Rotation limits *Cirsium arvense*, but not *Elymus repens* or annual weeds

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Direct weed control of annual as well as perennial weeds was necessary to diminish the amount of weeds in crop rotation experiments at 3 locations in Denmark http://web.agrsci.dk/pvj/plant/croprot/indexuk.shtml . For Canada thistle however, the rotation was the most important controlling factor: the rotation with grass-clover had less thistle biomass than the one without. Catch crops limited this weed as much as intensive mechanical weed control but had apparently no effect on other weeds. Manure increased the weed biomass relative to total biomass at two out of three locations.

Crop rotation experiment

A crop rotation experiment was initiated in 1996/97 at three sites in Denmark with the aim of investigating the possibilities of increasing the organic production of cereals. The sites are:

- Jyndevad (coarse sand) in Southern Jutland,
- Foulum (loamy sand) in Central Jutland
- Flakkebjerg (sandy loam) at Zealand

The crop rotations represent systems with different proportions of cereals and nitrogen fixing crops (Table 1). The crop rotations have been tested with four different combinations of catch crops (with (+CC) and without (-CC)) and manure (with (+M) and without (-M)). http://orgprints.org/346/

All manure was applied as slurry in the spring at a rate corresponding to 40% of the nitrogen demand in the cereal crops at rotation level (Table 1). 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 also left in the field. The crops were irrigated at Jyndevad.

Harrowing was used to control annual weeds. A reduced effort was used in the rotations with catch crops as the catch crops were established by undersowing in spring, but this effort differed between locations and first and second course of the rotation (Table 2). Perennial weeds were, if there was a problematic infestation, primarily controlled by stubble cultivation in autumn after cereal and pulse crops without undersown catch crops.

Increased weed control decreased weed biomass

At the outset of the experiment, there were quite different weed pressures at the three locations. At Jyndevad, more than 7000 weed seeds m^{-2} were found in the soil, while the level at the two other locations was 2000 – 4000 weed seeds m^{-2}. In spite of this, the mean biomass of annual weeds across all treatments never exceeded 40 g m^{-2} during the experiment (Fig. 1), although the biomass of annual weeds in some cases exceeded 100 g m^{-2} at all three locations.

At Jyndevad, the weeds were controlled in all crops (Table 2), which resulted in low annual weed biomass most years in all crops. An exception was winter rye in 2002, where a severe attack of mildew made an explosive development of the weed biomass possible.

During the first rotation at Foulum, weeds were not controlled in spring barley, and only in the –CC treatment in pea:barley. Especially in spring barley this resulted in large amounts of weed. From 2001, the weed control was carried out in all treatments at Foulum by delaying sowing of the undersown grass-clover till after the completion of the weed control. This resulted in a decrease in weed pressure. Winter wheat was sown late, around Oct. 1st, except for the crops harvested in 2001 and 2002, which were sown in the middle of September. In 2001, this resulted in a high weed biomass, while the effect was reduced in 2002 by a dry spring. From 2003, the practice of late sowing was used again.

At Flakkebjerg, there was a very small annual weed biomass the first year of the experiment in all crops. This gradually increased until 1999,after which time it has been stable. An exception was caused by the dry spring in 2002, which decreased weed biomass in all crops. There were no differences in weed biomass between crops.

Manure increases weed biomass

At Foulum and Flakkebjerg there was more weed biomass in the +M than in the –M treatments, but this was not the case at Jyndevad (Fig. 2). Also the proportion of weeds of the total biomass was increased at Foulum and Flakkebjerg, while the opposite was seen at Jyndevad. This indicates that the crops at Jyndevad utilized the applied manure better than the weeds, while the opposite was true at Foulum and Flakkebjerg.

Intensive control of perennial weeds only works for one year

Perennial weeds were scarce and unevenly distributed at the outset of the experiment. At Jyndevad mainly *Elymus repens* and at Flakkebjerg mainly *Cirsium arvense* developed to at problematic level within the course of the experiment (Fig. 1).

At Jyndevad intensive stubble cultivations were carried out in the autumn of 2001, even in some +CC plots, resulting in a decrease in 2002. The effect didn't last for more than one year. Because of this, a new strategy, mid-summer fallow, was introduced in the grass-clover at Jyndevad in 2000: ploughing the crop in June, carrying out weekly cultivations for 4-6 weeks before ploughing and sowing a catch crop in rotation 1 and the winter cereal (2000-2001) or a catch crop (2002-2003) in rotation R2. This decreased the level of *E. repens* in the crops grown the year after this treatment, but already the following year, the effect of the treatment was eliminated (fig. 3).

Repeated stubble cultivations in the previous crops seemed to be able to keep *E. repens* at a stable level in spring barley with undersown ley in the -CC treatments. In the autumn 2001 the +CC treatments were also stubble cultivated, resulting in a decrease in 2002 (fig. 4).

Rotation is the most effective control of Canada thistle

At Flakkebjerg *C. arvense* was pulled out in all crops at the time of anthesis in all treatments. In the –CC treatments stubble cultivations were carried out, and in 2000-2002 winter wheat in the –CC treatments was sown at double row distance and row hoed. The fresh weigh of thistles was lower in R2 (with grass-clover) than R4 (without grass-clover), and lowest in the first crop after grass-clover, while there was no difference between the rotations in the crop three years after grass clover, and no differences between the crops in R4 (fig. 5). There were no differences between thistles biomass in the –CC and +CC treatments in spite of the intensive control in the –CC treatment. This indicates that the catch crops, which retain nutrients in the topsoil, and compete with the thistles in the stubble, have inhibited the weeds as much as the direct control measures.

Conflicts of interest

Often the weed management gives rise to conflicts of interest. An example is the choice of sowing time of the winter wheat at Foulum. From the start of the experiment winter wheat was sown around 1st October. At Foulum this resulted in a weak stand in spring. In autumn 2000 and 2001, the sowing was done around 1st September, which should lead to a better development of the wheat, resulting in better growth in the spring. Despite intensive weed control with row hoeing in the autumn and weed harrowing and row hoeing in the spring, the weeds, notably scentless mayweed (*Tripleurospermum inodorum*), developed vigorously. From autumn 2002 the late sowing was used again.

Figure 1. Development of annual and perennial weed biomass; mean of all treatments and crops at all three locations.

Figure 2. Effect of manure on a. weed biomass and b. percentage weed biomass of total biomass at each location. Mean of 1997-2003, all rotations and +/- catch crop.

Figure 3. Shoots of *E. repens* at Jyndevad without fallow in the grass-clover (until 2000) or with fallow in the grass-clover (from 2001). First crop after grass-clover is the mean of three years; second crop after grass clover is the mean of two years. Both are means of all treatments.

Figure 4. Development in number of shoots of *E. repens* in spring barley at Jyndevad in the –CC, which received stubble cultivations in the previous crops, and the +CC treatments, which were not stubble cultivated except for the fall of 2001. Mean of rotations and manure treatments.

Figure 5. Fresh weight of *C. arvense* in different crops at Flakkebjerg, mean of 1999-2003. a. Rotation 2 (R2) and rotation 4 (R4), mean of all catch crop and manure treatments. b. Without (-CC) or with (+CC) catch crops, mean of rotations and manure treatments.

Table 1. 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). In the table is indicated in which crops catch crops are undersown (+CC) and in which crops manure is applied (+M). The amount of slurry is shown in the table.

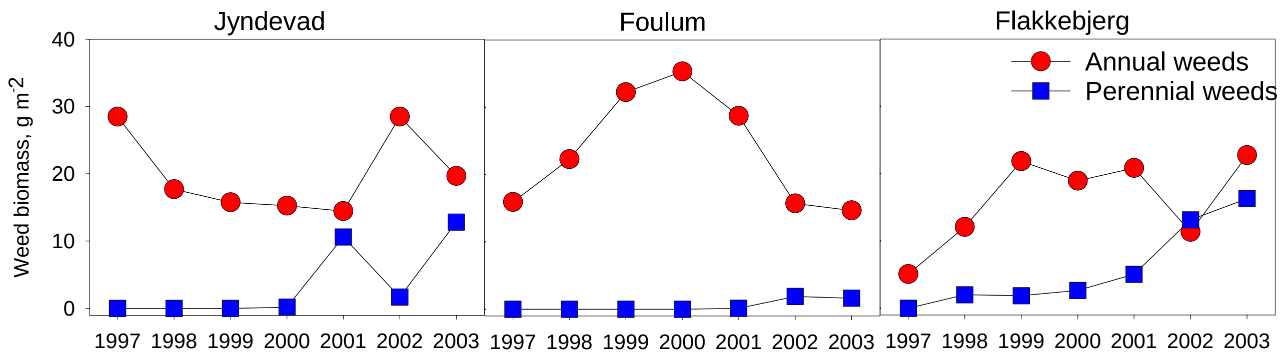
	Rotation 1			Rotation 2			Rotation 4		
	R1	+CC	+M	R2	+CC	+M	R4	+CC	+M
	Spring barley:		50	Spring barley:		50	Oats	●	40
First	undersown ley			undersown ley			Winter wheat	●	70
course	Grass-clover			Grass clover			Winter cereal	●	70
1997-2000	Spring wheat	●	50	Winter wheat	●	50	Pea/barley	●	
	Lupine	●		Pea/barley	●				
	Spring barley:		50	Spring barley:		50	Winter wheat	●	50
Second	undersown ley			undersown ley			Oats	●	50
course	Grass-clover			Grass-clover			Spring barley	●	50
2001-2004	Oats	●	30	Winter cereal	●	50	Lupine/barley*		
	Pea/barley	●		Lupine/barley	●				
	Jyndevad			Jyndevad					
Locations				Foulum			Foulum		
				Flakkebjerg			Flakkebjerg		

● : Catch crops in +CC treatments **30-70**: kg ammonium-N/ha in +M treatments

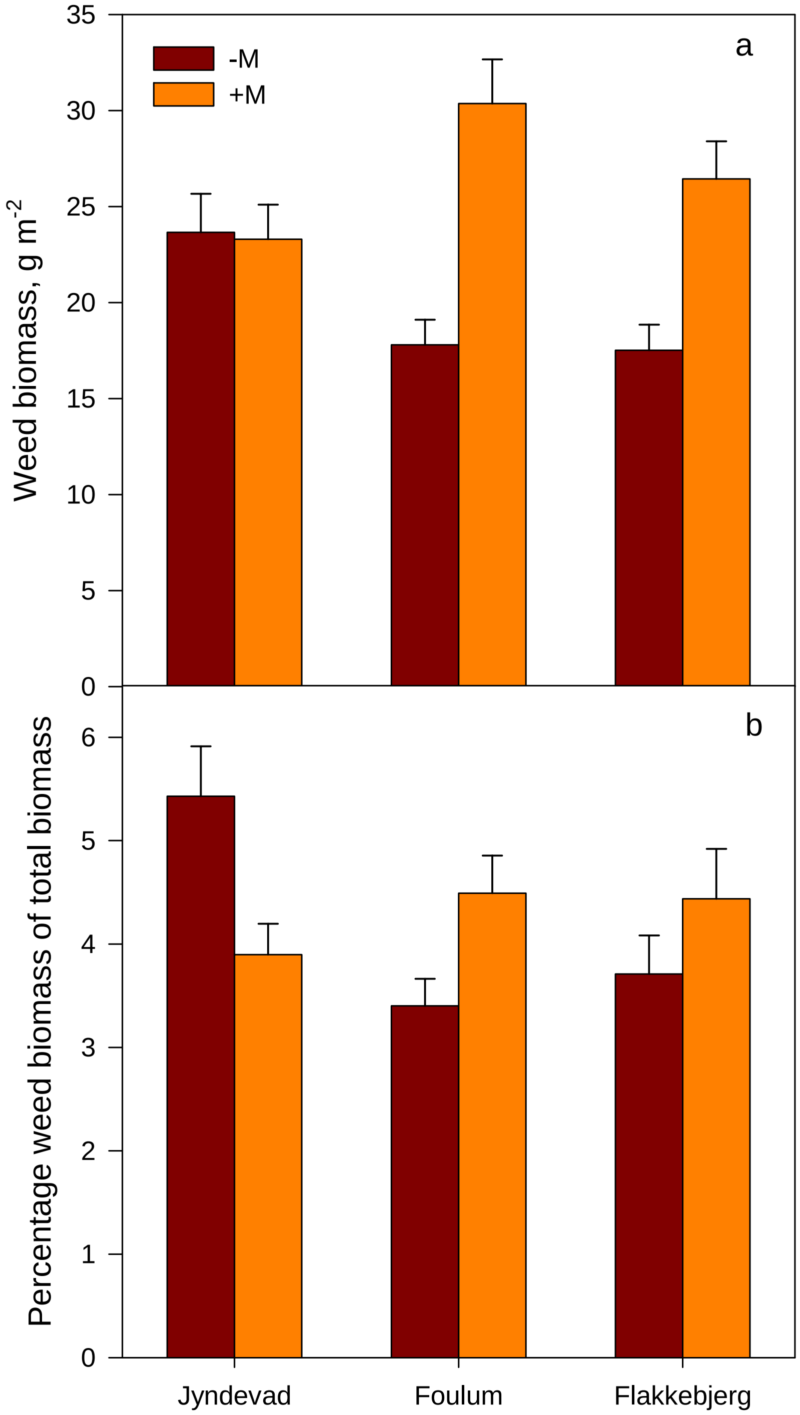
* : Pure lupine at Foulum

Table 2. Mechanical weed control carried out at the three locations in first and second course of the rotations. + indicates that weed harrowing and/or row hoeing has been carried out. Control is usually less intensive in the +CC than the –CC treatments, except for spring barley, where control is equal between treatments.

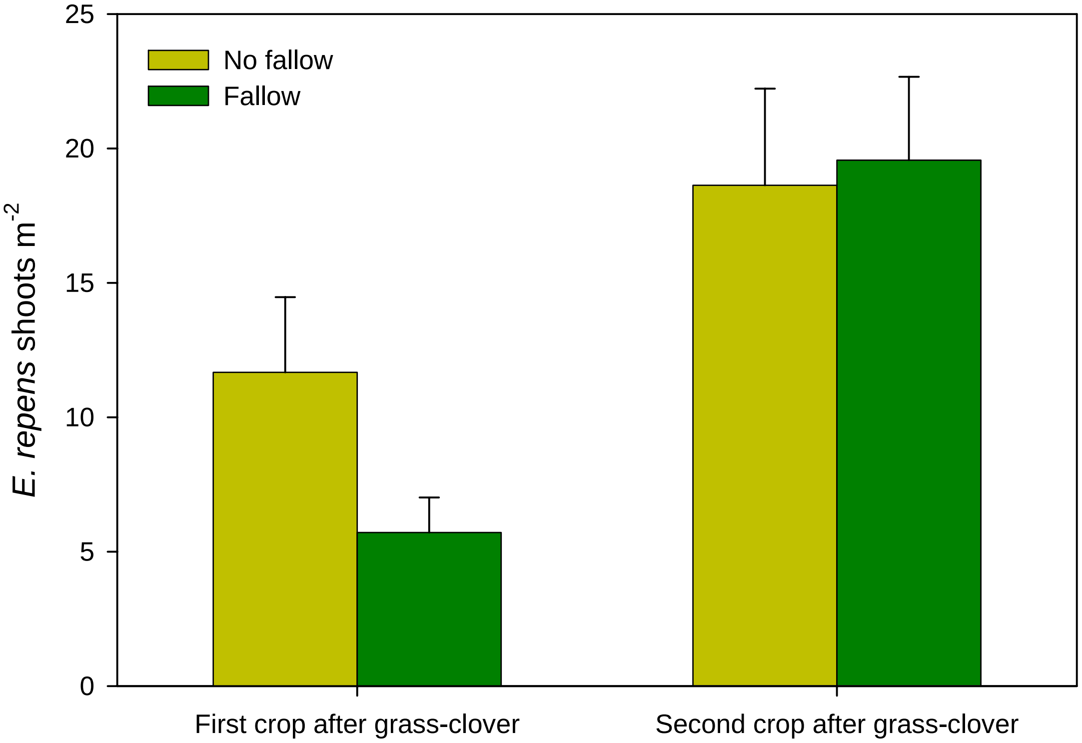
		Jyndevad		Foulum		Flakkebjerg	
		-CC	+CC	-CC	+CC	-CC	+CC
First course (1997-2000)	Spring barley: undersown ley	+	+	-	-	-	-
	Winter cereal	+	+	+	+	+	+
	Spring cereal or pulses	+	+	+	-	+	-
Second course (2001-2004)	Spring barley: undersown ley	+	+	+	+	-	-
	Winter cereal	+	+	+	+	+	+
	Spring cereal or pulses	+	+	+	+	+	-

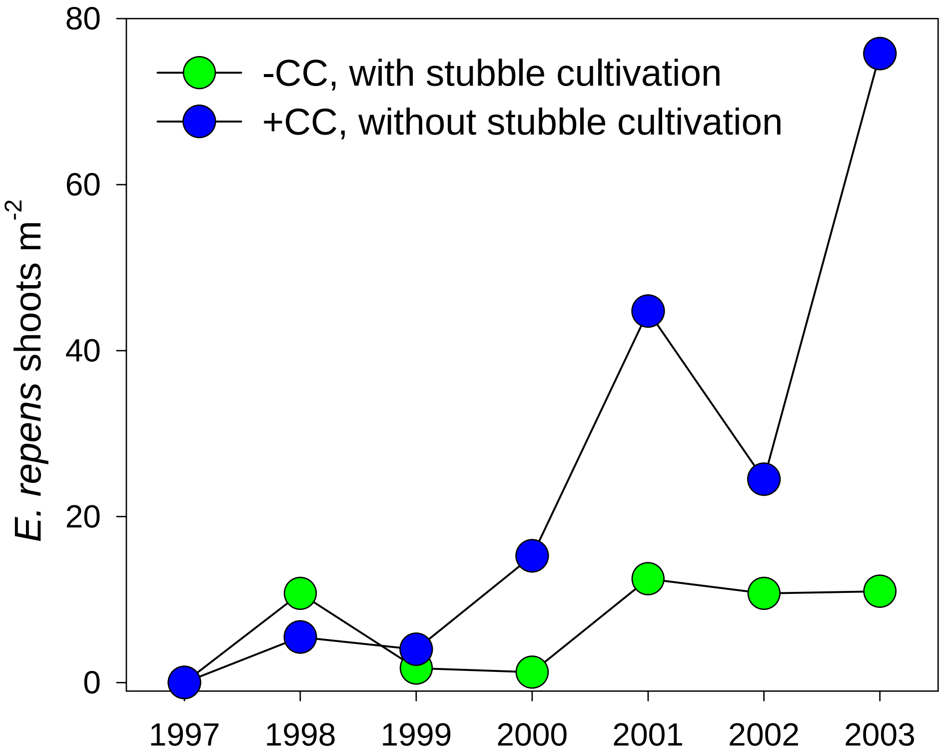


Jyndevad
Foulum
Flakkebjerg
Annual weeds
Perennial weeds
Weed biomass, g m-2
40
30
20
10
0
1997 1998 1999 2000 2001 2002 2003 1997 1998 1999 2000 2001 2002 2003 1997 1998 1999 2000 2001 2002 2003

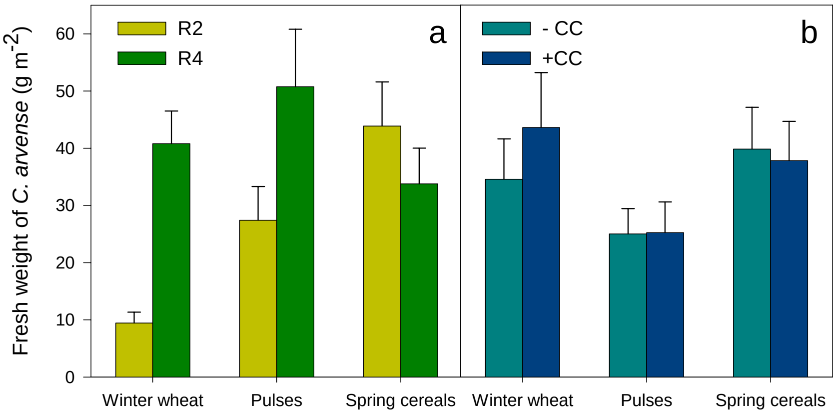


a
b
-M
+M
Weed biomass, g m-2
Percentage weed biomass of total biomass
35
30
25
20
15
10
5
0
6
5
4
3
2
1
0
Jyndevad
Foulum
Flakkebjerg


No fallow
Fallow
E. repens shoots m-2
25
20
15
10
5
0
First crop after grass-clover
Second crop after grass-clover



-CC, with stubble cultivation
+CC, without stubble cultivation
E. repens shoots m-2
0
20
40
60
80
1997
1998
1999
2000
2001
2002
2003



Fresh weight of C. arvense (g m-2)
R2
R4
a
- CC
+CC
b
0
10
20
30
40
50
60
Winter wheat
Pulses
Spring cereals
Winter wheat
Pulses
Spring cereals