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The role of pollinators, pests and different yield components for organic and conventional white clover seed yields

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ABSTRACT

A high and stable seed production of both organic and conventional white clover (*Trifolium repens* L.) is needed to meet market requirements. Seed yields of white clover are, however, known to vary greatly, and organic yields are often considerably lower than conventional yields. Our aim in this study was to estimate the roles of pollinators, pests and different yield components for organic and conventional white clover seed yields. We surveyed pollinators (honey bees, bumble bees and solitary bees), reared the main insect pests (*Protapion fulvipes* Geoffroy and *Hypera* spp. weevils) from flowers and measured the yield components (inflorescences per area, flowers per inflorescence, seeds per flower and weight per seed) in organic, conventional untreated and conventional insecticide treated plots in 27 white clover seed fields over two years in southernmost Sweden. Unexpectedly, densities of bees other than honey bees were higher in insecticide treated plots compared to organic plots, but pollinator densities were not related to seed set. The lower pollinator visitation in organic plots might have been caused by pest damage to the flowers, as *P. fulvipes* and *Hypera* spp. weevils were more common in organic plots than in conventional insecticide treated plots. The abundances of both *P. fulvipes* and *Hypera* spp. weevils were negatively related to seed set, with *P. fulvipes* being most damaging for seed set. Seed yield was considerably lower (42%) in organic plots compared to conventional insecticide treated plots, and this was driven by a lower (36%) seed set. Taken together, our results indicate that pollinator densities are not limiting yields in either conventional or organic white clover seed production, whereas *P. fulvipes* crop damage is an important factor limiting organic yields via negative effects on seed set. Research efforts to raise white clover seed yield with minimized environmental impacts should include a focus on integrated pest management of *P. fulvipes*, including the development of control methods accepted in organic farming.

1. Introduction

Clovers (*Trifolium* spp.) are important forage and green manure crops, and they are essential for nitrogen supply in organic farming systems (Stockdale et al., 2001). White clover (*T. repens* L.) is one of the commercially most important species, and a high and stable seed production is needed to meet market requirements (Boelt et al., 2015). Seed yields of white clover are, however, known to vary greatly (Boelt et al., 2015). This is true for both organic and conventional seed yields of white clover in Sweden, with organic yields also being considerably lower than conventional yields (Swedish Seed and Oilseed Growers, 2016). The factors causing these suboptimal and variable yields and their relative importance are, however, not known. Moreover, the reasons for the lower organic seed yields have not been identified.

Pollination by insects is essential for seed set in white clover (Darwin, 1861). Honey bees (*Apis mellifera* L.) and wild bees, such as bumble bees (*Bombus* spp.), are the most important pollinators (Free, 1993). The recommended stocking rates for honey bees are 1–2 colonies per hectare (Free, 1993). In general, crop pollinating wild bees are often more common in organically compared to conventionally managed fields (Kennedy et al., 2013), and pollinator densities may be negatively affected by insecticide use in conventionally managed fields (Rundlöf et al., 2015). It is, however, not known whether this is also the

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case in white clover seed production. Previous studies have found that managed honey bees provide efficient pollination of white clover, and hence seed yields are rarely limited by insufficient pollination (Palmer-Jones et al., 1962; Free, 1993; Thomas, 1996; Goodwin et al., 2011). However, both wild and managed bees are threatened by multiple and interacting factors in modern agricultural landscapes (Goulson et al., 2015), stressing that updated information is needed on whether pollinator abundances in clover seed fields are sufficient to fully pollinate the crop.

Insect pests have the potential to strongly limit white clover seed yields (Hansen and Boelt, 2008; Boelt et al., 2015). In organic white clover seed production in Denmark, for example, the white clover seed weevil (*Protapion fulvipes* Geoffroy) and the lesser clover leaf weevil (*Hypera nigrirostris* Fabricius) are important factors limiting yields (Langer and Rohde, 2005). Crop damage by *P. fulvipes* is primarily caused by the larvae that feed on developing ovules and seeds (Bovien and Jørgensen, 1934; Hansen and Boelt, 2008). *Hypera nigrirostris* crop damage is caused both by adult feeding, which can lead to stem breakage, and larval feeding on inflorescences, stipules, stems and buds (Sechriest and Treece, 1963; Weiss and Gillot, 1993; Hansen and Boelt, 2008). The clover head weevil (*Hypera meles* Fabricius) also occurs on white clover in Fennoscandia (Markkula and Myllymäki, 1964). Compared to *H. nigrirostris*, *H. meles* larval feeding is more concentrated to inflorescences; otherwise the life histories of these two related species are similar (Detwiler, 1923; Markkula and Myllymäki, 1962). *Protapion fulvipes* is common in white clover seed fields in Sweden (Nyabuga et al., 2015), but *Hypera* spp. weevil abundance and the effects of insect pests on Swedish white clover seed yields are unknown. Conventional farmers in Sweden typically pursue pest control of clover seed weevils by applying insecticides, whereas no treatment options are available for organic farmers. It is not known, however, if the insecticide treatments used in conventional fields provide efficient crop protection.

Seed yield in white clover is the product of four yield components: inflorescence (flower-head) density (number of inflorescences per area unit), inflorescence size (number of flowers per inflorescence), seed set (number of seeds per flower) and seed weight (weight per seed). In particular, high inflorescence density has been identified as a crucial factor that sets the stage for high white clover seed yields (Boelt et al., 2015). There are important differences between conventional and organic farming of white clover seed which could potentially lead to systematic variation in inflorescence densities. For example, in organic farming there is no use of inorganic fertilizers, or herbicides for weed control. By comparing data from organic white clover seed fields with published results for conventional fields, Langer and Rohde (2005) came to the conclusion that inflorescence density and size are similar under organic and conventional management. We are not aware of any studies, however, that directly compared these yield components in a controlled design with both conventional and organic fields included in the study, or dissected yield differences between organic and conventional clover seed production into its yield components. Such information would be crucial in order to determine how efforts should be directed to overcome organic seed yield limitation.

Our aim in this study was to estimate the impacts of pollinators, pests and different yield components on organic and conventional white clover seed yields, and to seek factors that could explain why organic yields are lower than conventional yields. More specifically, we asked the following questions: (i) Do pollinator densities vary between organic and conventionally managed fields, and is pollinator density related to seed set? (ii) Do pest abundances vary between organic and conventionally managed fields, and is pest abundance related to seed set? (iii) Which yield components vary between organic and conventionally managed fields?

Table 1
Field characteristics. Man = field management, organic (Org) or conventional (Conv), Size = field size in hectares, Cultivar = name of white clover cultivar grown, I = insecticide use, letters indicate insecticides used in the order they were applied, α-c = α-cypermethrin, β-c = β-cyfluthrin, λ-c = λ-cyhalothrin, tc = thiacloprid, τ-f = τ-fluvalinate, HBs = number of managed honey bee colonies per hectare, BBs = number of managed bumble bee (*Bombus terrestris*) colonies per hectare, % agr = percent annually tilled agricultural land in 1 km buffers around the focal field.

Year	Field	Man	Size	Cultivar	I	HBs	BBs	% agr
2011	1	Org	10	Klondike	–	2.0	0.0	45
2011	2	Org	28	Jura	–	1.4	0.0	75
2011	3	Org	13.5	Hebe	–	0.5	0.0	82
2011	4	Org	9	Lena	–	1.7	0.0	61
2011	5	Org	3.6	Hebe	–	1.4	0.0	69
2011	6	Org	20	Klondike	–	1.0	0.0	87
2011	7	Conv	28	Merlyn	tc, τ-f	2.0	2.0	78
2011	8	Conv	12	Klondike	tc	1.3	0.0	55
2011	9	Conv	7	Lena	τ-f	1.4	0.0	83
2011	10	Conv	6	Undrom	tc, τ-f	0.3	2.5	85
2011	11	Conv	7	Abercrest	tc	0.0	0.0	84
2011	12	Conv	21	Hebe	τ-f, tc	1.4	0.0	91
2011	13	Conv	8	Hebe	tc	2.5	1.5	81
2011	14	Conv	9	Hebe	α-c, tc	1.3	0.0	64
2011	15	Conv	16	Hebe	tc	1.6	0.0	47
2014	16	Org	11	Undrom	–	1.4	0.0	61
2014	17	Org	8.5	Hebe	–	2.0	0.0	84
2014	18	Org	10	Hebe	–	5.0	0.0	82
2014	19	Conv	6	Klondike	β-c, τ-f	3.3	0.0	54
2014	20	Conv	23.6	Hebe	tc	1.0	0.0	80
2014	21	Conv	8	Hebe	tc, τ-f	2.8	2.3	88
2014	22	Conv	6.5	Lena	tc	0.0	2.8	87
2014	23	Conv	9	Hebe	tc	1.2	1.7	74
2014	24	Conv	16	Hebe	τ-f	1.9	0.0	80
2014	25	Conv	10	Klondike	tc	1.3	0.0	59
2014	26	Conv	20	Hebe	tc	1.0	0.0	73
2014	27	Conv	15	Hebe	λ-c, tc	2.0	0.0	74
Mean	–	–	12.7	–	–	1.6	0.5	73

2. Materials and methods

We conducted the study in 27 white clover seed fields in 2011 and 2014 in Scania in southernmost Sweden (Table 1). Nine conventional and six organic fields were included in 2011, and another nine conventional and three organic fields were included in 2014. Fields were commercially grown white clover of several cultivars (Table 1) intended for seed production. The distance between fields within each year was at least 1.7 km. Sample sizes of organic fields were lower because of limited availability of such fields in the region. Field sizes ranged from 3.6 to 28 ha (mean = 12.7 ha), and were similar between conventional and organic fields (Wilcoxon two-sample test, $Z = 0.28$, $p = 0.78$, Table 1). Growers had an average of 1.6 honey bee colonies per hectare of white clover during crop bloom, with no significant differences in stocking densities between conventional and organic fields ($Z = -0.70$, $p = 0.48$, Table 1). Three conventional growers in each year also added managed bumble bee colonies (*Bombus terrestris* L.) to their fields during crop bloom (stocking densities are presented in Table 1). Because it was more common among conventional growers to use managed bumble bees compared to organic growers we accounted for this factor in the main statistical analyses (see below).

Both pollinators and pests may be strongly affected by the landscape composition around a given field (Kennedy et al., 2013; Veres et al., 2013). When comparing highly mobile insects in conventional versus organically managed fields it is therefore important to take into consideration landscape composition, or at least to control for it (Rundlöf and Smith, 2006). We therefore analyzed land use in 1 kilometer buffers around the focal fields by GIS analysis in QGIS Desktop 2.4.0 using data from the Integrated Administration and Control System from the Swedish Board of Agriculture. Land use was dominated by agriculture and main crops grown were wheat, barley, oilseed rape and ley (fertilized grassland). The percent annually tilled