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Method, timing and duration of bare fallow for the control of *Cirsium arvense* and other creeping perennials

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ABSTRACT

The control of perennial weeds is of great concern in organic farming. Mouldboard ploughing and other soil tillage operations are the main methods for combating weeds, often combined with competition from a green manure cover crop. Inclusion of a period with bare fallow may at times become necessary. Repeated soil tillage may however cause erosion and loss of nutrients, more so with autumn tillage than with spring tillage. The timing and effectiveness of the operations are therefore important. The aim of the present work has been to evaluate if autumn ploughing contributes to increased weed reduction if spring fallow is performed, how to combine stubble cultivation, fallow and establishment of a green manure cover-crop and to compare the two and the optimum duration of spring fallow compared to an established green manure cover-crop.

The effectiveness of operations varied between weed species and was related to their biology. Overall, the perennial species studied developed least total biomass in a mown, one-year green manure crop or after complete underground cutting by shallow ploughing after harvest or by deep ploughing in spring. The green manure cover-crop seemed to be established most successfully after stubble harrowing in autumn and spring or when undersown the previous year. Autumn ploughing had little impact on the biomass of perennial weeds when spring bare fallow treatments were performed or when a green manure cover-crop was established in spring. Only a high number of harrowings competed well with the undersowing of a green manure cover-crop for the regulation of the individual species, except in the case *Elymus repens*.

The number of fallow operations may be kept to a minimum when followed by a green manure cover-crop, or when such a crop is undersown the previous year. If fallowing in spring is performed, we found no benefit from increasing the number of fallow operations from three to four harrowings. Shallow ploughing after harvest followed by tine harrowing in autumn reduced total perennial weed biomass to the same extent as two or three harrowings in spring without subsequent ploughing, or two harrowings in spring followed by ploughing. We found in general an increase in cereal yield with the inclusion of a green manure cover crop, preferably undersown in the first experimental year. A prolonged period with fallow treatments had a negative effect on the cereal yield and the number of spring operations for optimization of cereal yield was lower than that required for optimum weed control. We need therefore to find a balance between these two factors.

1. Introduction

Perennial weeds pose a great challenge in plant production in most agricultural systems. They store nutrients for regeneration in their roots or rhizomes and produce large amounts of biomass in spring, thus competing strongly with the cultivated crop. Soil cultivation to control perennial weeds should focus mainly on reducing the storage of food reserves needed for regrowth (Håkansson, 2003). In spring, this implies preventing transport of nutrients from roots or rhizomes to more shallowly-located or above-ground plant parts, whilst in autumn it is important to reduce the transport of nutrients from above-ground green organs

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to the roots or rhizomes.

When perennial weeds are present in such a number that yield reduction is expected, a period with bare fallow may in organic farming become unavoidable. Such a fallow period in the crop rotation is known to reduce the regeneration of perennial weeds (Bond and Grundy, 2001). In general, bare fallow throughout the whole season is not commonly practiced. More frequently, a shorter bare fallow period is combined with the establishment of a green manure cover-crop, to provide competition with weeds already weakened by mechanical treatment.

Mouldboard ploughing to approximately 18–25 cm is the main method for primary tillage in Scandinavia and elsewhere (Reicosky and Archer, 2007). It is traditionally used to loosen the soil, combat weeds and bury green plant parts and crop residues (Håkansson et al., 1998; Vakali et al., 2011). However, mouldboard ploughing has been found to be directly related to CO_2 losses from the soil and it increases the use of fuel (Reicosky and Archer, 2007). Moreover, erosion risk is greater with deep than with shallow tillage (Øygarden, 2000; Lundekvam, 2007; St. Gerontidis et al., 2001). Shallow tillage is thus recommended in order to avoid these side-effects, but when used alone, shallow primary tillage generally results in a higher number of weeds, especially of perennials (Ekeberg et al., 1985; Børresen and Njøs, 1994; Håkansson et al., 1998; Gruber and Claupein, 2009; Brandsæter et al., 2011). Shallow ploughing or rotary tillage shortly after harvest, combined with shallow or deep ploughing in late autumn, has been found to give significant reductions of *Cirsium arvense*, *Sonchus arvensis* and *E. repens* (Håkansson, 2003; Gruber and Claupein, 2009). Soil tillage in late autumn may, however, increase the risks of nutrient leaching and soil erosion (Fykse et al., 2002; St. Gerontidis et al., 2001) and N leaching increases with the number of tillage operations in autumn (Askegaard et al., 2011). Ploughing and intensive tillage should therefore preferably be deferred until spring, although this may cause some delay in sowing time.

Well-timed shallow tillage operations and/or competition from a green manure cover-crop combined with mowing have been found to reduce the regeneration of *C. arvense* (Graglia et al., 2006; Gruber and Claupein, 2009; Thomsen et al., 2011: Brandsæter et al., 2012). Such increased competition may be the weed-control option with the lowest environmental impact. Green manure cover-crops might be expected to leave excess nitrogen in the soil, but inclusion of 25% green manure cover-crop in the crop rotation was not found to increase N leaching when compared to that from a cereal/pea rotation (Askegaard et al., 2011).

On this background we have in the present study aimed at evaluating if autumn ploughing contributes to increased weed reduction if spring fallow is performed, how to combine stubble cultivation, fallow and establishment of a green manure cover-crop and what is the necessary number of spring fallow operations and comparing this with an established green manure cover-crop. We also evaluated the effect of these operations on cereal yield.

2. Materials and methods

The study consisted of three experiments, designated Experiment I, II and III.

2.1. Site description

2.1.1. Experiment I

The study was located at Øsaker, Grålum (59° 23′N, 11° 02′E, 40 m asl) in south-east Norway. The soil is a clay loam with imperfect natural drainage, classified as Luvic Stagnosol (Clayic) (World Reference Base, 2006). The topsoil contains 30–40 % clay and 40–50 % silt, overlying heavy clay (52%) subsoil.

2.1.2. Experiments II and III

The two experiments at Ås were located within an experimental organic cropping system (59° 40′N, 10° 47′E, 75 m asl) at the Norwegian University of Life Sciences, Ås. The soils are described as silty clay loam with poor natural drainage (Bakken et al., 2006) and classified as Epistagnic Albeluvisol (Siltic) (World Reference Base, 2006).

2.2. Experimental description

The timing of management operations and weed assessment in the experiments is presented in Table 1.

2.2.1. Experiment I, 2004–2006

We here studied the effect of autumn ploughing, on weed growth and cereal yield, if spring fallow was performed combined with the duration of spring fallow. Short (3 wks) versus prolonged (6 wks) fallow periods were performed prior to sowing the green manure cover crop. The experiment was initiated in autumn 2004 after cultivation of a cereal crop. The experimental treatments included ± autumn ploughing combined with seven different spring treatments in a factorial split-block design with three replicates. Two treatments, with and without autumn ploughing comprised the main plots in three 28 × 15 m replicate blocks. Within each block seven fallow treatments were randomly located on split plots (4 × 15 m). The blocks were separated by 10–20 m borders to allow for normal driving speed and tractor turning. The plots of two of the treatments (6 and 7) were shallow ploughed to 12 cm shortly after grain harvest, followed by two passes of a S-tine harrow (5–7 cm working depth). In late autumn 2004, half of each block was deep ploughed to 25 cm. In spring 2005, the plots that had not been ploughed in autumn were rotary harrowed with a Dyna-Drive ground-driven, surface cultivator (EarthMaster®, USA) working depth 5–8 cm. The experiment consisted thus of 14 different treatments (Table 2).

Following these treatments all the plots were seeded with a green manure cover-crop (see Table 2) in early summer 2005. The earliest sown treatments (nos. 2, 4 and 6) were mown twice whereas the remainder were mown only once. In late autumn 2005 all plots were ploughed to 25 cm and normal seedbed preparation was performed in spring 2006 before sowing wheat.

Deep ploughing was performed with a Kverneland mouldboard plough, body No. 8 (Kverneland ASA, Norway), with disc coulter and skimmer. The depth wheel was set at 25 cm and furrow width was 40 cm, resulting in semi-inverted furrow slices. A Kverneland Ecomat plough, with share knife and skimmer, was used for shallow ploughing (treatments 6 and 7). The depth wheel was set at 12 cm and furrow width was 35 cm, resulting in completely inverted slices. For fallow treatments a disc cultivator (Kverneland ASA, Norway) were used with a working depth of approximately 10 cm.

Secondary tillage in 2005 and 2006 comprised levelling with an under- and over-beam drag leveller, followed by harrowing with an S-tine cultivator. Sowing was performed at right-angles to the tillage, using a Suffolk coulter drill. After sowing, all plots were rolled with a Cambridge roller in the same direction as ploughing. All tractor tyre pressures were maintained at 80 kPa throughout the experimental period. Mowing operations were carried out with a PTO-driven Kverneland FH180 Chopper at a stubble height of approximately 5 cm.

2.2.2. Experiment II, 2004–2006

The aim of this part of the study was to find out how to combine stubble cultivation, fallow and establishment of a green manure cover-crop and to compare the two with respect to optimum weed