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Impact of tillage on the crop pollinating, ground-nesting bee, *Peponapis pruinosa* in California

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ABSTRACT

Wild bees, especially ground-nesting species, are important for crop pollination. However, the extent to which regular disturbance, such as tillage, impacts ground-nesting bees is poorly known. We conducted a two-year tillage experiment on the squash bee, *Peponapis pruinosa* (Say), to quantify how tillage impacted offspring survival, offspring sex ratio, and timing of emergence. We established *P. pruinosa* nests in twenty 3 m by 3 m cages and then randomly assigned a tillage treatment to half of those cages. The following summer we trapped emerging offspring. We used a Bayesian framework to analyse the data. Offspring emergence varied greatly, but there was modest evidence that tillage reduced offspring emergence in treatment cages. There was limited evidence that tillage reduced the proportion of male bees emerging into cages, suggesting that tillage did not impact sex ratio. There was strong evidence that tillage delayed emergence of surviving offspring. Tillage practices should be considered when managing fields for this ground nesting bee. However, even disturbed squash fields may contribute to this species' persistence in agricultural landscapes.

1. Introduction

Wild native pollinators, including ground-nesting bees, are important for global crop pollination (Garibaldi et al., 2013; Klein et al., 2007). They directly increase crop yields and can also interact synergistically with honey bees to increase the pollination effectiveness of honey bees (Brittain et al., 2013a,b; Garibaldi et al., 2013; Greenleaf and Kremen, 2006). Although wild pollinator diversity benefits crop yield (Brittain et al., 2013a,b; Garibaldi et al., 2013; Hoehn et al., 2008; Winfree and Kremen, 2009), agriculture is a leading driver of land use change and biodiversity loss (Tilman et al., 2001; Foley et al., 2005). In addition, agricultural intensification increases management practices that negatively impact native bee abundance and diversity (Tscharntke et al., 2005; Winfree et al., 2009; Williams et al., 2010).

Agricultural landscapes are often mosaics of disturbed and undisturbed ground. Within these landscapes ground-nesting bees nest in natural and semi-natural areas including hedgerows (Sardiñas et al. 2016), flower strips (N. Williams unpublished data), forest fragments (Cane, 1994), grasslands and chaparral (Sardiñas and Kremen, 2014; Straka and Rozen, 2012). They also nest in fallow and active crop fields, which experience regular disturbance in the form of tillage (Minckley et al., 1994; Kim et al., 2006; Julier and Roulston 2009; Xie et al., 2013; Sardiñas et al., 2016). Intensified agricultural landscapes are dominated by ground that is frequently disturbed, which may reduce the population persistence of, and pollination by, wild pollinators (Tscharntke et al., 2005).

Tillage is used to incorporate soil amendments, manage crop residues, control weeds, and reduce soil compaction as part of normal farm management to improve crop yield (Köller, 2002). These practices can negatively affect ground-nesting bees, but ground-nesting bee population persistence in agricultural landscapes may depend on whether some, all, or no bees survive tillage (Williams et al., 2010). Many ground-nesting bees nest at a depth that is within the tillage zone, e.g. <30 cm from the soil surface (Cane and Neff, 2011). Thus tillage may directly kill developing offspring or alter emergence cues such as soil moisture and temperature (Wuellner, 1999). If male and female offspring are placed at different depths within the nest, as is the case for *Calliopsis persimilis* (Danforth, 1990), then tillage may alter the population's sex ratio. Tillage may also have positive effects on soil properties for ground-nesting bees such as creating open bare ground, loosening compacted soils, or changing the predator community (Roger-Estrade et al., 2010).

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The few studies investigating the impact of tillage on bees in agricultural fields provide conflicting results. Anecdotal evidence suggests that tillage can directly impact bee survival and delay emergence time (Mathewson, 1968; Wuellner, 1999). Observational studies on squash and pumpkin (*Cucurbita* spp.) farms in the United States found that the abundance of a ground-nesting bee (*Peponapis pruinosa*) was negatively correlated with tillage in the previous season (Shuler et al., 2005). However, a follow up study on pumpkin (*Cucurbita pepo*) found no such effect (Julier and Roulston, 2009). Neither study directly measured the impact of tillage on ground-nesting bees.

We conducted a two-year, tillage experiment on the squash bee, *Peponapis pruinosa*. We were specifically interested in parameters that might influence the population dynamics of this species and asked the following questions: (1) Do fewer offspring emerge in tilled plots? (2) Does tillage alter the sex ratio of emerging offspring? (3) Do offspring emerge later in tilled plots compared to control plots?

2. Materials and methods

2.1. Study site

The experiment was carried out at an agricultural field station in Yolo County located in the Central Valley of California (−121.69648, 38.518914). This region has a Mediterranean climate, and the study site's soils are primarily made up of Yolo Loam (http://websoilsurvey.sc.egov.usda.gov/). Yolo Loam is a well-draining, silty loam (soil family: fine-silty, mixed, superactive, thermic Fluventic Haploxerepts; https://soilseries.sc.egov.usda.gov/OSD_Docs/Y/YOLO.html). Vertical soil properties associated with the Yolo Series are fairly similar, all horizons from 0 cm to152 cm are made up of a silty loam except for the horizon at 41–58 cm which is made up of a silt clay loam. *Peponapis pruinosa* is a univoltine, specialist, ground-nesting bee that nests preferentially under plants of the genus *Cucurbita*, its host plant (Hurd et al., 1974; Julier and Roulston, 2009; Mathewson, 1968). Previous nest excavations in the northern Central Valley of California suggested that nest cells can range from 8.9 cm deep to 68.6 cm deep, with most falling between 12.7 cm and 30.4 cm (Hurd et al., 1974).

2.2. Establishing artificial nesting sites

On August 15, 2012 we set up twenty 3 m × 3 m × 1.8 m sealed flight cages over plantings of three varieties of squash planted earlier in the season. This included 14 cages over: *C. pepo* cv. "Reward", 2 cages over *C. pepo* cv. "Magician", and 4 cages over *C. maxima* cv. "Redondo de Trunco" (see Fig. 1). Cages were made of fine mesh Lumite screen (Lumite Inc, Alto, Georgia, USA). Cloth landscape fabric (30 cm wide) was staked down on the internal perimeter of each cage to prevent bees from nesting near the cage edge. Plants were drip irrigated, and fruit were harvested regularly to extend bloom following usual agricultural practices.

Previous studies suggested that female *P. pruinosa* bee populations peak in mid-August (Tepedino, 1981). On August 20, 2012 we established artificial *P. pruinosa* nesting sites within each flight cage. In the early morning we collected 40 female and 40 male *P. pruinosa* from a single farm located 42 km from our study site. Females were only collected if they were not carrying pollen. We assumed that these individuals had not yet established nests. Bees were placed in individual plastic vials and transported in coolers to the study site. Later that morning we marked each bee for individual recognition with paint (Testors Enamel paint, Testors, Vernon Hills, Illinois, USA) on the thorax and then released two females and two males into each 3 m × 3 m × 1.8 m cage. *Peponapis pruinosa* is a gregarious ground-nesting bee where nesting densities can range from an average of 1.7 nests to 5.3 nests per 0.09 m^2 (Hurd et al., 1974.) However, when walking through squash fields, isolated nests are also observed (K. Ullmann, pers. observation.) To confirm that bees were nesting, we surveyed each

Fig. 1. Cages set up over *Cucurbita* spp. Two female and two male *P. pruinosa* were released into each cage to establish nests.