 °C. The following ones were for the seeds after 300 °C and 400 °C heat treatment. The exposition times were increasing from left to right from 2 s to 10 s and in the next line from 20 s to 60 s for each temperature.

Figure 4: Germination of tomato seeds after three weeks (© Fraunhofer UMSICHT)

3.4.2. Germination experiments with weed seeds

The design and conduction of the germination experiments has already been described in detail in Andreasen et al. [13].

3.5 Pelletizing experiments

Besides reducing weed infestation on fields, the aim of the project Sweedhart is to make chaff as biomass feedstock for different applications available. Using chaff directly is unfavorable because of its low bulk density. Transportation of loose chaff will not be efficient. Thus, pelletizing chaff is a possibility to increase the bulk density significantly.

The pellet press 14-175 from Amandus Kahl has been used to evaluate the pelletizability. A bore ratio (l/d) of 4 and 5 was investigated. The initial water content of the chaff was varied between 8 to 28 %. Finally, it was also tested, if starch in 1% and 2% additions can improve the pelletizing process and the quality of the pellets. The produced pellets were evaluated against the EN Plus standards for pellets [19].

3.6 Material use assessment of chaff

The wheat chaff is analyzed by Nuclear Magnetic Resonance Spectroscopy (NMR) in order to define available metabolites in the chaff fraction. This might indicate new fields of application for chaff.

In addition, a literature research was carried out in order to summarize existing utilization pathways for chaff.

4 INTERMEDIATE RESULTS AND DISCUSSION

4.1 Results of hygienisation concept (pillar 1)

Tomato and cress seeds were chosen as model substances for the experiments in order to identify conditions where a change in germination capacity emerges. Experiments were made with regard to direct and indirect heat treatment. The inactivation was examined with germination tests. The investigation of the influence of thermal treatment has successfully shown its potential in reducing the germination capacity of weed seeds. Dependent on temperature and exposition time a thermal inactivation up to 100 % was achieved.

Cress and tomato seeds were compared to black-grass (*Alopecurus myosuroides*) seeds concerning their germination behavior after heat treatment. The germination experiments for the model plants were carried out in triplicate. Black-grass germination tests were only carried out once for a rough comparison. More detailed experiments with black-grass and other weed species were investigated by Andreasen et al. [13]. The chosen model species are a good approximation for real weed seeds. For the treatment with higher exposition times black-grass showed a similar behavior as tomato seeds and cress seeds.

Figure 5 and 6 show the exposition and temperature dependence on the germination capacity (from green (no germination) to red (everything germinated)) exemplarily for tomato and black grass seeds under convective heat treatment. The initial germination percentages (= no thermal treatment) for the substances are 87.8 ± 18.4 % for tomatoes and 44.8 ± 15.8 % for black grass.

	2 s	5 s	10 s	20 s	40 s	60 s
100 °C	100 ± 0	100 ± 0	100 ± 0	93 ± 9	87 ± 9	93 ± 9
150 °C	100 ± 0	80 ± 16	87 ± 9	93 ± 9	40 ± 16	0 ± 0
200 °C	87 ± 19	93 ± 9	73 ± 16	60 ± 16	0 ± 0	0 ± 0
250 °C	80 ± 16	87 ± 9	67 ± 9	0 ± 0	0 ± 0	0 ± 0
300 °C	87 ± 9	100 ± 0	27 ± 9	0 ± 0	0 ± 0	0 ± 0
400 °C	80 ± 0	53 ± 41	13 ± 19	0 ± 0	0 ± 0	0 ± 0

Figure 5: Convective heat treatments of tomato seeds and the resulting germination percentages (+/- standard errors)

	2 s	5 s	10 s	20 s	40 s	60 s
100 °C	40 %	73 %	53 %	73 %	53 %	93 %
150 °C	73 %	53 %	47 %	67 %	60 %	7 %
200 °C	60 %	67 %	60 %	80 %	7 %	0 %
250 °C	47 %	47 %	67 %	0 %	0 %	0 %
300 °C	47 %	53 %	47 %	7 %	0 %	0 %
350 °C	7 %	27 %	0 %	0 %	0 %	0 %

Figure 6: Convective heat treatments of black grass seeds

The thermal treatment of black-grass showed that the germination percentages increased when seeds were exposed to low temperatures and/or small exposition times, meaning that these treatments have broken the dormancy of many black-grass seeds.

The investigations with model seeds as well as with ordinary weed seeds [13] showed that seeds can be killed or seriously damaged by heat treatment. Nevertheless, some improvements needs to be done in terms of optimizing the heat transfer into different weed species by adapting the experimental set-up. Some restrictions exists in terms of available heat inside the combine harvester and limited residence time because of harvesting velocity. Further research is necessary to establish online hygienisation on the combine harvester as a viable concept.

The determined treatment parameters could theoretically be fulfilled inside the combine harvester to kill or damage weed seeds seriously. But variations in terms of moisture content or other “real life” influences during harvesting make it difficult to guarantee an effective hygienisation throughout the complete harvest.

Depending on the weed species and the heat treatment, this could lead to release of seed dormancy of some species and consequently make them sensitive to weed control before the new crop has been established instead of being incorporated into the soil seed bank. Long-term research is necessary to evaluate the effect on the soil seed bank.

Another limitation for implementing the online hygienisation is the available heat of the exhaust gas. If the moisture content of the harvested material is high, the temperature may not be high enough to heat the seeds up until the core reached 80 °C. Too high moisture contents would lead only to surface evaporation without affecting the germination capacity of seeds. Furthermore, the chaff may have an isolating effect, which protect some weed seeds to be exposed for a sufficient high temperature damaging them significantly. Thus, the concept of online hygienisation needs to be refined. An additional sieving step inside the combine harvester or beneath the harvester to separate the weed seeds from the chaff would be beneficial. The weight reduction of chaff that is exposed to the exhaust gas heat would lead to harmonize the unbalance of available heat and material that needs to be heated up. A realization inside a combine harvester is unlikely. A separation beneath the harvester possibly makes a hygienisation not necessary, because weed seeds could thus be easily removed from the field.

Finally, the concept could become more viable when the chaff is brought into contact directly with the exhaust gas instead of just transferring the heat. The first investigations indicate that the exhaust gas itself has a significant influence in reducing the germination capacity [14]. Thus, more moderate hygienisation conditions could be applied. Vice versa, the question of sputtering the chaff with toxic components from the exhaust gas still needs to be answered. Bringing toxic components to agricultural fields needs to be avoided under all circumstances.

The concept of pillar 1 shows that the idea of an online hygienisation inside the combine harvester is in principle possible, but further research is necessary to establish this as an applicable alternative to current harvesting concepts.

4.2 Chaff collection and utilization (pillar 2)

In pillar 2 the concept of a total harvest is pursued.

Without doubt, with a total harvest also all harvested weed seeds will be removed from the field. Thus, only the utilization pathways of the additional biomass feedstock chaff have been investigated. Possible utilization pathways are an energetic utilization in terms of combustion and the material use of chaff.

4.2.1 Energetic use of chaff

A prerequisite for using chaff energetically is to increase to bulk density of chaff significantly in order to ease the handling and to decrease the efforts of logistics.

In Sweedhart, applicable pretreatment and pelletizing conditions for chaff have been found. It was possible to produce pellets that meet the ENPlus standards for pellets [19]. The details of these investigations are summarized in Weiß and Glasner [20].

The characteristics relevant for combustion and the combustion behavior of the pellets itself were analyzed, too.

Chaff pellets can be used in existing combustion applications, but some constraints need to be taken into account resulting from a higher ash content compared to wood pellets. Nevertheless, by considering these limitations chaff pellets are a viable fuel for energetic use.

4.2.2 Material use of chaff

As previously discussed in section 4.2.1, chaff can be pelletized. This makes chaff a viable source for pellets used in stables as litter.

Based on the literature research and NMR analysis some promising applications of chaff have been determined. These are:

- Construction (insulating boards, cardboard, bedding)
- Soil improvement (mulch, mushroom compost)

- Agricultural use (weed growth inhibitor, for animals diet, mushroom cultivation)
- Wheat water extracts contain significant quantities of high added value compounds (betaine, GABA, sugars and essential amino acids)

The details of these investigations are currently prepared for publication and thus cannot be discussed in this paper in detail.

4.3 Effect of precise chaff handling (pillar 3)

As chaff contains all harvested weed seeds, pillar 3 pursues the concept of removing the chaff from the field and to use it for purposes already described in section 4.2. The removal of chaff can be done in different manners, but always needs to be integrated into the conventional harvesting process. Therefore, the chaff need to be directed in a controlled manner (cf. Fig. 7) instead of blowing it out uncontrollably (cf. Fig. 1). In the following two handling options are discussed.

Figure 7: Guided chaff deposition on top of the straw swath (© CLAAS)

4.3.1 Straw-chaff swath baling (pillar 3)

As initial step, the chaff was placed on top of the straw swath (cf. Fig. 7). This worked sufficiently and the uncontrollably blow out of chaff was prevented and thus the wide distribution of weed seeds. The next step was to bale the straw-chaff swath as done normally with straw swaths.

Here, some limitations of the proposed concept become obvious:

1. Straw swaths might remain on the field in order to reach the desired moisture content of the straw before it is baled. Doing the same with the straw-chaff swath may result in spreading of light particles like seeds if they are exposed to wind. Counteracting this distribution can only be done, if the swath is baled directly after harvest. This may further lead to too moist bales with mold resulting in loss of such bales.
2. The material need to be taken up for baling. Here, chaff and other light particles fell out and were lost on the field.
3. During baling further chaff and light particles were lost.

Although some negative effects have been observed, positive ones in comparison to conventional harvesting also exist.

I. Seeds that fall out before and during baling are more concentrated on the field than in conventional harvesting. A wider distribution is prevented by this method.

II. Although there are many losses, some seeds will end up in the straw-chaff bales and thus a certain amount of seeds are removed from the field by this method.

The conclusion is that this method may have limited effect on the weed seed removal. Continuous overloading as discussed in 4.3.2 is far more effective. In addition, continuous overloading is more cost efficient especially when the bales are broken apart again besides the field. If straw-chaff bales are used for other purposes without further processing then this concept may be a viable option for future harvesting methods that make additional biomass available and that reduce simultaneously the weed pressure on agricultural fields.

4.3.2 Continuous overloading (pillar 3)

During the field tests, a continuous overloading of chaff with an adapted harvester onto an accompanying trailer was tested. It was observed that the complete chaff stream can be transferred without any losses. Therefore, the weed seed removal from the field is very efficient.

One disadvantage of this concept is that additional efforts are necessary. The trailer makes additional personnel expenditure necessary and additional costs for the trailer will occur. However, a new biomass feedstock becomes available that can be used for purposes according to section 4.2. Finally, a positive cost-benefit ratio should be possible.

Even if no additional monetary benefit can be generated the positive effect of removing weed seeds and avoiding weed spreading in the next years will overweight. Pillar 3 is a viable concept based on the results achieved so far. The long-term effects still need to be observed and the chaff removal from the field should not have any significant effect on the organic matter in the soil.

4.4 Transfer to other crops

The investigations in this work rely on wheat fields only. A transfer of the results to other crops like rapeseed, barley etc. is still ongoing.

5 CONCLUSIONS

Field tests to evaluate the weed reduction on fields by mechanical measures were carried out in 2016 and 2017.

The results achieved so far are promising. While the long-term effect of reducing weed seeds in the soil seed bank by the proposed measures remains object to future evaluation, the basic principles have been approved successfully. Nevertheless, chaff can be made available as a so far unexploited biomass feedstock. The energetic use and pelletizing of chaff was investigated and can be recommended. Chaff can also be used materially for different purposes, but the most practical and efficient way still needs to be determined. The hygienisation experiments showed that it is in principle possible to kill harvested weed seeds by the energy created during the harvest process, but that it will be difficult to implement this concept without changing the construction of the combine harvester significantly.

New harvesting methods could contribute to reduce weed infestation and to lower problems with herbicide resistant species. This work provided some new successful approaches. A catalogue of evaluated measures will be worked out and published in 2019.

6 REFERENCES

[1] M. Peterson, A. Collavo, R. Ovejero, V. Shivrain, M. Walsh, The challenge of herbicide resistance around the world: a current summary, Pest Management Science, (2017), doi:10.1002/ps.4821.

[2] I. Heap, The International Survey of Herbicide Resistant Weeds, Online, Internet, Tuesday, January 16, (2018), Available www.weedscience.org.

[3] C. Andreasen, H. Stryn, Increasing weed flora in Danish beet, pea and winter barley fields, Crop Protection, 36 (2012), pag. 11–17.

[4] C. Weiser, V. Zeller, F. Reinicke, B. Wagner, S. Majer, A. Vetter, D. Thraen, Integrated assessment of sustainable cereal straw potential and different straw-based energy applications in Germany, Applied Energy, 114 (2014), pag. 749–762.

[5] D. Kiš, N. Jovičić, A. Matin, S. Kalambura, S. Vila, S. Guerac, Energy value of agricultural spelt residue (Triticum spelta L.) - forgotten cultures, Technical Gazette, Vol. 24 Issue 2 (2017), pag. 369–373.

[6] W. Wiwart, M. Bytner, L. Graban, W. Lajszner, E. Suchowilska, Spelt (Triticum spelta) and Emmer (T. dicoccon) Chaff Used as Renewable Source of Energy, BioResources, Vol. 12 Issue 2 (2017), pag. 3744–3750.

[7] EUROSTAT, Wheat and spelt by area, production and humidity, URL: http://ec.europa.eu/eurostat/tgm/refreshTableAction.do;jsessionid=eH4_MMw5my4ZJsLm9XGH-vHfBwdwl57X2k8Dc6MFqgjMIlC62ouD!1614172686?tab=table&plugin=1&pcode=tag00047&language=en, (2018), Accessed May 8, 2018.

[8] D. McCartney, H. Block, P. Dubeski, A. Ohama, Review: The composition and availability of straw and chaff from small grain cereals for beef cattle in western Canada, Canadian Journal of Animal Science, 86 (2006), pag. 443–455.

[9] J. Grube, M. Böckelmann, The harvest home and dry – key figures for grain drying, Landtechnik, Vol. 66 Issue 4 (2011), pag. 276–281.

[10] A. Walsh, R. Harrington, S. Powles, Harrington Seed Destructor: A new nonchemical weed control tool for global grain crops, Crop Science, 52 (2012), pag. 1343–1347.

[11] M. Walsh, P. Newman, Burning narrow windrows for weed seed destruction, Field Crops Research, 104 (2007), pag. 24–30.

[12] M. Walsh, J. Ouzman, P. Newman, S. Powles, R. Llewellyn, High levels of adoption indicate that harvest weed seed control is now an established weed control practice in Australian cropping, Weed Technology, 31 (2017), pag. 341–347.

[13] C. Andreasen, Z. Bitarafan, J. Fenselau, C. Glasner, Exploiting waste heat from combine harvesters to damage harvested weed seeds and reduce weed infestation, Agriculture, Vol. 8 Issue 42 (2018), doi:10.3390/agriculture8030042.

[14] K. Jakobsen, J. Jensen, Z. Bitarafan, C. Andreasen, Killing weed seeds with exhaust gas from a combine harvester, Plant Protection, (2018), Submitted.

[15] R. McLeod, Harvesting system and method, Patent CA2180691C, (1996).

[16] J. Rumpler, Method and device for harvesting threshed crops, Patent US8961286B2, (2010).

[17] G. Bollen, The selective effect of heat treatment on the microflora of a greenhouse soil, Netherlands Journal of Plant Pathology, (1969), pag. 157–163.

[18] U. Baier, Thermal inactivation of plant seeds in sewage sludge, Water Science and Technology, 36 (1997), pag. 197–202.

[19] EN Plus: Anforderungen an die Pelletqualität, from ENPlus Handbuch für Deutschland, Österreich und die Schweiz, 3rd edition, Berlin: Deutsches Pelletinstitut GmbH, (2015), pag. 73–78.

[20] B. Weiß, C. Glasner, Evaluation of the process steps of pretreatment, pellet production and combustion for an energetic utilization of wheat chaff, Frontiers in Environmental Science - Agroecology and Land Use Systems, (2018), submitted and accepted.

7 ACKNOWLEDGEMENTS

This work was done as a part of the project Sweedhart - Separation of weeds during harvesting and hygienisation to enhance biomass production in the long term. Sweedhart is a transnational research project funded in the frame of the ERA-NET Cofund FACCE SURPLUS (Sustainable and Resilient agriculture for food and non-food systems), which is formed in collaboration between the European Commission and a partnership of 15 countries in the frame of the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI). FACCE SURPLUS is committed to improve collaboration across the European Research Area in the range of diverse, but integrated, food and non-food biomass production and transformation systems, including biorefining. We thank the German Federal Ministry of Education and Research (project number 031B0164A and 031B0164B), Innovation Fund Denmark and the Research Council of Norway (project 259858) for financial support at national level. The Authors are grateful to the students of Fraunhofer UMSICHT for their helpful cooperation, namely Barbara Weiß, Ruth Schlautmann and Markus Thiele. The responsibility for the contents of this publication is taken fully by the Authors.

8 LOGO SPACE

sweedhart

Project partners:

Fraunhofer
UMSICHT

UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

NTNU – Trondheim
Norwegian University of Science and Technology

CLAAS