

Influence of soil tillage methods on the weediness and yields of spring wheat, spring barley and field pea in organic crop rotation

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Abstract. The influence of different soil tillage methods - (1) reduced tillage without soil inversion, 8–10 cm (RT), (2) ploughing only 18–25 cm (P) and (3) stubble cultivation, 8–10 cm and ploughing, 18–25 cm (SC+P) on the weediness and yield of grain crops are analysed in this paper. The studies were made in an organic crop rotation: spring barley with undersown red clover/timothy - red clover/timothy - red clover/timothy - spring wheat - field pea, which was set up at Kuusiku Testing Centre in 2003. There were only a few wandering perennials (WP) on the experimental plots of SC+P and grain yields of spring wheat, spring barley and pea were highest. The WP spread quickly on the P plots and the grain yield of spring wheat and pea were lowest. The weediness of WP in the case of RT was lower than with P, but higher than SC+P. Conversely, the number of annual weeds in the summer wheat and pea was highest in SC+P. The grain yield of spring barley was lowest using RT.

Key words: annual weeds, organic farming, ploughing, reduced tillage, stubble cultivation, wandering perennial weeds

INTRODUCTION

Organic farming began to spread in Estonia during the 1990's, and scientific experiments in organic agriculture commenced at the beginning of the 2000s. In 2003, Kuusiku Testing Centre began a long-term, 3-factorial organic crop rotation experiment (soil tillage method, manure application, sowing time).

On-site visits of organic farms have shown that a large number of Estonian organic farmers are having problems with weeds in their fields - one reason for low yields of organic crops. The problem might be that organic farmers often use only ploughing for soil tillage and do not combine this with prior stubble cultivation that would help to exhaust and extinguish weeds. Stubble cultivation dismembers the propagation organs of wandering perennial weeds and prevents diversion of resources from storage organs to shoots. After being buried by deep ploughing, these organs are exhausted and shoots are often unable to reach the soil surface, thus are extinguished. This is a classical approach for controlling perennial weeds (Håkanson, 2003).

At the same time, we lack data suggesting whether stubble cultivation, together with ploughing, is in the long run sufficiently effective in organic farming (where herbicides cannot be utilised), in order to control weeds and increase crop yields, compared to plough-based soil tillage. Regarding soil tillage in conventional farming,

there is a rapidly spreading method today to use reduced tillage without ploughing, which is much more economical than ploughing. Reduced tillage decreases organic matter mineralization in soil, soil erosion, nutrient leaching and improves soil structure. This soil tillage method has become of interest for Estonian organic farmers. In conventional farming, successful weed management consists of reduced tillage, combined with chemicals. In the case of organic farming, there is no sufficient information for deciding whether this soil tillage method is appropriate in controlling the spread of weeds and the yield of crops. Many studies have noted that with reduced tillage, there is an increase in perennial weed species and annual grass density, however shallow tillage may decrease the soil seed bank more rapidly through seedling emergence and action of seed predators and pathogens should be greatest on the soil surface (Mohler, 2001).

The aim of the article is to analyse how different soil tillage in autumn - reduced tillage (RT), ploughing only (P), stubble cultivation and ploughing (SC+P) affects the weediness and yields of organically grown grain crops.

MATERIALS AND METHODS

The experimental area is located on silty clay loam, *Calcaric Cambisol* by WRB classification (2006). This is one of the main field soil types on the island of Saaremaa, one of the largest organic agriculture regions in Estonia. Previously, conventional farming had been carried out in the field.

The fertility (before experiment) of tith (25 cm) in the soil was not high: org-C - 1.8%, pH_{KCL} - 6.7, P - 53 mg kg⁻¹, K - 144 mg kg⁻¹, Ca - 3387 mg kg⁻¹, Mg - 94 mg kg⁻¹, Cu - 0.9 mg kg⁻¹, Mn - 1.01 mg kg⁻¹, B - 1.12 mg kg⁻¹. Generally, organic agriculture in Estonia takes place in soils with low and average fertility.

The studies were conducted in a 5-field crop rotation: red clover/timothy – red clover/timothy – spring wheat – turnip rape or pea – spring barley with undersown red clover/grasses. A block-design method with four replications was used. A field trial comprised 3-factors: time of sowing, different autumn-time soil tillage and fertilising/non-fertilising with manure. There were 240 experimental plots; the plot size was 75 m².

Aiming at weed control, spring wheat was twice harrowed with a flex-tine harrow in spring - for the first time, upon crop germination-emergence, then at the 3–4 leaf stage. Pea was harrowed once when the average plant height was 10 cm. The spring barley was not harrowed due to the undersown crop. Stubble cultivation and reduced soil tillage was done intermittently with a disk harrow and chisel cultivator to the depth of 8–10 cm., twice in total, immediately after grain crop harvesting or up to 1.5 weeks later. The time interval between stubble cultivation operations and ploughing was approximately two weeks. The last soil tillage (ploughing and reduced tillage operation) was conducted in the middle of September within the entire experimental area simultaneously. The depth of ploughing was within 18–25 cm. In the 2nd year red clover/timothy were ploughed in autumn at 2005–2007 and in spring in 2008 on all the experimental area, so there was an after-effect of reduced tillage and stubble cultivation with ploughing on the following spring wheat crop. Manure, 30 t ha⁻¹ with 20.3% of average dry mass content, was applied to spring wheat and spring barley

(earlier to turnip rape 45 t ha⁻¹). No manure was applied to the other section of the trial plots. Spring wheat, spring barley and field pea was sown in two sequences: in spring, upon the first possibility for soil tillage, and 2–2.5 weeks later. Depending on the year, the first sowing took place, pursuant to the actual soil tillage opportunity, within the period from 12 April - 8 May.

The aboveground-parts of the weeds were collected at the end of June and in July, depending on their annual development speed. One (1) or 2 samples were taken from a 0.25 m² area of each trial plot. The species or families, and the number of weeds (shoots) were determined, and also their dry mass, based on the raw mass of the above-ground parts, presented per 1 m². The weeds are divided into wandering and stationary perennials and annuals by Håkanson (1982).

Data regarding the weediness and yield in spring barley were collected for all experimental factors in 2004–2008. The experimental study of soil tillage for spring wheat was not introduced or implemented until 2007-2008. Field pea is a new crop replacing turnip rape, which had failed in previous years. Thus, the data concerning the weediness and grain yields of pea are presented only for 2008.

Grain yields of crops were recalculated per 1ha, based on dry mass content. Dry mass and number of weeds (shoots) and grain yields, on the background of different soil tillage methods, are presented as an average of remaining experimental factors (sowing time, non-manured or manured).

Experimental data was processed statistically utilising the dispersion and correlation analysis.

RESULTS AND DISCUSSION

The weediness of wandering and stationary perennials

Upon conversion from conventional farming to organic farming during 2003–2004, the weediness was low in the experimental area (Sepp et al., 2005). However, since 2005, in the case of ploughing only (P), the share of wandering and stationary perennial weeds (PW) started to increase quickly. In grain crops, *Sonchus arvensis* L. dominated among wandering perennials. The share of *Cirsium arvense* L. was remarkably smaller. To a lesser extent, there was also *Elitrigia repens* L. and *Stachys palustris* L. There was only one species of stationary perennial - *Taraxacum officinale* - with reduced tillage (RT).

The dry mass (DM) and number of shoots of wandering and stationary perennial weeds (number of PW) in spring barley with undersown red clover/timothy in case of P was respectively 90.6% and 90.9% larger than in the case of SC+P (Figs 1, 2). Still, over the experimental years, the number of WP in barley was remarkably smaller than in wheat and pea. At the same time, the dry mass and number of PW, in the case of P, differed substantially during different years. For instance, in 2006, the number of PW, in the case of P, was the highest among the compared years (55 shoots of PW per square metre) however, due to a strong drought during the vegetation time, the size and mass of their aboveground parts remained relatively small. Likewise, in the case of RT, the DM and number of PW were relatively small, exceeding, non-significantly, the DM and number of WP in comparison with stubble cultivation and ploughing (SC+P). This indicates that repeated RT managed to control PW in barley. As a whole, the general

proportion of *Sonchus arvensis* and likewise PW, in barley with undersown red clover/timothy, during all years, was significantly smaller than in the case of the other crops. Likewise, the initial results of a study carried out in Norway show that red clover, when undersown to oats, reduced the biomass of *Sonchus arvensis* (Teasdale et al., 2007). According to Rasmussen et al. (2005), the undersown cover crop keeps the nutrients in the upper soil level enhancing the growth of shallow-rooted crops in relation to *Cirsium arvense* which has deep roots. Based on the studies by Rasmussen et al. (2006), the influence of the cover crop on reducing the weediness is equal to low intensity weed harrowing.

With regard to spring wheat, the effect of different soil tillage methods on the weediness was clearly noticeable after growing red clover/timothy for 2 years (without soil tillage). Thus, during 2007–08, the WP dry mass and number in spring wheat, upon P was on average, respectively 74.1% and 75.8% larger than in SC+P. Likewise, as an after-effect of RT, the WP percentage in spring wheat was relatively smaller than in P, nevertheless non-significantly exceeding the dry mass and number of WP in comparison with SC+P.

Pea, as a crop with a relatively low competitive ability, was severely invaded by WP in 2008 upon P and RT. Generally, cereal crops are more competitive than grain legumes (Blackshaw et al., 2007). The drought (in late April-May) and low air and soil temperatures during the emergence of crops did not favour the development of pea plants. On the other hand, abundant precipitation during the rest of the vegetation period facilitated the rapid development of thistles. In the case of P, *Sonchus arvensis*, the dominant weed uniformly and densely covered the entire experimental area of every one of the ploughing variants, so that the suppressed pea plants remained low in growth, which probably explains their extremely low yields (Table 1). In the experimental area with SC+P, there was a relatively low emergence of *Sonchus arvensis* (although more than in spring wheat and spring barley). The DM and number of PW in pea (2008), in the case of SC+P was, respectively, 63.0% and 87.0% smaller than upon P, and 61.4% and 65.1% in comparison with RT. In the case of RT, *Sonchus arvensis* spread in the trial plots in large foci, so that there were also relatively thistle-free spaces in between the foci where pea plants could develop in a more normal manner.

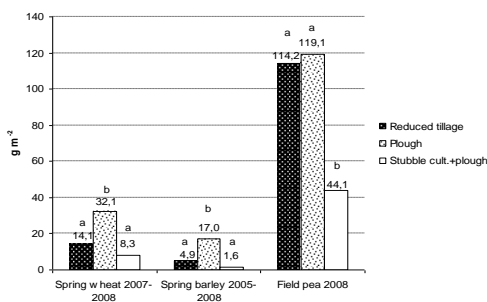


Fig. 1. Dry mass (g m^{-2}) of wandering and stationary weeds in crops. Different letters indicate significant differences ($P < 0.05$)

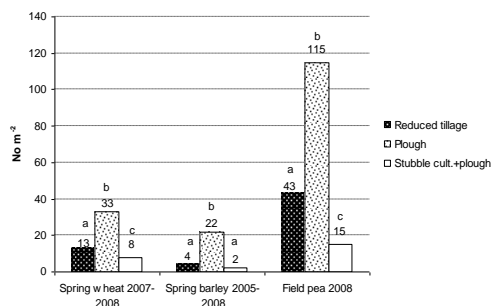


Fig. 2. Number (No m^{-2}) of wandering and stationary weed shoots in crops. Different letters indicate significant differences ($P < 0.05$)

Therefore, the fall in the grain yields of pea was not as low here as in P (Table 1). In 2008, there was a focal spread of *Stachys palustris* in pea, in comparison with the other crops and years. A stationary perennial *Taraxacum officinale* was found with RT, but was absent with plough-based soil tillage methods. Håkanson (1995) argues that with strongly reduced soil tillage and direct drilling, some of the stationary perennials become significant weeds in annual crops. It gives evidence that deep ploughing efficiently controls *Taraxacum officinale*, whereas shallow (reduced) tillage alone does not have such an effect.

The weediness of annuals

The most dominant annual weeds (AW) were *Fumaria officinalis* L., *Veronica arvensis* L. and *Polygonum convolvulus* L.; there were few specimens of other species. In the course of years, the differences in the number and DM of AW were relatively remarkable. In 2005 and 2006, the proportion of AW in crops was generally smaller, as the vegetation period was relatively drought-affected and the AW remained small in growth; the majority dried as early as the first part of July. On the other hand, the vegetation periods of 2007 and 2008 were relatively rich in precipitation and the number of AW was noticeably higher and their growth better.

In spring barley with undersown red clover/timothy, the average number of AW (2004–2008) was the largest with RT, in comparison with other soil tillage methods (Fig. 4), due to the fact that in 2006 and in 2008, the number of AW was abruptly higher upon RT, when compared with other soil tillage methods. Cloutier et al. (2007) have presumed that techniques of reduced tillage might even stimulate weed seed germination. Yet in 2005, and in 2006, the number of AW was the smallest in the case of RT.

In spring wheat (2007–2008) and pea (2008), the smallest average AW was upon RT, in comparison with other soil tillage methods. It has been noted that sod crop in crop rotation manages to remarkably increase the mortality of weed seeds, and reduces their share in the soil seed bank (Warnes & Andersen, 1984). Therefore, red clover/timothy, preceding spring wheat, together with crop harrowing, could reduce the number of AW in wheat. In the case of RT (8–10 cm), mixing involves only the topsoil where, at the depth of 5–7 cm, the majority of weed seeds are able to germinate; the emerged weeds should be extinguished by recurrent stubble cultivation.

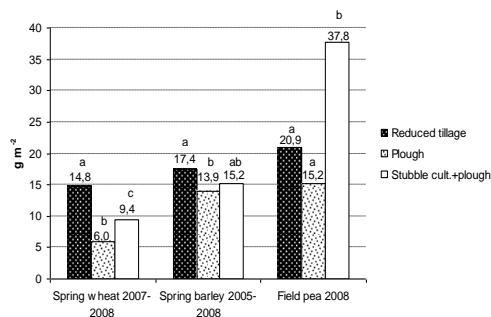


Fig. 3. Dry mass (g m^{-2}) of annual weeds in crops. Different letters indicate significant differences ($P < 0.05$).

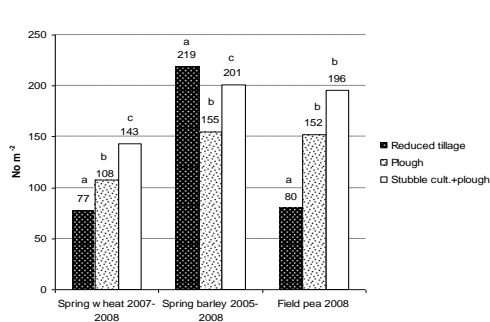


Fig. 4. Number (No m^{-2}) of annual weeds in crops. Different letters indicate significant differences ($P < 0.05$).

New weed seeds are not brought up from the deeper soil layer. For example, Wilson (1981) and Mohler (1993) found that ploughing caused a higher density of germinated and emerged weeds in the first year of the experiment than no-till and reduced tillage. In the following years it was contrary, probably because burial of seeds in the case of ploughing enforces dormancy of weed seeds. An ongoing study should indicate whether the share of AW is reduced with RT or not.

In general, in each year, the number of AW in barley was greater than in the other grain crops, possibly due to undersown red clover/timothy, which prevented harrowing the barley for weed control. During the droughts of 2005 and 2006, the growth of AW, together with undersown red clover/timothy, remained small; in 2007 and 2008, due to abundant precipitation, the voluminous grown red clover also suppressed the growth of AW. Therefore, the DM of AW remained relatively small compared with their number (Figs 3 and 4). A negative correlation occurred ($R = -0.43$; $n = 48$, $P < 0.05$) between PW and AW.

Each year, the amount of AW was higher upon SC+P than in the case of P (Figs 3 and 4). Thus, the number of AW per m² in case of P was 22.9% smaller in spring barley, 24.5% in spring wheat and 22.4% in pea (2008) than with SC+P. In RT, the number of AW per m² was 46.2% smaller in spring wheat and 59.2% in pea (2008) than upon SC+P. Generally, the more often the soil is cultivated the higher is the percentage of annuals in the weed community (Holzner, 1982).

Nitrates, released from organic matter upon soil tillage, may also facilitate the germination of weed seeds (Pons, 1995). However, based on the given experiment it is impossible to claim that the above-mentioned factors also increase the germination of weed seeds as an after-effect of more intensive soil tillage (e.g. stubble cultivation and ploughing). At the same time, the more intensive germination of AW could have been caused by the small number of wandering perennial weeds and greater mixing of soil during stubble cultivation and ploughing. The other reason for vertical distribution of weed seeds in tilth by this tillage method, is that ploughing the following year brings back weed seeds from deeper soil layer to the surface.

In 2008, the dry mass of AW in pea was abruptly larger upon stubble cultivation and ploughing. In general, pea has a weak competitive ability with regard to weeds and as there were relatively few PW that could have suppressed the development of AW, this might have allowed the AW to form a bigger mass. There was a negative correlation between DM of PW and AW ($R = -0.48$; $n = 48$, $P < 0.05$).

Grain yields of crops

There was a negative correlation between DM of PW and grain yield (wheat: $R = -0.34$; $n = 48$; $P < 0.05$, pea: $R = -0.52$; $n = 48$; $P < 0.05$), likewise the number of PW and grain yield (wheat: $R = -0.37$; $n = 48$; $P < 0.05$, pea: $R = -0.72$; $n = 48$; $P < 0.05$). Similar correlations were absent between AW and grain yields.

In the case of P, the grain yield of spring wheat decreased 14.9%, and that of pea, upon the very strong spread of WP in 2008, 55.9% compared to SC+P (Table 1). In comparison with RT, the grain yield of spring wheat was 9.2% and the grain yield of pea 42.6% smaller in the case of P. The weediness was considerably smaller in spring barley than in other crops and this did not affect the grain yield substantially.

Table 1. Grain yields of crops on the background of different soil tillage methods, in dry mass.

Soil tillage method	Spring wheat (2007-2008) kg ha ⁻¹	Spring barley (2005-2008) kg ha ⁻¹	Field pea (2008) kg ha ⁻¹
Reduced tillage (2-times)	1947	1453	1320
Ploughing only	1767	1809	758
Stubble cultivation (2-times) and ploughing	2076	1863	1719
<i>LSD</i> _{0,05}	122	81	183

*LSD*_{0,05} = Least significant differences at $P < 0.05$

During all years of the experiment, the smallest grain yield occurred with RT. Thus, the grain yield of barley, using RT, was 22.0% smaller than in case of SC+P and 19.7% smaller than in case of P. Upon RT, there was more intensive spreading of root rot and leaf diseases than in the case of other soil tillage methods. It is possible that the yield decrease also occurred, in the case of RT, due to non-availability of plant nutrients, on account of non-decomposed plant-derived remains.

CONCLUSION

Experimental results clearly indicate that in the case of using SC+P in organic farming, the share of WP weeds (mainly *Sonchus arvensis* and *Cirsium arvense*) remains relatively low, in comparison with P. After conversion to organic agriculture, there was a rapid increase, starting from the 3rd year, in the percentage of such WP as *Sonchus arvensis* and *Cirsium arvense* in the case of P. Due to the weediness, the grain yields of spring barley and field pea decreased remarkably. In spring barley with undersown red clover/timothy, the weediness was smaller upon P than in other crops and did not cause a substantial yield loss. It occurred that in the case of (2-times) RT alternately with disc harrow and chisel cultivator, the share of WP is remarkably smaller than upon P, yet bigger than in SC+P. It needs to be clarified whether this tendency continues in the future. *Taraxacum officinale* spread in the case of RT, but was absent in other soil tillage methods of the experiment. *Taraxacum officinale* can be extinguished by deep ploughing.

In comparison with P, SC+P did not reduce the share of AW in grain crops during the four years of the experiment. Indeed, the weediness with AW was even higher in SC+P than in P.

With RT, the number of AW (not dry mass) in spring barley with under-sown red clover/timothy was higher, in two years of the four-year experiment, than upon other tillage methods, on average and this also caused a higher average number of AW in spring barley in all experimental years. At the same time, the grain yields of spring barley were clearly smaller in the case of RT than upon the utilisation of other soil tillage methods, during all experimental years. The relevant reason might be a more intensive spread of barley root rot and leaf diseases or the non-availability of plant nutrients on account of non-decomposed stalk and root parts, rather than the weediness. The highest grain yields of crops were formed in case of SC+P.

Based on the experiment results, it is possible to say that in organic farming, SC+P should definitely be done once or twice, in order to control the spread of WP and to avoid the decrease in grain yields of crops. However, it is necessary to be cautious in

implementing RT in organic agriculture as the concurrent changes in weediness are not clear and grain yields of crops might decrease.

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