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What is known about the effect of stubble tillage – what is unknown?

So far, the implication of stubble tillage has not been studied intensively. Recommendations of early and shallow stubble tillage are based on experience and potentially observation by farmers. It seems to be correct that stubble tillage controls effectively perennial weeds. However, stubble tillage will not necessarily have the same effect on annual weeds and volunteer crops. Early stubble tillage can result in increased weed and volunteer problems. The data basis with respect to decomposition of straw as affected by stubble tillage is very scarce. Soil moisture apparently will not be conserved by early stubble tillage in every case. The current data basis tends to contradict this observation. Preliminary research showed that stubble tillage tends to increase yields. Further research to quantify the effects of stubble tillage is necessary.

Keywords
Stubble tillage, water conservation, weed emergence, seed losses, mineralisation of straw

Abstract
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Soon after harvesting of combine crops stubble normally receives a shallow cultivation. This is recommended by almost every German-language crop husbandry textbook. As current example [1] is mentioned here. Normally stubble tillage is seen as a measure encouraging the germination of volunteer grain and weed seeds so that the resultant young plants can be destroyed by subsequent cultivations. The technique is also believed to reduce perennial weed density. A further reason is encouragement of soil moisture retention through interruption of upward capillary moisture transport. Decomposition of harvest residues and organic manure is also said to be encouraged and this is also thought to have a positive influence on control of plant diseases transferable via straw and stubble. Summarised, stubble tillage should positively influence yields of subsequent crops in the rotation through such effects.

The correctness of such assumptions has been insufficiently researched so far and the aim of this work is to present existing data on stubble tillage to highlight gaps in research.

Encouraging emergence of seed losses

Stubble regrowth occurs where there's sufficient soil moisture or precipitation, a process clearly seen following oilseed rape or cereal harvest. Stubble regrowth leads to the assumption that stubble tillage has a positive effect on the germination of seed lost before or during the harvesting process. However, not taken into account in this respect is that such lost grain can germinate without any tillage, especially where the seed is small (fig. 1). Also not considered is that the amount of volunteer seeds in stubble can be reduced through other factors, e.g., through consumption (ground beetles, mice, birds) or by dying-back through lack of moisture post-germination.

With grain seed, tillage appears to increase emergence (**table 1**). In a trial on the training and research farm at Tachenhausen (Nürtingen-Geislingen University) a stubble cultivation trial was set up in 2007 in cooperation with the company Lemken (**figure 2**) .In total, two passes in stubble with cultivator increased plant emergence compared with a single pass or no cultivation at all (= control). In the "control" variant stubble remained uncultivated between harvest and tillage in preparation for the following crop. **Table 1** shows in each case the sum of emerged plants from seed losses, counted and totalled before each successive cultivation.

Whether the encouragement of emergence also means that seed survival and, with that, the possibility of its appearance as volunteers in the following crop was reduced, is not confirmed by this result. There were no counts of soil seed population carried out for this trial. So far, volunteer plants have not appeared in any of the trial plots in the following rotation.

Counts of soil seed reserves have been conducted during long-term trials concerning oilseed rapeseed losses [2]. Hereby it was determined that no linear correlation existed between the numbers of emergent oilseed rape volunteers in stubble and seed survival. On the contrary, trials conducted in a number of European countries have shown, especially with earlier stubble tillage under dry soil conditions, that there's an increased likelihood of secondary dormancy. If, on the other hand, oilseed rape seeds are left lying on uncultivated stubble post-harvest, thereby exposed to daylight, no dormancy develops. Instead,

Fig. 1

Fig. 1: Lost seeds can sprout on stubble even without soil cultivation

Fig. 2

Fig. 2: Repeated stubble tillage improved the emergence of volunteer cereals

Table 1

Table 1: Number of cereal plants [plants • m^{-2}] that emerged during the years 2007–2009 on the stubble. The data show the sum of plants that emerged in the time between crop harvest and seed bed preparation of the following crop. Letters indicate significant differences between treatments within one year at $p < 0.05$

Jahr/ *Year*	Kontrolle/ *Control*	1 × Grubber/ *1 × Cultivator*	2 × Grubber/ *2 × Cultivator*
2007	30.3 b	42.0 b	60.8 a
2008	74.5 c	34.8 b	112.0 a
2009	78.5 b	72.5 b	112.5 a

the seeds germinate as soon as they receive sufficient moisture, or after the first precipitation.

Encouraging emergence from weed seeds

It is generally assumed that, as with crop plants, weed seeds germinate as a result of stubble tillage and then are destroyed by subsequent cultivation passes so that the number of new volunteers in overall population is thereby reduced. This correlation appears not to be the case with weeds. Two things have to be considered here. Firstly, most weed seeds display strongly developed dormancy at harvest and in summer (primary dormancy). This is how they can survive the intercrop fallow period with regular tillage operations and why one finds hardly any emerged weeds in the stubble, whether cultivated or not. Secondly, the majority of weed seeds are very small. Thus improving moisture supply through incorporation in the soil is less relevant than with crop plant seeds. Weed seeds need extremely small amounts of moisture for germination and can in many cases be sufficiently supplied from dew as well as from capillary soil moisture supply. Alongside this, dormancy established at maturity tends to be reduced under the dry, warm conditions present on the field surface post-harvest (compared with conditions in the soil). This means that germination is more likely for these types during the intercrop fallow period when they are lying on the surface of stubble than when incorporated with the soil.

Literature from the 1960s indicates that stubble tillage can increase weed populations (**table 2**). As part of a trial, different techniques of stubble tillage were carried out over five years or, in one variant the respective stubble areas were left uncultivated (control variant). The least seed weeds occurred in summer cereals during spring in the trial plots where stubble had not been cultivated [3]. Similar results were reached in a trial of stubble tillage in organically managed farming a few years ago in Kleinhohenheim [4]. With this in mind, the theory of controlling annual weeds through stubble tillage is to be regarded very critically. Special investigation is required into the effect of stubble tillage on the widespread grass weed, blackgrass (Alopecurus myosuroides). Possibly, part of the current blackgrass problem can be traced back to the fact that, often, stubble cultivations aim at an early and good straw incorporation. Here, the farmer wants to see as much straw as possible incorporated into the soil and the ground thoroughly loosened-up. In every case the aim is for a shallow tillage. But even this approach can help seed survival for a number of weed varieties, as suggested by results of a model trial conducted by Jensen [5]. Under the conditions of the trial referred to here blackgrass played only a minor role in each case.

Table 2

Table 2: Weeds in cereals in spring 1964. Effect of varied stubble tillage of the previous five years. Field experiment carried out by Koch and Rademacher close to Stuttgart [3]

Stoppel-bearbeitung/ ***Stubble tillage***	**Samenunkräuter [Pflanzen • m^{-2}]/** ***Annual weeds [plants • m^{-2}]***	**Wurzel-unkräuter [Triebe • m^{-2}]/** ***Perennial weeds [shoots • m^{-2}]***	**Ackerkratzdistel [g • m^{-2}]/** ***Canada thistle [g • m^{-2}]***
Schälpflug/ *Shallow plough*	368	56.6	10.9
Fräse/ *Rotavator*	457	57.0	16.6
Scheibenegge/ *Discs*	359	70.9	26.1
Kontrolle/ *Control*	302	96.2	20.1

Table 3

Table 3: Gravimetric soil water content in percent in 0–30 cm depth assessed on the stubble tillage experiment Tachenhausen in September 2007-2009. The standard deviation is shown In brackets. Letters indicate significant differences between treatments within one year at $p < 0.05$. The data from 2009 had heterogenous variances and could not be homogenised by transformation. Only descriptive statistics are therefore shown.

Datum/ ***Date***	**Kontrolle/** ***Control***	**1 × Grubber/** ***1 × Cultivator***	**2 × Grubber/** ***2 × Cultivator***
17.09.2007	19.5 c *(0.48)*	18.7 b *(0.33)*	17.7 a *(0.22)*
18.09.2008	18.1 b *(0.30)*	18.0 b *(0.05)*	17.2 a *(0.41)*
18.09.2009	18.9 *(0.71)*	20.3 *(5.27)*	17.1 *(0.25)*

Combating perennial weeds

In contrast to annual weeds, perennial weeds are definitely reduced by stubble tillage. Several literature references confirm this; as do the already quoted publications [3; 4]. More recent investigations into the effect of stubble tillage under organic management also clearly show that for combating and suppression of perennial weed populations, in particular of creeping thistle (Cirsium arvense) und couch grass (Elymus repens), optimally timed stubble tillage is important. For this reason stubble tillage cannot really be done without in organic farming. There is evidence that in such cases the skim plough, or the Zobel version of the same technique (the "stubble-plane"), are more effective through their soil inverting effect than non-inverting implements such as rigid tine cultivators.

In conventional farming perennial weeds don't usually play a dominating role and this can effect the evaluation of stubble tillage as a weed control operation.

Conservation of soil moisture

The general opinion is that stubble tillage prevents excessive loss of soil moisture through interruption of the soil capillary action bringing moisture to the surface. Verification of this was not possible in the study presented here. In the few experiments carried out on this concept so far, the evidence was rather that the action had the opposite effect and led to a drying out of the soil (**table 3**). A trial looking into the influence on moisture retention of stubble tillage (and of straw on the soil surface) it was additionally shown that the combination of uncultivated stubble with straw on the surface conserved soil moisture especially well [6].

Data available from trials on direct drilling show this is no surprising result. There's a need for further trials on this question. But these have to be carried out under drier soil conditions than are usually experienced in southwest Germany in summer. Possibly the conditions in central Germany change things around. There, interruption of the capillary moisture ascent might have a greater influence on moisture balance than evaporation reducing effects. Evaporation effects directly following stubble tillage would be different too.

Encouraging decomposition of harvest residues and organic manure

According to widespread opinion, increasing contact surface area between soil and organic material in stubble encourages breakdown of this material. This is confirmed by results from conservation cultivation trials [7]. Small sacks filled with oilseed rape straw left lying on a field surface, or buried there, from March to August in a Canadian trial, mineralised faster when buried. The extent to which the months of the intercrop fallow period were relevant in terms of comparison is so far not known. Important is a rapid rotting of straw for the interruption of the infection chain from straw of the previous crop to the young plants of the next crop. In a trial at Tachenhausen in 2009 the extent of eye spot (*Pseudocercosporella herpotrichoides*) infection in wheat was recorded at harvest (**table 4**).

Results come from a single year only so must be interpreted with great caution. However, they tend to indicate an encouragement of infection through stubble tillage rather than the opposite effect.

Fusarium spec., a further important fungal disease carried over on harvest residues, was not significantly present in this trial so that no conclusion can be made in this respect.

Table 4

Table 4: Proportion of wheat plants [%] infected with Pseudocercosporella herpotrichoides at harvest 2009 on the stubble tillage experiment in Tachenhausen. Letters indicate significant differences between treatments at p < 0.05

	Kontrolle/ *Control*	**1 × Grubber/ *1 × Cultivator***	**2 × Grubber/ *2 × Cultivator***
Stark erkrankt/ *Severely infected*	6.0 b	15.5 a	10.8 ab
Mittel erkrankt/ *Medium infected*	27.3 a	28.8 a	29.5 a
Leicht erkrankt/ *Weakly infected*	40.8 a	38.0 a	45.5 a
Gesund/ *Healthy*	26.0 b	17.5 ab	14.0 a

Yield increases related to stubble tillage

At the end of the 2007 harvest a trial was set-up to investigate the effect of stubble tillage on yield. Site was an almost weed-free trial field (cereal seed production farm) on very fertile farmland (loess based para-brown soil) at Tachenhausen training and research farm. **Table 5** shows grain yields in the first three trial years. In particular the summer crops oats and spring barley were supported by stubble tillage. No difference was found in the yields of winter wheat.

On Kleinhohenheim research farm (organic management) omitted stubble cultivation proved to be very yield-reducing because of the massive increase in creeping thistle population. In the stubble tillage trial at Tachenhausen this effect could not be the reason for the reduced yields in oats and spring barley that were experienced. There has to be another reason. Possibly the plots without stubble tillage had a poorer soil structure than those where one or two stubble cultivation passes were carried out.

Conclusions

The results presented here emphasise the many unknown factors remaining regarding effects of stubble tillage. Unequivocally, stubble cultivations decrease populations of perennial weeds. Thus the technique is indispensable in organic crop production, or in general under growing conditions with high densities of perennial weeds. Hereby, recommendation of early and, where necessary multiple, stubble cultivations is definitely correct.

Under growing conditions where perennial weeds are less important, on the other hand, the question may be asked whether early intensive stubble tillage is always meaningful. In some cases, grass weed problems, e.g. with blackgrass, could be encouraged by the action. There's something to be said for the opinion that thereby the dormancy of blackgrass is increased and thus its survival supported. Effect on yield is not clear.

Table 5

Table 5: Yields [dt • ha^{-1}] at 14 % moisture content on the stubble tillage experiment Tachenhausen in the years 2008 to 2010. Letters indicate significant differences between treatments within one year at p < 0.05

Kultur/ *Crop*	**Jahr/ *Year***	**Kontrolle/ *Control***	**1 × Grubber/ *1 × Cultivator***	**2 × Grubber/ *2 × Cultivator***
Hafer/ *Oats*	2008	86.4 b	91.0 ab	92.3 a
Winterweizen/ *Winter wheat*	2009	80.8 a	81.2 a	80.5 a
Sommergerste/ *Spring barley*	2010	87.3 b	90.7 a	91.8 a

The trial presented here in this connection was based on three years of results on a single site. Further trials are therefore urgently required. Especially for farmers that cultivate without the plough it's important to know to what extent soil cultivation in the intercrop fallow period can compensate for the negative effect of non-inversion cultivations.

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