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A new concept for the control of *Elytrigia repens* in organic crop production

by

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Summary

The control of perennial weeds in organic crop production needs reconsideration to minimise losses of nutrients through leaching. Long post-harvest periods with mechanical weed control hinder a plant cover with the purpose of taking up nutrients not being utilised by the main crop to maintain soil fertility. To meet the interests of nutrient and weed management, we suggest a new concept for the control of perennial weeds with propagules placed within the plough layer. The concept comprises uprooting and immediate removal of *Elytrigia repens* rhizomes with modified machinery to allow for a quick re-establishment of a plant cover to avoid longer periods of bare soil. Four passes with a modified cultivator where each pass was followed by rhizome removal and finally catch crop growing reduced *E. repens* shoot growth in a subsequent spring barley crop by 84 and 97%, respectively, in two field experiments on a sandy soil. Small remains of rhizomes in the soil following uprooting did not result in a higher shoot production rate than larger residuals as otherwise hypothesised. For the further development of the concept, we suggest focusing on lifting principles known from potato harvesters as effective uprooting and removal might be achieved with fewer passes.

Keywords: perennial weeds, rhizome, uprooting, removal, belowground propagule, catch crop

Introduction

There is a need to rethink current practice to control *Elytrigia repens* (L.) Desv. ex Nevski in organic farming. Infestations with *E. repens* are traditionally controlled by repeated stubble cultivation in the post-harvest period from harvest to ploughing in Northern Europe. However, post-harvest tillage is undesirable due to the need for retaining nutrients, particularly nitrogen, in organic cropping systems (Melander *et al*., 2011). Nutrient losses through leaching can be substantial in the humid North European climate prevailing in autumn and winter if the soil is tilled and left bare without a plant cover. For example, nitrogen losses averaged 55 kg ha^{-1} in Danish long-termed crop rotation experiments following repeated stubble cultivation to control perennial weeds. In contrast, nitrogen losses averaged 20 kg ha^{-1} where a catch crop was grown including significant reductions in the loss of potassium from a coarse sandy soil at one of the sites studied (Askegaard & Eriksen, 2008; Askegaard *et al*., 2011). Nutrient losses are particular problematic on stockless farms with limited access to manure, often leading to low yielding crops exerting poor suppression on weeds.

The management of nutrients and perennial weeds in organic arable cropping thus calls for a compromise in which effective weed control is achieved within a short time span after crop harvest to allow the re-establishment of a plant cover (Melander *et al*., 2011). This may not be possible with all perennial weed species posing problems in organic farming but the prospects for *E. repens* appear promising. Rhizomes of *E. repens* are placed within the plough layer of 0-20 cm soil depth with hardly any rhizomes found below 20 cm (Håkansson, 1969; Lemieux *et al*., 1992). A complete uprooting and removal of rhizomes from the plough layer seems likely with *E. repens* in contrast to other perennials having roots or rhizomes penetrating the soil more deeply, such as *Cirsium arvense* (L.) Scop. and *Tussilago farfara* L. Tine or disc-based stubble cultivators only partly uproot belowground propagules with the fragmentation of rhizomes and roots being the most important effect. In Danish tests of different tool configurations and their abilities to uproot *E. repens* rhizomes, only power take-off (PTO) -driven implements with vertically rotating tilling devices were applicable for uprooting purposes; one pass on a sandy soil could uproot almost half the rhizome biomass (Melander *et al.*, 2008; Pedersen, 2010). A supplementary test in which multiple passes with a vertically rotating tool resulted in 63 and 93% uprooting of the rhizome biomass with 2 and 4 passes, respectively, (Nørremark *et al.*, 2009; unpublished data). However, the rhizome biomass that remained in the soil after treatment declined exponentially with the number of passes, implying that complete uprooting may not be attained with a vertically rotating tilling device. Even a small amount of residual rhizomes may produce substantial shoot biomass in the subsequent year because inter-competition between *E. repens* shoots with ample space is smaller than in denser stands. This should result in a negative exponential relationship between initial infestation level and final shoot or rhizome biomass at crop maturity as shown for initial shoot density in spring barley (Melander, 1995) and potatoes (Baziramakenga & Leroux, 1998). The tests also revealed that multiple passes loosened the soil considerably, which potentially can lead to manganese deficiency and yield reductions on sandy soils (Melander *et al*., 2012). A drawback that needs attention when light soils are tilled intensively.

The establishment of a catch crop immediately after uprooting rhizomes may further strengthen the overall control effect against *E. repens*. A dense and fast growing catch crop can suppress shoots emerging from remaining rhizome fragments, especially when preceded by mechanical interventions (Graglia *et al*., 2006; Teasdale *et al.*, 2007). The more efficiently a catch crop absorbs light, nutrients and water, the more weeds are suppressed (Hartwig & Amon, 2002). A vigorous post-harvest ground cover also serves other agronomic goals, such as improved soil fertility and reduced erosion. Improved soil fertility and the release of nutrients from decomposing catch crop plant materials can strengthen crop growth and yield resulting in a stronger suppression of *E. repens* shoots that may have survived the treatment from the previous year.

This study aimed at investigating the concept of rapid post-harvest rhizome uprooting and removal followed by catch crop growing, and quantifying the effects on *E. repens* shoot growth and the yield of a subsequent crop. We hypothesised that: a) the shoot biomass production from residual rhizome biomass the year after uprooting correlates negatively exponentially with increasing remains of rhizome biomass; b) growing a catch crop immediately after uprooting will further reduce *E. repens* shoot biomass production and enhance yield of a succeeding crop; and finally c), soil compactness can be restored through modified seedbed preparation despite the loosening caused by uprooting tillage.

Materials and methods

Experimental layout and treatments

Two experiments (expts) were conducted on a sandy soil at Jyndevad Experimental Station (54°54'N, 9°07'E). The first experiment (expt A) was established in August 2009 and the second one (expt B) in August 2010 on an adjacent area. Both areas had been cropped according to organic standards for several years and had a large and uniform population of *E. repens* when the experimentation was commenced. Seven post-harvest treatments were randomised within four blocks resulting in 28 treatments in total. Treatment details are provided in Table 1. Treatment 2 was done using a *Vibro Flex* stubble cultivator from Kongskilde (Kongskilde Industries A/S, Denmark) with goosefoot shares mounted on vibrating S-shaped tines cutting the soil over the full working width. Treatment 2 was included to compare treatments 3-7 with a standard stubble cultivation practice. Treatments 3-7 were accomplished with a power take-off (PTO)-driven rotary cultivator, *Howard Rotalabour 600B-305S* from Kongskilde (Kongskilde Industries A/S, Denmark), with slightly angled blades entering the soil vertically. *Rotalabour* was mounted with winged shares at the front to furnish a full cut over the entire working width at 20 cm soil depth. *Rotalabour* throws a large proportion of the loosened rhizomes into the air, usually landing on the soil surface resulting in a complete exposure. Gross plot size was 6 x 20 m of which the central 2.4 x 10 m was used for assessments of weed and crop growth. Spring barley (variety *Simba*) was grown in 2009, 2010 and 2011 at a target crop plant density of 350 pl. m^{-2}: 178 kg ha^{-1} sown on 20 March 2009; 158 kg ha^{-1} sown on 29 March 2010; 176 kg ha^{-1} sown on 30 March 2011. The whole experimental area was mouldboard ploughed to 22 cm soil depth each year in March shortly before crop sowing. All plots were rolled right before and after ploughing using a concrete roller (936 kg per meter working width, diameter 900 mm) to compact the soil after ploughing and previous year's cultivations. Then the seedbed was prepared with a powered harrow. Slurry was applied just before crop sowing using an amount corresponding to 70 kg total nitrogen ha^{-1} (approx. 51 kg NH_4 ha^{-1}), 13-14 kg phosphorus ha^{-1} and 41-55 kg potassium ha^{-1} in all years. Manganese was applied in early May using 1000 g ha^{-1} in both years. Annual weeds were controlled in both years with a weed harrow: one pass pre-emergence and post-emergence, respectively. All field operations were made in the longitudinal direction of the plots to avoid spreading of rhizomes from neighbouring plots.

Assessments

The amount of rhizome biomass that remained in the soil immediately after treatments was recorded on 21 August 2009 in expt A and 14 September 2010 in expt B (Table 1). Two 0.5 m^2 quadrates were randomly placed in each plot of treatments 1, 3, 4 and 6 (Table 1). All rhizomes within the quadrate and down to 20 cm soil depth were dug out and separated from the soil. The majority of rhizomes occurred in the 10-15 cm soil layer with no rhizomes seen at 20 cm depth (and further down which was checked several times).

Aboveground *E. repens* biomass production following the treatments in Table 1 was recorded in the subsequent year on 10 August 2010 in expt A and 9 August 2011 in expt B shortly before harvesting spring barley. Three 0.25 m^2 quadrates were randomly placed in each plot but away from the places where rhizomes had been dug out in the previous year. All above-ground plant material within the quadrate was cut at ground level. The plant material was separated into three fractions: crop, *E. repens* and other weeds among which *Chenopodium album* L., *Galinsoga* Ruiz & Pav., *Spergula arvensis* L., *Viola tricolor* L., *Bilderdykia convolvulus* (L.) Dumort. and *Stellaria media* (L.) Vill. were the principal species. Dry matter of each fraction was obtained by drying the plant material in the oven for 24 h at 80°C.

Ground cover of the catch crop established in treatments 2, 5 and 6 (Table 1) was estimated from digital images taken approx. one month after establishment; 21 Sep 2009 in expt A and 13 October 2010 in expt B. Each image was taken of the whole quadrate from a perpendicular position above the centre of the quadrate. The images were subsequently analysed in the laboratory by overlaying electronically a 17×17 grid, and the number of grid intersections touching living plant tissue on the image was counted. Percentage plant coverage in the quadrate was then calculated by dividing the number of touched intersections with the total of 289 intersections. Coverage was estimated for vetch, rape and weeds separately and if possible also with a distinction between rye and *E. repens* shoots depending on the quality of the images. Counting intersections was considered to be a more objective method than visual scores of plant coverage (Melander *et al*., 2009).

The compactness of the top 60 mm soil layer before growing spring barley in the years 2010 (expt A) and 2011 (expt B) was measured using a handheld penetrometer with a flat, circular point (diameter 10 mm). The penetrometer measures the maximum force encountered when the point penetrates the soil to 60 mm soil depth. Fifteen penetrations were randomly made in each plot before and after seed bed preparation (rolling + ploughing + rolling + harrowing) and sowing.

Each plot was combined for barley grain yield in August in both expts following the biomass cuts. Grain yields were adjusted to 85% dry matter content after grain samples had been dried in the oven for 24 h at 80°C.

Data analyses

Data were analysed using a general linear mixed model with normally distributed data (McCullagh & Nelder, 1989). Response variables were rhizome biomass, aboveground *E. repens* and other weed biomasses prior to crop harvest, catch crop ground coverage, grain yield and penetration resistance. Fixed effects were the categorical variables EXPERIMENT and TREATMENT with blocks nested under EXPERIMENT and included as a random effect. Rhizome biomass was included as a covariate when the relationship between rhizome biomass and *E. repens* shoot biomass was analysed. Penetration resistance after crop establishment was regressed against penetration resistance before crop establishment, and grain yields were regressed against aboveground *E. repens* biomass. Non-linearity was checked by including squares of the covariates to the linear model to test whether this model extension significantly improved the description of data.

Except for the analyses on non-linearity and on regressions needing transformation, parameters of the linear models were estimated using residual likelihood estimations. Calculations were made with the MIXED procedure of SAS (SAS release 9.2), and means were calculated as least square means (LSM). Models were reduced by excluding non-significant effects based on likelihood ratio tests and Akaike's information criterion (Akaike, 1974). The denominator degrees of freedom (DDF) in *F*-tests and *t*-tests for mean separations were calculated according to Kenward & Rodger (1997). In some cases, biomass-data were log-transformed to obtain homogeneity of variance.

The SAS-procedure NLIN was used to estimate the parameters when analysing non-linearity and for the handling of transformation in regressions. Variances were stabilised using a transform-both-sides technique (Carroll & Ruppert, 1988). Parameter values in full models depended on the categorical variable EXPERIMENT. BLOCK effects were nested under EXPERIMENT and assumed to affect all parameters in the model. Models were successively reduced on the basis of *F*-test leaving out non-significant effects at the 5%-level.

Results

The amount of rhizome biomass that remained in the soil following rotary cultivation declined markedly for each pass conducted (Table 2). For example four passes resulted in 80% and 90% reductions in expts A and B, respectively, as compared to untreated. Rhizome biomass correlated linearly to aboveground shoot biomass in the subsequent year with no indications of any curvilinearity (P=0.4069) within the range of data studied (Fig. 1). The simplest model had different slopes (P<0.0001), no block effects (P=0.0701) and one common intercept for both expts (P=0.2597) that did not deviate significantly from 0 (P=0.1314).

Four passes with the rotary cultivator (treatments 6 and 7) gave the highest shoot biomass reductions in the subsequent year (Table 2) in expt A, while only minor differences were present among the treatments in expt B. Two passes with a traditional stubble cultivator (treatment 2) gave more *E. repens* control in expt A than one pass with the rotary cultivator (treatment 3). Growing a catch crop to suppress any regrowth of *E. repens* after treatment generally did not reduce shoot biomass reduction further (P=0.2349). Crop yields were also not affected by catch crop growing. The catch crop developed poorly in both expts, only covering less than 10% of the soil surface in the autumn but weed coverage tended to be higher where no catch crop was present (data not shown).

The compactness of the sandy soil was restored after crop establishment in spring and reached a common value for both experiments and all treatments (Fig. 2). Only the measurements made prior to seedbed preparation showed some differences with the treatments not including a catch crop being less compacted than those having a catch crop.

The amount of aboveground *E. repens* biomass strongly affected the other two biomass fractions in expt A: crop and other weeds (Fig. 3). Especially crop biomass was inversely and linearly related to *E. repens* biomass (correlation coefficient R=-0.7029, P<0.001) while the inverse relationship between other weeds and *E. repens* biomasses was less pronounced (*R*=-0.5947, *P*=0.0008). The impact of *E. repens* biomass on crop growth also became evident on grain yield in expt A, as crop yield responses could largely be explained by the amount of *E. repens* shoot biomass (Fig. 4). The biomass of other weeds did not correlate significantly to crop biomass in expt A (*R*=0.2376, *P*=0.2233). Correlations between *E. repens* biomass and crop and other weeds biomasses were not present in expt B because of a lower infestation level of *E. repens*. Only when relating other weeds biomass to crop biomass, a slight correlation occurred (*R*=-0.4148, *P*=0.0282).

Discussion

Curvilinearity between residual rhizome biomass and the shoot biomass of the following year was not present and hence a negative exponential function was not needed to describe data; hypothesis a) could not be demonstrated. A negative exponential relationship would have meant that the rate of shoot biomass production would have been higher from small remains of rhizomes than from larger amounts. The comprehensive and detailed studies of Håkansson (1968a, 1968b) on *E. repens* growth and reproduction in pure stands from planted rhizome fragments also do not explicitly show a larger shoot production rate from small amounts of rhizomes. The composition of rhizome fragment lengths in the rhizome biomass considered and the depth from which they sprout strongly affect shoot growth. Short fragments looses their reproductive capacity more quickly with increasing depth of burial than larger fragments benefiting from more food reserves for shoot growth. Rhizome fragment length following the repeated treatments and the placement of remaining fragments in the soil was not recorded in this study. However, measurements of fragment lengths were made when the uprooting ability of different implements was tested (Melander *et al.*, 2008), showing no length differences when the *Rotalabour* rotary cultivator was used at a forward speed of 4 or 8 km h^{-1}, respectively. Fragment length was very constant at 30 cm with approx. 11 nodes on each fragment. The rotary cultivator is not designed for cutting purposes but originally for tilling purposes. Since the whole experimental area was mouldboard ploughed in spring and the rotary cultivator was used at the same working depth for each pass, we do not believe that the number of passes with the rotary cultivator appreciably affected fragment length or depth of placement.

The curve fitting in Fig. 1 also included data from treatment 3 despite the fact that uprooted rhizomes were not removed but left exposed on the soil surface until they were ploughed under in spring. However, this exposed fraction has not contributed to the production of new shoots and did not cause a deviation from the linearity obtained. Rhizome buds were considered unviable in spring, although this was not tested. The rhizomes had an appearance similar to crop residues and only few buds had sprouted with a wilted appearance in spring. Desiccation, predation, decay and frost are all factors that promoted rhizome bud mortality during the seven months from treatment in late summer until next spring. For example, temperatures were unusually cold in January, February and December 2010 averaging -3.0, -1.4 and -4.8, respectively.

Traditional stubble cultivation (treatment 2) did not differ significantly from treatments involving one or two passes with the rotary cultivator in terms of shoot biomass reductions. Only four passes with rotary cultivation resulted in less shoot biomass. Tine-based stubble cultivators do not uproot rhizomes and roots to the same extent as the rotary cultivator used here (Melander *et al*., 2008). The controlling mechanisms are achieved through fragmentation of the rhizomes and by interrupting autumn shoot growth; both factors apparently of significant importance in this study. Also mouldboard ploughing before the establishment of a catch crop (Table 1) is likely to have improved the effectiveness of tine cultivation. Former experiments with tine-based stubble cultivation strategies conducted over longer periods in the autumn for *E. repens* control on different soil types have demonstrated variable results with effectiveness mostly in the range of 50-60% control (Permin, 1987). The strongest uprooting of rhizomes achieved with four passes rotary cultivation in this study clearly points to the potential of developing machinery for uprooting and removal. Alternatively, destruction of the uprooted rhizomes would allow nutrients imbedded in the rhizomes to be recycled (Melander *et al*., 2011).

Catch crop growing did not improve control effectiveness or crop yield, and hypothesis b) could not be supported. The catch crop canopy developed poorly in both expts, which partly can be attributed to the sandy soil poor in nutrients with a limited water holding capacity. Moreover, post-harvest establishment of catch crops in mid-August or later in Northern Europe is rather late for achieving sufficient catch crop growth owing to short growing periods between crops (Melander *et al*., 2013). Undersowing the catch crop in a main crop gives the catch crop a better start after crop harvest for subsequent growth. For example, undersowing red fescue in winter wheat can reduce late autumn biomass of *E. repens* rhizomes by 40% (Bergkvist *et al*., 2010). Unfortunately, undersowing catch crops is not compatible with the concept of post-harvest uprooting. Improvements of catch crop suppression should rather address aspects such as ideal attributes of plant species for weed suppression in the post-harvest period including ideal timing and methods for catch crop establishment under a Northern European climate.

Hypothesis c) was supported as soil compactness in the upper soil layer had reached the same level for all treatments including untreated when spring barley had been established. According to former measurements on soil compactness following concrete rolling on the same location, the compactness achieved in the upper soil layer can also be ascertained further down in the plough layer (Schjønning P., personal communication). The higher compactness measured in the plots where a catch crop had been grown, but before establishing spring barley, was probably due to ring rolling and rooting from the catch crop that may have caused some resistance when penetrating the soil.

Rhizome uprooting and removal/destruction becomes especially important at high *E. repens* infestations for the preservation of crop yield as seen in expt A in which vigorous *E. repens* shoot growth suppressed the growth of other plants. There were no indications of factors other than competition from *E. repens* that detectably had affected barley grain yield. A linear relationship between grain yield and shoot biomass was also demonstrated by Melander (1995) for approx. the same shoot biomass range growing in conventional spring barley. Absolute yield loss per unit shoot biomass, expressed as a steeper slope in the regressions, was higher in Melander (1995). However, the relative yield loss was lower because considerably more grain was produced under conventional conditions; approx. 16% yield loss per 100 g m^{-2} shoot biomass in Melander (1995) versus 21% in this study.

For the further development of implements for uprooting of rhizomes and other sub-surface propagules, we suggest focusing on lifting principles such as rolling webs for transporting objects from a pick-up unit as known from harvesting potatoes (e.g. www.grimmeuk.com, accessed 19 September 2012). Actually, we also used a beach cleaner (www.beach-tech.com/en/products/beachtech.html, accessed 19 September 2012) in the test of implements mentioned in the introduction section. The beach cleaner also uses rolling webs and a pick-up unit for the collection and removal of waste from sand beaches. The cleaner was able to provide an almost complete removal of rhizomes in just one pass but only for a few meters. The implement needs modifications to become operational in a field situation but the perspectives look very promising. Another major research question for the future is whether the concept of quick uprooting and removal (or destruction) of propagules is feasible on more loamy or clayey soils.

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Table 1 Treatments conducted in experiments A and B.

Treatment	Date of treatment	No. of passes	Removal of exposed rhizomes*	Catch crop (CC)**	Cultivation depth (cm)	Implement settings
1. Untreated	-	-	-	No		
2. Stubble cultivation	14, 21 Aug (expt A) 7, 14 Sep (expt B)	2	No	Yes	6 cm (first pass), 8 cm (second pass)	Forward speed 10 km h^{-1}
3. Rotary1(-CC)	21 Aug (expt A) 14 Sep (expt B)	1	No	No	20 cm	Forward speed 5.2 km h^{-1}, 330 rotations min^{-1}
4. Rotary2(-CC)	21 Aug (expt A) 14 Sep (expt B)	2	Yes	No	20 cm	Forward speed 5.2 km h^{-1}, 330 rotations min^{-1}
5. Rotary2(+CC)	21 Aug (expt A) 14 Sep (expt B)	2	Yes	Yes	20 cm	Forward speed 5.2 km h^{-1}, 330 rotations min^{-1}
6. Rotary4(-CC)	21 Aug (expt A) 14 Sep (expt B)	4	Yes	No	20 cm	Forward speed 5.2 km h^{-1}, 330 rotations min^{-1}
7. Rotary4(+CC)	21 Aug (expt A) 14 Sep (expt B)	4	Yes	Yes	20 cm	Forward speed 5.2 km h^{-1}, 330 rotations min^{-1}

* Removed after each pass using a PTO-driven rotary rake

** A catch crop (CC) mixture of winter vetch (20 kg ha^{-1}), winter rye (40 kg ha^{-1}) and winter oil seed rape (0.75 kg ha^{-1}) was sown after the last pass. Treatments 5 and 7 were ring rolled after sowing the catch crop. The plots were mouldboard ploughed to 22 cm depth prior to sowing the catch crop in treatment 2.

Table 2 Effects of the treatments presented in Table 1 on *E. repens* rhizome biomass remaining in the soil after treatment and *E. repens* shoot biomass production in a subsequent spring barley crop shown for expts A and B. Standard errors of the means are shown in parentheses. SED is the maximum standard error of differences between means.

Experiment	Treatment	Rhizome biomass (g m^{-2})	Shoot biomass (g m^{-2})		
			Log-transformed	Back-transformed	Effects relative to untreated
A	1. Unt.	522.3 (75.95)	5.190 a	179.5	
	2. St.cult.(+CC)	-	4.336 b	76.4	-57%
	3. R1(-CC)	475.6 (17.36)	4.968 a	143.7	-20%
	4. R2(-CC)	247.8 (62.92)	4.176 bc	65.1	-64%
	5. R2(+CC)	-	4.071 bc	58.6	-67%
	6. R4(-CC)	107.1 (25.08)	3.727 ce	41.6	-77%
	7. R4(+CC)	-	3.335 e	28.1	-84%
	SED		*0.2872*		
B	1. Unt.	261.3 (121.35)	3.629 a	37.7	
	2. St.cult.(+CC)	-	1.482 bc	4.4	-88%
	3. R1(-CC)	79.2 (13.90)	1.930 b	6.9	-82%
	4. R2(-CC)	57.8 (15.77)	1.637 bc	5.1	-87%
	5. R2(+CC)	-	1.647 bc	5.2	-86%
	6. R4(-CC)	28.2 (6.58)	0.479 bc	1.6	-96%
	7. R4(+CC)	-	0.155 c	1.2	-97%
	SED		*0.8510*		

Figure legends

Fig. 1 Relationship between residual rhizome biomass in the soil after rotary cultivation and the amount of shoot biomass produced in the subsequent year shown for expts A and B. Observed values are back-transformed means from analysing on log-transformed data. Parameter values are from the simplest model obtained.

Fig. 2 Soil compactness measured before and after crop establishment in spring shown for all seven treatments (Table 1) and averaging expts A and B. Horizontal bars are standard errors of the means of soil compactness before crop sowing and vertical bars are standard errors of the means of compactness after crop sowing.

Fig. 3 Aboveground biomasses of crop, *E. repens* and other weeds, respectively, in expts A and B following the seven treatments explained in Table 1. Biomasses were recorded in early-mid August. Bars shows standard errors of means of total biomasses.

Fig. 4 The relationship between spring barley grain yield and the amount of aboveground *E. repens* biomass in expt A following the seven treatments explained in Table 1. Horizontal bars are standard errors of the means of *E. repens* biomasses, and vertical bars are standard errors of means of grain yield.

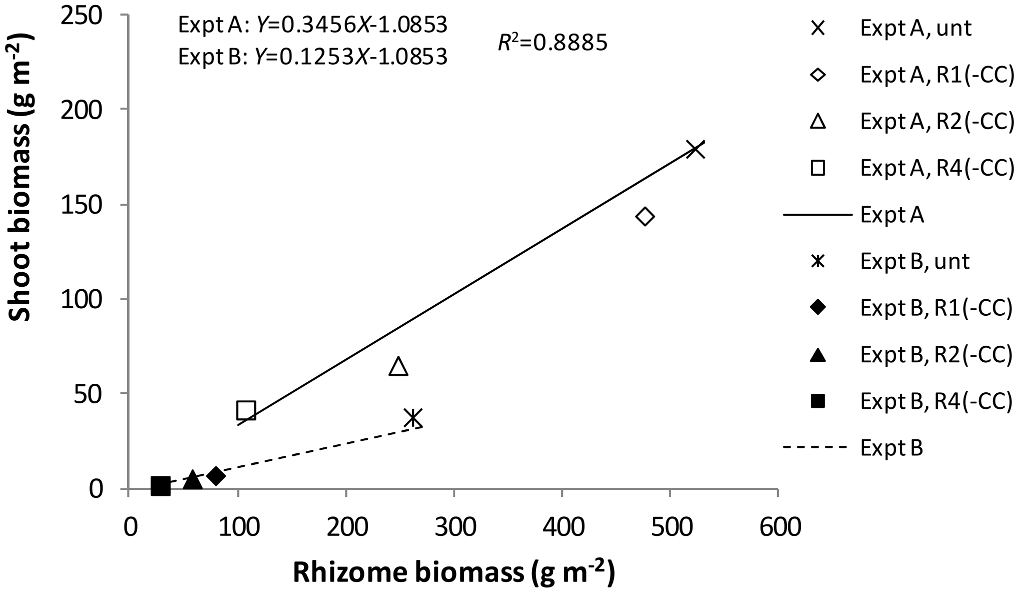
Expt A: Y=0.3456X-1.0853
Expt B: Y=0.1253X-1.0853
R²=0.8885
Shoot biomass (g m⁻²)
Rhizome biomass (g m⁻²)
250
200
150
100
50
0
0
100
200
300
400
500
600
Expt A, unt
Expt A, R1(-CC)
Expt A, R2(-CC)
Expt A, R4(-CC)
Expt A
Expt B, unt
Expt B, R1(-CC)
Expt B, R2(-CC)
Expt B, R4(-CC)
Expt B

Fig. 1

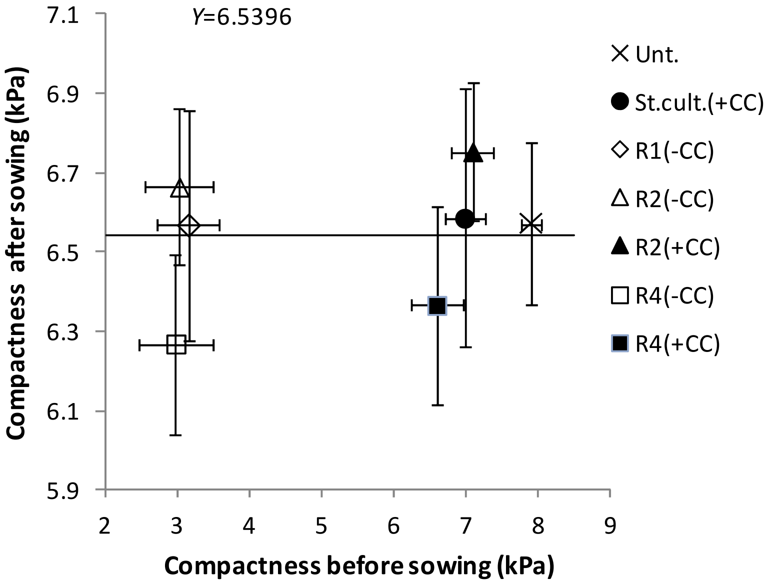
Y=6.5396
Compactness after sowing (kPa)
7.1
6.9
6.7
6.5
6.3
6.1
5.9
2
3
4
5
6
7
8
9
Compactness before sowing (kPa)
× Unt.
● St.cult.(+CC)
◇ R1(-CC)
△ R2(-CC)
▲ R2(+CC)
☐ R4(-CC)
■ R4(+CC)

Fig. 2

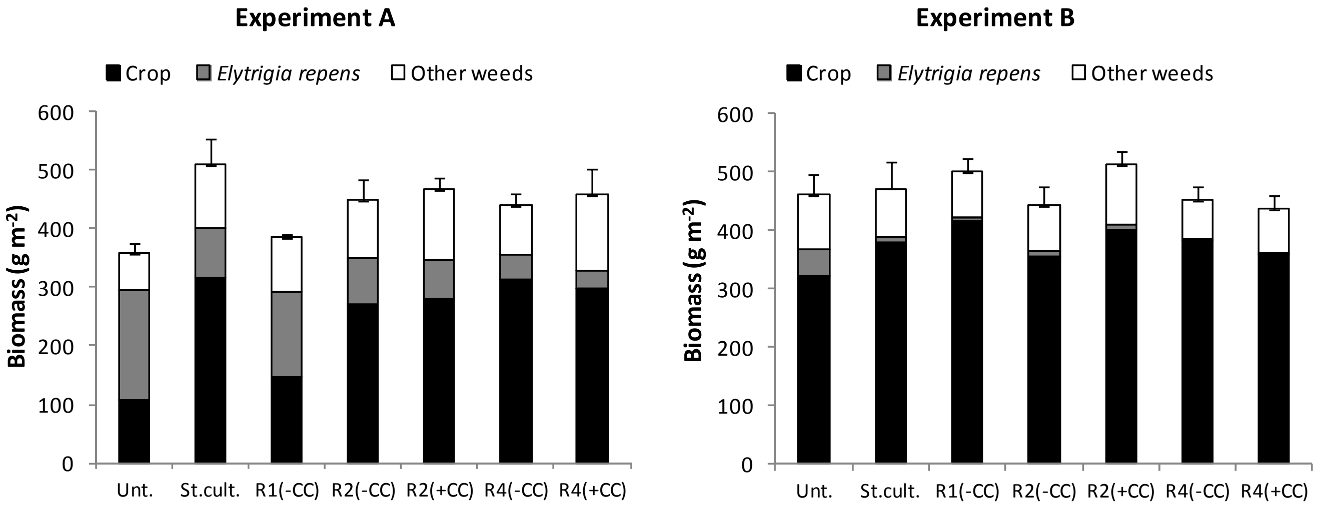
Experiment A
■ Crop ▨ *Elytrigia repens* ☐ Other weeds
Biomass (g m-2)
0
100
200
300
400
500
600
Unt.
St.cult.
R1(-CC)
R2(-CC)
R2(+CC)
R4(-CC)
R4(+CC)
Experiment B
■ Crop ▨ *Elytrigia repens* ☐ Other weeds
Biomass (g m-2)
0
100
200
300
400
500
600
Unt.
St.cult.
R1(-CC)
R2(-CC)
R2(+CC)
R4(-CC)
R4(+CC)

Fig. 3

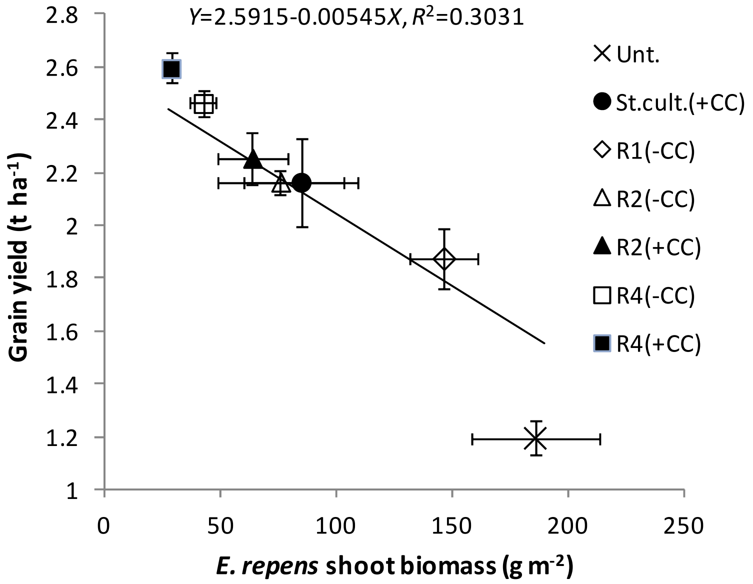
Y=2.5915-0.00545X, R²=0.3031
Grain yield (t ha⁻¹)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
50
100
150
200
250
E. repens shoot biomass (g m⁻²)
× Unt.
● St.cult.(+CC)
◇ R1(-CC)
△ R2(-CC)
▲ R2(+CC)
□ R4(-CC)
■ R4(+CC)

Fig. 4