LONG-TERM ORGANIC CROP ROTATION EXPERIMENTS FOR CEREAL PRODUCTION – PERENNIAL WEED CONTROL AND NITROGEN LEACHING

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Abstract

In long-term organic crop rotation experiments for cereal production, stubble cultivation to control perennial weeds increased nitrogen leaching compared to catch crops grown after harvest. Stubble cultivation contributed to the control of *Elymus repens* on a sandy soil, but not to the control of *Cirsium arvense* on a loamy soil. Manure application had a tendency to decrease *E. repens* density in one rotation at the sandy soil. Grass-clover green manure decreased *C. arvense* in the succeeding crops. Despite high infestations of perennial weeds, yields were at the same level with as without stubble cultivation. The results point to an important dilemma in organic farming: should the farmer control perennial weeds in the stubble at the expense of losing nitrogen by leaching? Or should catch crops be grown that preserve nitrogen, but allow *E. repens* to proliferate?

Introduction/Problem

In arable organic farming, there are many conflicting effects of management decisions leading to dilemmas. An example is the control of perennial weeds. In Denmark, perennial weeds such as *Elymus repens* L. Gould and *Cirsium arvense* L. are traditionally controlled by stubble cultivation in the autumn after harvest of a cereal or pulse crop. When the weed no longer reappears after stubble cultivation, or when soil or weather conditions prohibit the cultivations, the field is ploughed either in late autumn/early winter on heavier soils or in spring prior to sowing of spring crops on lighter soils. Carrying out cultivation during autumn prohibits growing a catch crop. Since autumn and winter is the time of excess precipitation, cultivation may lead to higher risks of nutrient leaching. Contrary to this, when a catch crop is grown, nutrients are retained within the topsoil by being incorporated in the biomass of the catch crop. If the catch crop is a leguminous species, N_2-fixation can further increase the N supply for the next crop. Thus catch crops will both reduce N leaching and increase yields of the following crops. Thus mechanical control of perennial weeds may have negative effects for the N supply in the crop rotation. Results of a Danish crop rotation experiment with and without catch crops were used to analyze treatment effects on the development of perennial weeds and the N leaching at two sites.

Methodology

A crop rotation experiment was initiated in 1996/97 at three sites in Denmark, but only data from two sites are used in this paper (Table 1). The crop rotations represent three systems with different proportions of cereals and nitrogen fixing crops in a four-year rotation (Table 2). The crop rotations were tested with four different combinations of catch crops and manure (Table 2) (Olesen et al., 2000, 2002). The plots receiving manure were supplied with anaerobically stored slurry at rates where the NH_4-N amount corresponded to 40% of the N demand of the specific rotation based on a Danish national standard (Plantedirektoratet, 1997). The N demands for grass-clover, pea/barley and lupin or lupin/barley were set to zero. The target rates for application are shown in Table 2. All cereal and pulse crops were harvested at maturity. The grass-clover was used solely as a green manure crop, and the cuttings were left on the ground. All straw was left in the field. The crops were irrigated at one site (Jyndevad).

Table 1. Soil texture, content of organic C and total N, and pH in the top 25 cm of the soil at the three sites in autumn 1996 prior to the onset of the experiment and mean annual precipitation. pH is taken as pH (CaCl2)+0.5. Soil minerals, organic C and total N were measured in percent of dry soil (Olesen et al., 2000).

Site	Clay $< 2\ \mu m$	Silt 2-20 μm	Fine sand 20-200 μm	Coarse sand 200-2000 μm	Organic C	Total N	pH	Precipitation mm
Jyndevad	4.5	2.4	18.0	73.1	1.17	0.085	6.1	964
Flakkebjerg	15.5	12.4	47.4	22.9	1.01	0.107	7.4	626

Weed harrowing and row hoeing were used to control annual weeds. A reduced effort was used in the treatments with catch crops. Perennial weeds were primarily controlled by stubble cultivation in autumn after cereal and pulse crops without catch crops. For *E. repens* this was done when a threshold of 5 shoots m^{-2} was reached in the plot, which happened in 25-100% of the –CC plots at Jyndevad from 1998 to 2002. Most years stubble cultivation was carried out by shallow ploughing (10-15 cm) in order to loosen the rhizomes, followed by repeated stubble harrowings alternating with rotavations, 2-8 treatments in all. In 2001, the *E. repens* infestation in the +CC treatment of the pulse crops at Jyndevad was so severe that half of the plots were stubble cultivated. The rhizomes brought to the soil surface in these plots were removed manually. *C. arvense* plants were pulled out in all plots at the time of budding, which coincided with anthesis of the cereals. At Flakkebjerg in 2000 to 2002, winter wheat was row hoed in the –CC treatments to control *C. arvense*. The decision whether to carry out stubble cultivation against *C. arvense* was made from visual evaluation of the infestation. One to four stubble cultivations were carried out with a stubble harrow with goosefoot shears, so wide that the whole area was cut through, at increasing depths from 5 to 15 cm in 36-100% of the -CC plots at Flakkebjerg from 1999 to 2002. No stubble cultivations were carried out in 2003 at either location.

Table 2. The crop rotations are carried out with the treatments: without catch crops (-CC), with catch crops (+CC) in combination with the treatments: without manure (-M) and with manure (+M). It is indicated in which crops catch crops are undersown (+CC), and the target rates of NH_4-N (kg ha^{-1}) applied in slurry is shown for the +M treatments.":" indicates undersown ley, "/" indicates intercropping.

	Rotation 1 (R1)	+CC	+M	Rotation 2 (R2)	+CC	+M	Rotation 4 (R4)	+CC	+M
First	Spring barley:ley		50	Spring barley:ley		50	Oats	+	40
course	Grass-clover			Grass clover			Winter wheat	+	70
1997-	Spring wheat	+	50	Winter wheat	+	50	Winter cereal	+	70
2000	Lupin	+		Pea/barley	+		Pea/barley	+	
Second	Spring barley:ley		50	Spring barley:ley		50	Winter wheat	+	50
course	Grass-clover			Grass-clover			Oats	+	50
2001-	Oats	+	30	Winter cereal	+	50	Spring barley	+	50
2004	Pea/barley	+		Lupin/barley	+		Lupin/barley		
Sites	Jyndevad			Jyndevad Flakkebjerg			Flakkebjerg		

+CC: + = catch crops in +CC treatments +M: 30-70 = kg ammonium-N/ha in +M treatments

Nitrate leaching was measured using ceramic suction cells installed at 0.8 m depth at Jyndevad and at 1.0 m depth at Flakkebjerg in selected plots. Above-ground shoots of *C. arvense* were counted and weighed (fresh weight) in the whole plot at the time of anthesis of the cereals. Shoots of *E. repens* that extended above the crop were counted in five 0.1 m^2 areas two weeks after anthesis.

Results and brief discussion

The nitrate leaching losses were largest at Jyndevad and least at Flakkebjerg ($p<0.001$) (Table 3). Catch crops reduced nitrate leaching in both rotations at Jyndevad. The same tendency was seen in rotation 2 at Flakkebjerg ($p=0.09$). At Jyndevad, in six combinations of crop and year, stubble cultivation for control of *E. repens* was carried out in one of the two –CC/+M replicates only, due to

Table 3. Effect of crop rotation and catch crop on nitrate leaching (kg NO_3-N ha^{-1} yr^{-1}) at the two experimental sites. Values with the same letter within a row are not significantly different ($P<0.05$) (Askegaard et al. 2005).

Site	Rotation 1		Rotation 2		Rotation 4	
	– CC	+ CC	– CC	+ CC	– CC	+ CC
Jyndevad	106 a	56 b	104 a	65 b		
Flakkebjerg			35 a	26 a	29 a	28 a

differences in infestation with couch grass. This allowed for a comparison of nitrate leaching between +CC plots, –CC plots without stubble cultivation and –CC with stubble cultivation. Stubble cultivation after pulses (lupin and pea/barley) in the –CC plots doubled the nitrate leaching compared with no harrowing. After cereals there was no effect of stubble cultivation on nitrate leaching (Askegaard et al. 2005).

At Jyndevad, the *E. repens* infestation developed into a problem during the first few years. Stubble cultivations decreased *E. repens* density in the –CC treatments (Table 4). Application of manure decreased the *E. repens* density in rotation 2 (Table 4). In spite of the high level of *E. repens* infestations in the +CC treatments at Jyndevad, the mean of cereal and pulse yields where higher in the +CC than in the –CC treatments, probably because of an improved nutrient supply.

Table 4. Mean density of shoots of *E. repens*, no m^{-2}, with and without catch crops and manure in the two crop rotations for the two courses at Jyndevad. In course 1, 1997 is not included in the mean since the effects of catch crop, stubble cultivation and manure had not appeared yet.

Rotation	Course	-CC	+CC	-M	+M
1	1 (98-00)	7.7	5.8	9.5	4.0
	2 (01-04)	9.8	34.8	21.2	23.4
2	1 (98-00)	6.5	14.9	14.6	6.8
	2 (01-04)	9.2	34.9	28.6	15.5

At Flakkebjerg, there was a lower infestation of *C. arvense* in rotation 2 than in rotation 4, with least biomass in the crop the year after grass-clover (Fig. 1). There was no significant difference between the biomass of *C. arvense* in the –CC and +CC treatments (Fig. 2), in spite of the fact that stubble cultivations and row hoeing were carried out in the –CC and not in the +CC treatments. The reason was most likely because the nutrients retained in the topsoil by the catch crops benefited the crops, which became more competitive against the weeds. There was no significant difference in the nitrate leaching between the catch crop treatments at Flakkebjerg, but a yield increase in the +CC treatment in rotation 4 (data not shown). Yields of spring cereals were consistently increased after catch crops (data not shown).

Conclusions

At sites with light soils and excess precipitation in autumn, stubble cultivations will most likely contribute to nitrogen leaching compared with growing catch crops in the same season. With stubble cultivations the following crop will be deprived of some important nutrition, and probably be less competitive against the weeds compared with the situation with catch crops. This is also indicated by the fact that manure applications in some cases reduced *E. repens* density. Our experiments show that although stubble cultivations reduce the *E. repens* infestation compared to the use of catch crops, the expected increase in the yield of the following crop may not be large enough to counter the negative effect of the nutrient loss.

The efficacy of direct control on perennial weeds in the succeeding crop interacts with nutrient leaching so that the yield effects may differ from what is expected. Experiments aimed solely at revealing efficacy of direct control measures may fail to describe the relationship between different

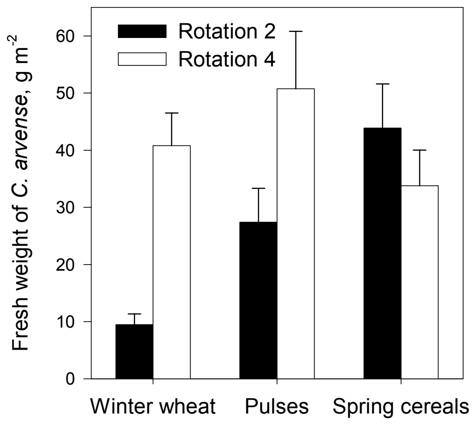

Figure 1. Fresh weight m^{-2} of *C. arvense* in different crops at Flakkebjerg in rotation 2 and rotation 4, mean of 1999-2003, catch crop and manure treatments. Bars indicate standard errors.

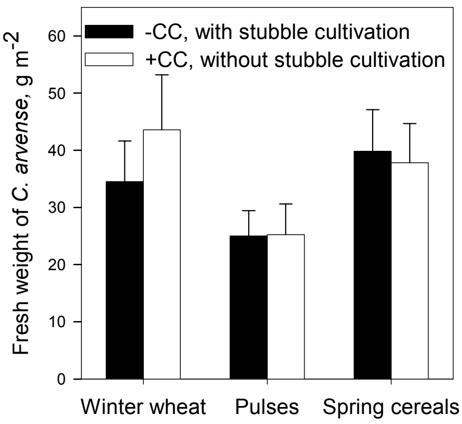

Figure 2. Fresh weight m^{-2} of *C. arvense* in different crops at Flakkebjerg without (-CC) or with (+CC) catch crops, mean of 1999-2003, rotations and manure treatments. Bars indicate standard errors.

treatments, which are very important in organic farming. Our results emphasize that long-term experiments are important for evaluating the effect of different measures.

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