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Research paper

Effects of farming intensity, crop rotation and landscape heterogeneity on field bean pollination

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ABSTRACT

Organic farming has the potential to enhance ecosystem services such as crop pollination. However, it is not known if a similar effect can be generated on conventional farms, without reducing external inputs such as inorganic fertilizers and pesticides, by using more complex crop rotations including ley for animal fodder production. In two separate designs, both located in southern Sweden, we tested if local organic farming and the landscape proportion of conventionally managed leys, along a landscape heterogeneity gradient, affected the pollination success of field bean. The number of developed pods was higher on organic farms compared to conventional ones. Development of beans, which demands high pollination efficiency, increased with increasing landscape heterogeneity, but only on organic farms. Increasing proportion of ley on conventional farms did not significantly influence the development of beans. The number of developed pods was not affected by the proportion of ley in the landscape. Our results demonstrate that in order to maximize pollination success it is important to improve both field management and preserve semi-natural habitats in the agricultural landscape. Reducing farming intensity with conventionally managed leys does not seem to be as effective as organic farming for delivering crop pollination services.

1. Introduction

Considering the importance of insect pollinated crops for humans (Eilers et al., 2011; Klein et al., 2007), it is critical to find cost-efficient measures to improve and sustain pollination in farmland. Furthermore, not only crops but also wild plants depend to a large extent on insect pollinators (Ollerton et al., 2011). Reliance on pollination by domesticated honeybees is risky for various reasons. Some crops are not effectively, or not at all, pollinated by honeybees (Klein et al., 2012), and show high variance in yield in the absence of wild pollinators (Garibaldi et al., 2011). A high diversity of pollinators can also be important to maintain high crop pollination under environmental change (Christmann and Aw-Hassan, 2012). In addition, honeybees are declining as a result of diseases and loss of managers (Potts et al., 2010).

To mitigate negative effects of agricultural practices on biodiversity European governments have adopted a number of agri-environment schemes (AES). One common AES, organic farming, has been shown to benefit pollinators (Holzschuh et al., 2007; Rundlöf et al., 2008) and crop pollination (Andersson et al., 2012). Organic farming reduces farming intensity by prohibiting inorganic fertilizers and pesticides. Organic farms may also differ from conventional ones by more complex crop rotations including e.g. leys (rotational grasslands) for weed control, green manure and animal fodder (Stockdale et al., 2001). However, it is not known which one of these factors (i.e. less pesticides or higher amounts intensively managed grasslands) are more important for enhancing pollinators and the pollination service they provide.

Leys for hay and silage production are thought to decrease land-use intensity, increase landscape complexity through crop diversification and thereby benefit biodiversity (Potts et al., 2009). Some organisms, like farmland birds (Piha et al., 2007), moths (Pettersson, 2011) and bumblebees (Persson and Smith, 2013) are known to benefit from leys. Furthermore, leys may benefit some ecosystem services provided by soil biota, such as N-mineralization, water infiltration and soil respiration (van Eekeren et al., 2008), but it is not known whether leys enhance aboveground ecosystem services such as pollination. Pollinators can be enhanced by the potentially higher density of flower resources in leys compared to arable fields or by leys providing nest-sites if they are not too intensively managed (Persson and Smith, 2013). If so, including a high proportion of leys in conventional farming may be equally beneficial for pollinators as organic farming. Hence, leys could be a

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cost-efficient AES measure in Europe compared to organic farming, which is frequently associated with a reduction of crop production (Seufert et al., 2012).

In this study, the field bean (*Vicia faba* L.) was used to measure whether pollination success is enhanced by organic farming and/or increased proportion of leys in the surrounding landscape. The field bean is an important protein source for livestock and also serves as a beneficial break crop in organic crop rotation (Robson et al., 2002). Field beans can self-fertilize to some extent, but insect pollination substantially affects the number of mature pods on a plant, as well as the number of developed beans in the pod (Aouar-sadli et al., 2008; Free, 1993). Bumblebees are considered the main pollinators of field bean, since more pods develop if bumblebees visit the flowers and for each pod to develop a maximal amount of beans visits from other bees than only honeybees are required (Free, 1993). The response in pollination success of field bean on organically compared to conventionally managed farms, and to an increasing proportion of conventionally managed ley in the surrounding landscapes was evaluated in two different but overlapping study systems in the same region. Both organic farming and increasing proportions of ley at the landscape scale were expected to improve the pollination potential in this bumblebee-pollinated crop. Pollination potential was also expected to increase with increasing landscape heterogeneity as semi-natural grassland provides source habitats for bumblebees (Ekroos et al., 2013; Öckinger and Smith, 2007) and field borders may increase connectivity for bumble bees (Cranmer et al., 2012).

2. Methods

Two independent study designs were implemented during one season in 2011 to measure if pollination potential of field bean depends on (i) proportion of ley in the landscapes (surrounding 23 conventionally managed farms), and (ii) farming practice (on 9 organic vs. 9 conventional farms). For both designs, farms were selected along a gradient of landscape heterogeneity in Scania, southern Sweden ranging from homogeneous areas dominated by cereal and oilseed rape on large annually tilled fields to a heterogeneous mixture of land uses typically including grasslands and small fields. Using a grid of non-overlapping circular landscapes (1 km radius) covering more than 80% of the main agricultural areas of Scania (and excluding landscapes with less than 40% farmland), we found that this heterogeneity gradient was best described by two correlated variables. These variables were field borders (FB), which can be important foraging habitats for pollinators, and semi-natural grasslands (SNG), which provide source habitats for bumblebees (Öckinger and Smith, 2007). A landscape heterogeneity index (LHI) was calculated by combining these variables into the first axis of a principal component analysis (PC1), with high and positive index values indicating greater habitat availability. LHI hence represented a general measure of the availability of pollinator habitats in the surrounding landscapes. The landscape characterization was based on land use data obtained from the Integrated Administrative and Control System database, IACS, interpreted with MATLAB R2012b. The *ley design* consisted of 23 conventional farms with varying proportion of ley of all farmland (mean = 28%, range 0.5–56%) in 1 km circular landscapes located along the landscape heterogeneity gradient. If pollinators are affected by amount of leys it is likely that the mean over years, rather than the amount of ley a particular year, is important. Therefore, the average amount of ley in the landscape extracted from IACS for the years 2009–2011 was used to take into account the variation in amount of ley over years generated by crop rotation. The amount of ley in the study year was, however, highly correlated with the average amount of ley during the years 2009–2011 (Pearson $r = 0.98$). For the *organic farm design*, 9 organic and 9 conventional farms were selected, also along the landscape heterogeneity gradient. The organic farms were all certified under the Swedish certification scheme (KRAV, 2012).

The selected landscapes were dominated by arable farmland (mean ± SD = 78 ± 14%) but included important nesting habitats for bumblebees, such as farmyards, field boundaries and semi-natural grasslands. For each selected landscape in the ley and organic farm design an individual LHI was calculated by combining the proportion of SNG (mean = 5.5%, range = 0.0–19.3%) and proportion of field border (mean = 1.8%, range = 0.8–2.5%) using the formula:

$$\mathrm{LHI}_{\text{focal landscape}} = \sin 45 \times \left\{ \frac{\mathrm{SNG}_{\text{focal landscape}} - \mathrm{meanSNG}_{\text{non-overlaping landscapes}}}{\mathrm{sdSNG}_{\text{non-overlaping landscapes}}} + \frac{\mathrm{FB}_{\text{focal landscape}} - \mathrm{meanFB}_{\text{non-overlaping landscapes}}}{\mathrm{sdFB}_{\text{non-overlaping landscapes}}} \right\}$$

The proportion of SNG was square root transformed prior to PC calculations to improve linearity. In effect, these calculations resulted in an LHI for each study landscape expressed on the scale of the main agricultural region in Scania.

All field bean plants were collected from a single field provided by the Swedish University of Agricultural Sciences, and replanted in 10 l pots using a commercial plant soil. A barley field was chosen from each farm (i.e. 23 fields in the ley design and 9 + 9 fields in the organic design). In the field margin of these fields, four pots of field beans were placed 0.5 m apart from each other, which enabled cross pollination between the four plants. Field beans were placed out in the fields in early June, before the flowers had opened. The plants were situated at the edge of a field in the middle of a circular landscape. We avoided placing plants close to mass-flowering crops or farmyards, as these could distort results either by concentration effects or by providing source habitats for pollinators in close proximity to the experimental plants (Samnegård et al., 2011; Westphal et al., 2003). After the beans were ripe in early September, all pods from each plant were collected. The number of pods and all visible undeveloped pods on the plants were counted. Later in the laboratory, all developed pods were opened and the number of developed and undeveloped beans in each pod was counted. As a measure of pollination success, the *number of developed pods* and the *proportion of developed beans per pod* were used. Consequently, the number of developed pods is a measure of pollination in general whereas bumblebees, especially long-tongued species, mainly determine the proportion of developed beans per pod.

2.1. Statistical analysis

The proportion of developed beans per pod was related to either the proportion of ley in the landscape (*ley design*) or farming practice (*organic design*) as well as the focal landscape heterogeneity index (both designs) using generalized linear mixed models assuming a binomial error distribution (proportion of developed beans per pod) or a Poisson error distribution (number of developed pods per plant). The glmer function in the lme4 package (Bates et al., 2013) in R version 2.15.1 (R Development Core Team, 2012) was used for all analyses. All full models included the interaction between LHI and the design variable (i.e. proportion of ley and farming practice, respectively), and in the final models the interaction was excluded if $P > 0.05$. Farm site was included as a random variable to account for non-independence between experimental plants within farms. Following the framework for collinearity diagnostics in Zuur et al. (2009), the explanatory variables did not show signs of collinearity ($r < 0.45$, VIF < 1.25 in all cases). No signs of heterogeneous variances were found in the