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Control of clubroot (*Plasmodiophora brassicae*) in oilseed rape using varietal resistance and soil amendments

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ABSTRACT

Clubroot is a major threat to global brassica production. It has been an increasing problem in UK oilseed rape (OSR) crops due to the persistence of the soil-borne pathogen responsible for disease, *Plasmodiophora brassicae*, exacerbated by close rotations. Field surveys in the UK in the years 2007–2010 showed that clubroot was present in all areas of the UK where OSR was grown with 52% of the selected sites testing positive. Varietal resistance and soil amendment with calcium carbonate, calcium cyanamide and boron alone or in various combinations applied before sowing were assessed for the potential to manage clubroot. Soil amendments gave variable control between sites and years but showed some potential as part of a clubroot management strategy. Varietal resistance remained the more effective management option providing 50–95% disease control at three sites in England. However, this control was not consistently effective at sites in Scotland where resistant OSR varieties have been heavily used in rotations. Yield losses were demonstrated at 0.03 t ha^{-1} for every 1% increase in clubroot severity in the susceptible variety Kommando. Yield losses were only slightly lower per 1% increase in clubroot severity for the resistant variety Mendel at 0.028 t ha^{-1} despite lower disease levels. Losses in affected crops can therefore equate to over 50% of potential yield in severely infected crops. Soil testing for clubroot and lengthening rotations are important to the long term management of clubroot as varietal resistance and soil amendments can reduce clubroot severity but provide inconsistent results.

1. Introduction

Clubroot is the most damaging disease of brassica crops globally, occurring in more than 60 countries where typical yield losses are in the range of 10–15% (Dixon, 2009a) but can reach in excess of 80% (Pageau et al., 2006; Hwang et al., 2011a). The disease is caused by the soil-borne root pathogen *Plasmodiophora brassicae* which can remain dormant in soils as long-lived resting spores for upwards of 15 years (Hwang et al., 2012b). The estimated half life of *P. brassicae* resting spores is 3.7 years (Wallenhammar, 1996) hence the disease is a major issue when brassica crops are grown in short rotations. Furthermore, clubroot can infect and survive on cruciferous weeds in arable rotations. The introduction of oilseed rape (OSR) into rotations in the UK in the mid 1970s further increased the risk of disease spread and build up. OSR is grown on a little under 700,000 hectares of land in the UK (Anon, 2014a), approximately 37,000 ha of which are in Scotland (Anon, 2014b). As break crop choices become increasingly limited OSR has become particularly important in arable rotations in the north of the UK. OSR is now commonly grown one year in three in arable rotations in Scotland and England, and one year in two is not uncommon. This frequency in the rotation increases the risk of clubroot multiplying and spreading across farms as has been observed across the major OSR and vegetable brassica growing regions of the world (Dixon, 2009a) including recently in Canada (Hwang et al., 2012b).

Clubroot is a disease typically associated with warm wet soils (Dixon, 2009b). Infection begins when resting spores germinate and motile zoospores swim through available soil water towards the host roots. This process is thought to be stimulated by root exudates (Rashid et al., 2013). During the primary infection phase the zoospores infect root hairs where they can multiply and go on to spread and form secondary infections in root cells (Webster, 1986; Hwang et al., 2011b). Pathogen development within root cortical cells leads to changes in root hormone balance resulting in hypertrophy and formation of galls which present as the typical clubroot symptom (Ludwig-Müller et al., 2009; Siemens et al.,

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Table 1
Soil amendments used in field trials.

	Field trial year		
	2007–2008	2008–2009	2009–2010
	Untreated control	Untreated control	Untreated control
	Calcium carbonate 2 t ha^{-1}		
	Calcium carbonate 4 t ha^{-1}	Calcium carbonate 4 t ha^{-1}	Calcium carbonate 4 t ha^{-1}
	Calcium carbonate 8 t ha^{-1}.	Calcium carbonate 8 t ha^{-1}.	Calcium carbonate 8 t ha^{-1}.
	Calcium cyanamide 250 kg ha^{-1} [a]	Calcium cyanamide 250 kg ha^{-1} [a]	Calcium cyanamide 250 kg ha^{-1} [a]
	Calcium cyanamide 250 kg ha^{-1}—not incorporated	Calcium cyanamide 250 kg ha^{-1}—not incorporated	
	Control with extra 50 kg ha^{-1} nitrogen	Control with extra 50 kg ha^{-1} nitrogen	
	Boron 20 kg ha^{-1}	Boron 20 kg ha^{-1}	
		Calcium carbonate 4 t ha^{-1} + calcium cyanamide 250 kg ha^{-1} [a]	Calcium carbonate 4 t ha^{-1} + calcium cyanamide 250 kg ha^{-1} [a]
			Calcium carbonate 4 t ha^{-1} + calcium cyanamide 250 kg ha^{-1} [a] + Boron 20 kg ha^{-1}
Total	8 treatments × 2 varieties × 4 replicates = 64 plots	8 treatments × 2 varieties × 4 replicates = 64 plots	6 treatments × 3 varieties × 4 replicates = 72 plots
OSR varieties	Kommando (S)[b] Mendel (R)	Kommando (S)[b] Mendel (R)	Kommando (S)[b] Mendel (R) Cracker (R)

[a] Calcium cyanamide shallow incorporated after soil preparation.
[b] Varietal resistance status against clubroot R = resistance, S = susceptible.

2006). The galls form strong metabolic sinks which alter the source-sink relationship and result in nutrients being transported to the roots leading to reduced green leaf area and consequent growth and yield penalties (Ludwig-Müller et al., 2009; Mitchell and Rice, 1979; Keen and Williams, 1969). Clubroot spread can occur via contaminated soil transferred on machinery wheels and although there is some limited movement of the resting spores through the soil profile, spread following field flooding is commonly noted (Dixon, 2009b). Disease symptoms often first appear in patches in the crop but can become distributed throughout the field in subsequent years. In vegetable cropping land is often rented and soil testing for the disease prior to field selection allows infected sites to be rejected (Dixon, 2009a). However, clubroot-free land is a diminishing resource and rejecting infested fields for OSR cultivation adds additional pressures to the holding's crop rotation strategy, as well as having financial implications. In recent years, reports of serious problems with clubroot infection in OSR and yield losses in commercial crops have increased.

Control of clubroot is particularly difficult due to the persistence of the pathogen in soil (Wallenhammar, 1996). Some fungicides have shown some control of clubroot (Peng et al., 2014; Stewart, 2007), but in the current legislative climate it is unlikely that any soil applied fungicide would gain approval for use, particularly on the scale of planting for OSR. Faced with an infected field, growers will usually opt to drill a clubroot resistant OSR variety which not only reduces disease levels in the crop but also has the potential to reduce inoculum levels in the field (Hwang et al., 2012a). Although numerous clubroot resistance sources have been found in brassica crops worldwide (Diederichsen et al., 2009), all clubroot resistant OSR in the UK contains a single major gene resistance source derived from the variety Mendel (Diederichsen et al., 2006; http://www.hgca.com/varieties/hgca-recommended-lists/winter-oilseed-rape-2015-16.aspx). However, this source of resistance is not effective against all pathotypes of clubroot present in the UK and significant disease can develop where it has been used several times in a rotation, indicating this source of resistance is unlikely to be durable (Diederichsen et al., 2006; Werner et al ., 2008; Oxley, 2007).

Soil amendments using non-synthetic compounds have potential for use in clubroot management strategies. High soil pH and calcium ion content are known to reduce clubroot severity in host crops but the precise mechanism for this control is not fully understood (Donald et al., 2004; Myers and Campbell, 1985; Niwa et al., 2007; Tremblay et al., 2005). A direct effect from calcium and pH on resting spores has been shown in previous research (Donald and Porter, 2009; Myers and Campbell, 1985) but only at extremes of low inoculum and high values for these two parameters. Timing of soil amendment application, such as lime products (Harling, 2006), is critical and the immediate three or four days following transplanting of vegetable brassicas has been identified as the most important (Webster, 1986). Control offered by raised pH and calcium, although potentially significant, is not complete. Even distribution in soil is also a key factor and this can be hard to achieve, which allows clubroot infection to occur in pockets of lower pH and available calcium. Other nutrients such as boron may also have an effect on clubroot (Donald and Porter, 2009). The mode of action is unclear but it is thought to act by reducing subsequent disease development in plants, rather than by reducing primary infection rates (Myers and Campbell, 1985; Webster, 1986).

Managing clubroot infections is essential to maintain OSR as a viable break crop in the UK. The aim of this study was to assess the incidence and severity of infestation in UK OSR crops, to screen varieties for resistance and to test the efficacy of soil amendments and the effectiveness of varietal resistance to control clubroot in different environments. Together these factors can be used to develop sustainable management strategies for clubroot in UK OSR agriculture.

2. Methods and materials

2.1. Survey of oilseed rape fields

In 2008–2010 a survey of commercial OSR fields in Scotland and England was undertaken. A total of 96 samples were collected, 42 from England, two from Wales and 52 from Scotland. Sampling was not random with fields selected by growers and agronomists (ADAS and SAC). Sites in England were mainly taken from known infected farms that were still growing winter OSR in the South East, South West, Midland and Northern regions. Fifty cores were taken to a depth of 15–20 cm from each sampling area (c. 2.5 ha) in autumn or winter to give a soil sample of approximately 2 kg. Cores were collected at regular intervals in a "W" pattern. Each soil had large stones and plant material removed before being mixed by hand and used to fill seed trays for bioassay testing. Seed trays with drainage holes (20 × 14.5 × 5.5 cm) were filled with each sample soil and placed into a larger tray with no drainage holes (33.5 × 21 × 5.5 cm).