Intercropping flowering plants in maize systems increases pollinator diversity

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Summary

1. Maize is a poorly competitive crop, as such, soil preparation and high application rates of herbicides are required to reduce early competition with weeds. This leaves a large amount of bare ground with few flowering weeds, providing a poor farmland habitat for pollinators.
2. This study evaluates the effect of four different maize management regimes on pollinator diversity and community composition.
3. Flowering plants intercropped with maize attracted pollinators, helping to support pollinator communities. Similar intercropping techniques using a grass ground cover did not increase pollinator density, demonstrating that pollinator richness, density and diversity is intrinsically linked to the presence of flowering plants.
4. A maize system with a diverse intercrop may make it possible for pollinators to thrive, however, these systems may only be attractive enough to bring pollinators in temporarily from the surrounding areas.

Synthesis

5. These results show that there can be significant improvements to pollinator diversity, density and community composition through modifying maize cultivation practices, however, these benefits must be balanced with yield penalties of ca. 60% to farmers.

Keywords

Agro-ecosystems, bee, community, density, diversity, maize, richness,

1. Introduction

Arable production, especially maize (*Zea mays* L.), adversely affects pollinator biodiversity (Geiger *et al*., 2010; Carvell *et al*., 2011), which is in decline globally (Biesmeijer *et al*., 2006; Carvell *et al*., 2011; Goulson, 2015). Whilst there is a need to produce versatile crops, such as maize, to meet agricultural demands (Edgerton, 2009), these must be balanced with protecting ecosystem services, including those that are facilitated by biodiversity (DeFries *et al*., 2004; Wodika & Baer, 2015) such as pollination (Delaplane *et al*., 2000). Pollinator biodiversity depends on four main characteristics of an agro-ecosystem: the diversity of vegetation within and around the system, the permanence of the various crops within the system, the intensity of management, and isolation of the system from natural vegetation (Altieri, 1999; Holzschuh *et al*., 2007; Batary *et al*., 2010).

Maize is an increasingly important, multifunctional crop with over 184,000 ha grown annually in the UK (DEFRA, 2015) being used as forage for cattle and is becoming increasingly important as a feed stock for biogas generation (Hochholdinger and Tuberosa, 2009; Adams, 1989; Banse *et al*., 2008). However, Maize is a poorly competitive crop; therefore intensive soil preparation and high application rates of herbicide are required to reduce early competition with weeds (Hall *et al*., 1992). This leaves a large amount of bare ground, providing poor habitat for biodiversity, especially for pollinators (Carvell *et al*., 2011; Hawes *et al*., 2009; Potts *et al*., 2006; Barbir *et al*., 2015). Wilson *et al*. (1999) identified that these reductions in the diversity and abundance of food plants leads to reduced invertebrate diversity, which is a result of the combination of frequent tillage, improved seed-cleaning technologies and herbicidal weed control. Unfortunately, conventional maize cultivation fulfils the criteria set out by Wilson *et al*. (1999) to erode pollinator biodiversity.

Novel maize cultivation techniques such as sowing the crop into an understorey of legume mixes or grasses have been shown to reduce negative environmental impacts such as nutrient and soil loss by promoting rainfall infiltration, improving soil stability and reducing run-off (Hartwig & Ammon, 2002; Manevski *et al*., 2015). These techniques have also been shown to support the farmland biodiversity by providing resources for many species (Pywell *et al*., 2005; Norris *et al*., 2016). However, because maize is a poor competitor in its early stages of growth it is easily outcompeted by intercrops. As such, intercrops must be controlled to maintain maize yield (Nakamoto & Tsukamoto, 2006). Mowing, grazing or spraying with a herbicide have all been shown to maintain crop yield similar to that found in conventional cropping systems, whilst maintaining the above benefits (Nakamoto & Tsukamoto, 2006). However, contrasting studies have shown that even with control of intercrops by mowing, maize yields can be significantly reduced due to root system competition (Liedgens *et al*., 2004; Norris *et al*., 2016).

Supporting pollinator diversity in arable systems is currently a hot topic (Goulson, 2015). Colonisation by invertebrates is generally dependent on natural dispersal from the regional species pool (Chateil, 2015), which can be highly fragmented (Hilderbrand *et al*., 2005), and where there are greater numbers of flowering plant species there will be greater richness, density and diversity of pollinators. In arable systems, a disturbance such as ploughing or tillage disrupts this colonisation process, and although biotic and abiotic conditions can be restored to these systems, community assemblages sometimes cannot (Hilderbrand *et al*., 2005). Despite this, recent work by Wodika & Baer (2015) has shown that this is not necessarily the case, even with soil fauna, which have lesser dispersal efficiency compared with pollinators (Giller, 1996). Wodika & Baer (2015) showed that after disturbance there can be a recolonisation by taxa comprising of a similar community assemblage to the pre-disturbance state, if the vegetative community is restored. Sadly, in conventional maize cultivation systems, there are often few flowering non-crop plants, which limits forage resources for pollinators (Hawes et al., 2009; Potts et al., 2006). As maize is wind pollinated, increasing pollinators in maize systems would not directly benefit the maize crop, however, supporting pollinators at the farm or landscape scale would benfit other crops such as *Brassica napus* L. as well as wild flora.

In this study, we investigated the effect of four contrasting maize cultivation and ground cover management practices on pollinator density, diversity and community composition and maize yields, to identify sustainable maize production techniques. We hypothesized that where greater numbers of flowering plants were sown in the strip tillage biodiverse seed mix cultivation methods, larger populations of pollinators would be encountered.

2. Materials and methods

2.1. Site description

Field experiments were established in a conventionally ploughed maize crop at two study sites over two cultivation seasons in April 2013; the first site was in the South West of England near Bow, Devon and the second in the east of the UK, near Fakenham, Norfolk. The study sites were selected for the freely draining, slightly acidic loam soil at Bow and freely draining slightly acid but base-rich soil at Fakenham (Driessen, 2001), which is typical of land under maize cultivation in the

UK. Maize is often grown in the same field year after year in the UK, as such the intercrops were established in 2013 and the maize in the subsequent two cropping seasons, drilled into the rows that the previous year's crop occupied. Twelve study plots at each site, 10 m wide and 60 m in length, with a 1 m gap between plots, were established in a randomised replicated block design with three replicates of each treatment. Four contrasting maize cultivation techniques were selected to test the effects on pollinator diversity and community structure: 1) conventional plough and subsoiled (PGH), 2) minimum tillage (MNT), 3) strip tillage into perennial ryegrass that was sown at a rate of 35kg ha^{-1} (RGS) in June 2012, and 4) strip tillage into a biodiverse seed mix (BSM). The BSM strip crop was over sown with a commercially available seed mix in June 2012 at 15 kg/ha^{-1} containing *Medicago lupulina* L. 20%, *Onobrychis viciifolia* L. 25%, *Trifolium hybridum* L. 20% *Trifolium incarnatum* L. *subsp. Incarnatum* 20%, *Lotus corniculatus* L. 10%, *Malva moschata* L. 5%. For a full experimental design and agronomic details please refer to Norris *et al*., (2016). At Fakenham in 2013, pre-emergence application of herbicides were 4.5 l ha-1 Stomp® (a.i Pendimethalin) to all treatments; 150ml ha-1 Reglone® (a.i Diquat) to the two strip tillage treatments and 3.5 l ha-1 of Hoedown® (a.i Glyphosate) was applied to the ryegrass treatment. Post-emergence application of herbicides were 1 l ha-1 Touchdown® (a.i Glyphosate) applied to the ryegrass plots; Callisto® (a.i Mesotrione) at a rate of 1 l ha-1 was applied to PGH and RGS and to the BSM treatment at a rate of 0.5 l ha-1. At Bow in 2013, Pendimethalin (Stomp ©) was applied to all plots except the BSM treatment at application rate of 3.0 l ha-1, with an additional 1.0 l ha-1 Samson applied to the perennial ryegrass plots. At Fakenham, in 2014, to reduce intercrop competition and improve yields additional herbicides were applied to the strip-tillage treatments compared with 2013; 5 l ha-1 Wing P®

(a.i Pendimethalin) was applied to all treatments. Touchdown® at 1 l ha-1 (a.i Glyphosate) was applied to all treatments except BSM where Touchdown® was applied at a half rate of 0.5 l ha-1. Post-emergence, Callisto® was applied at a rate of 2 l ha-1 to all treatments. At Bow, in 2014 Gallup® was applied to the BSM treatment at a rate of 1.5 l ha-1, Non-inversion at a rate of 3.0 l ha-1, Conventional at a rate of 3.0 l ha-1 and Ryegrass at a rate of 0.75 l ha-1. After the maize was sown at Devon Wing-P® was applied at a rate of 4 l ha-1 with an additional later spraying of Calaris® at 1 l ha-1 and Samson at 0.5 l ha-1 to reduce competition from the existing plant cover.

At both sites 150 kg N ha-1 of ammonium nitrate (a.i nitrogen) was applied to all treatments in 2013. At Fakenham in 2014 potash (175 kg ha-1) was applied to all treatments. At Bow in 2014 100kg N ha-1 in the form of Urea and 20 kg N ha-1 in the form of monoammonium phosphate (MAP) was applied to all cultivation methods, and at Norfolk N-fertiliser applications remained the same as in 2013.

2.2. Pollinator survey

Pollinators were counted using the line-transect method developed for the UK butterfly-monitoring scheme (Pollard & Yates, 1993), which has been adapted as a standard method for bee surveys (Roy *et al*., 2003; Banaszak, 1980). Pollinator transects were walked on a weekly basis during June and July in both field trial years, coinciding with the legume flowering period. Pollinator transects were carried out by walking 60 m along the intercrop area, but excluding the outermost 1 m of each plot. Surveyors used transect recording sheets to score the pollinators foraging on each plot. Given the need to identify bees while on the wing, counts were made for groups of bumble-bee (*Bombus*) species based on colour type, and Apis were also noted (Prys-Jones and Corbet, 1991). Walks were performed between 10.00 and 17.30 when weather conformed to UK butterfly monitoring scheme standards (wind speed less than 5.5 m s^{-1}, not raining, temperature greater than 17 °C if sky overcast or greater than 13 °C if sky at least 60% clear) (Pollard & Yates, 1993; Roy *et al*., 2003). The order in which transects were walked was randomised (Roy *et al*., 2003; Haughton *et al*., 2003), using a random number generator. The time taken for each transect depended on crop stage, but observers walked at approximately 12 m per minute (Banaszak, 1980; Roy *et al*., 2003;Westphal *et al*., 2007).

2.3. Vegetation survey

Visual assessments of vegetation were carried out in late July in 2013 and 2014. Six vegetation samples were located within the inter-row areas of each plot with a rectangular quadrat (1.0 m x 0.25 m) placed at different locations, parallel to the rows of maize. Percentage cover by vegetation, litter and bare ground, together with vegetation richness (number of plants 0.25 m^2) were recorded for each plot. At Fakenham, a conventional maize harvester was used to measure crop yield, with the harvested area of each plot being 7.5 m x c.60 m. At Bow, maize yields were measured from each plot from a 10 m by 2 m area, and each maize plant within the demarcated area was harvested by cutting approximately 15 cm above the soil surface. Maize plants from both sites were chopped using secateurs before analysis. Harvested samples were oven dried at 60 °C for 24 hours and the dry weight recorded. Dry weights were multiplied to give a total dry matter per plot and are reported on a tons per hectare basis.

2.4. Statistical analysis

All statistical analyses were conducted using R v3.0.1 (R Core Team, 2013). The plant community measurements and total numbers of pollinators observed over six sampling weeks in each sampling year were used to test for differences in richness, density and Shannon diversity using analysis of variance on Box-Cox transformed data (Højsgaard 2006). Density was expressed as the total number of pollinators observed over the six transect walks preformed at each site in 2013 and 2014, with field site being used as a random effect. Once data were normalised, Tukey HSD tests were used to test for significant differences between cultivation methods and field trial years. The diversity for each of the cultivation methods was determined using the Shannon-Weiner diversity index (*H*') calculated using the R package 'vegan' (Oksanen *et al*., 2007; Norris *et al*., 2016).

Pollinator community counts were Wisconsin square root transformed using Euclidian distances among sites and years to measure species that were associated with changes in vegetation, using two-dimensional non-metric multidimensional scaling (NMDS) which was selected using stress vs. dimensionality to identify the number of axes that best represented the community. The vegetative variables and plant species count data were fitted to the NMDS species scores using the function 'envfit' (Oksanen *et al*., 2007) based on 999 permutations. Vegetative variates and plant species with a significant influence on pollinator community composition ($P < 0.05$) were plotted based on the results from 'envfit'. As pollinators were predominantly observed in BSM plots (Table 1), further statistical analysis was performed by separating this cultivation method from the other three cultivation methods and assessing the influence plant species composition had on pollinator communities.

3. Results

The richness, density, and diversity of pollinator communities were significantly greater in the strip tillage into a biodiverse seed mix cultivation method compared to the other three cultivation methods (Table 1). Although some pollinators were encountered in the other cultivation methods, a majority of pollinators were observed in the strip tillage into a biodiverse seed mix cultivation method (Table 2).

In 2014, the increase in herbicide application reduced the richness of vegetation in the biodiverse seed mix cultivation method (Table 1 and Table S1). However, the overall richness, density, and diversity of the pollinator community was not significantly reduced (Table 1).

B. lapidarius and *B.* terrrestris/lucorum were the most frequently observed, predominately found foraging in the strip tillage into a biodiverse seed mix cultivation method (Table 2). Despite the increased application of herbicides in 2014, and the subsequent reduction in plant richness (Table 1) the number of *B. hortorum* observed increased (Table 2, P = 0.008). However, the abundance of *B. pascuorum* was significantly reduced in 2014 (P = 0.008).

Plant communities were composed of different species in the different treatments (P <0.001), which explained 50% of the variation (Table 3). Community composition between the two sites was significantly different (P <0.001), although these differences only explained 11% of the variation in overall pollinator composition (Table 3).

Vegetation richness had a significant influence (P <0.001) on pollinator community composition, explaining 32% of the overall variation (Table 3). Bare ground, negatively correlated with vegetation cover, had a significant influencing effect on community composition (*P* <0.001) explaining 15% and 26% of the variation respectively (Table 3).

Separating the BSM pollinator community for more detailed analysis showed that field site and sampling year had a significant effect (*P* <0.001) on pollinator community composition, which explained 88% of the variation (Table 3, Fig. 1). Vegetation cover also explained a significant (*P* =0.044) amount of variation (49%) in pollinator community composition (Table 3, Fig. 1).

Plant species composition also influenced the composition of pollinators ($F^{1,10}$ =7.54, *P* =0.020, slope = 15.29), Fig 1). The plants that were sown in the BSM cultivation method established well, however the plant species that influenced difference in composition between plots and sites were the opportunistic weed species that re-emerged after ploughing (Norris *et al*., 2016). *Urtica urens* L. correlated with greater observed numbers of *Api*s. (Table 6, Fig 1). In contrast, *Epilobium ciliatum* Raf., *Matricaria recutita* L., *Senecio vulgaris* L. and *Trifolium repens* L. were found to be associated with greater observed numbers of *B.* terrrestris/*lucorum* and *B. pratorum* (Fig 1).

Although cultivation year did not significantly effect (*P* = 0.775) community composition (Table 3) when considering both sites and all cultivation methods, there were significant interaction differences in community composition associated with the two sites which changed between the two years in the strip tillage into a biodiverse seed mix cultivation method (Fig. 1, r^2 = 0.88, *P* = 0.001). *B.hortorum* was associated with Bow in 2014, however, in 2013 the community observed at the Bow site was more associated with greater densities of *B.* terrrestris/lucorum (Fig. 1). *B. pascuorum* and *B. lapidarius* were associated with the Fakenham site in 2014.

Unlike at Bow, there was no significant difference in community composition between the two years at Fakenham (Fig. 1).

4. Discussion

Understanding how to manipulate agrosystems to promote ecosystem services such as pollination is a key goal of agro-ecology (Altieri, 1999). This study has shown that a flowering plant ground cover is important for supporting pollinators. There is strong evidence to suggest that having a number of flowering plants in the biodiverse seed mix ground cover significantly increased the richness, density and diversity of pollinators. (Table 1 and Table S1).

Maize in the UK is often grown year after year in the same field. As such, the experiment mimics conventional practice by performing the field trails for two consecutive years in the same fields using the previous year's maize crops as a guide for where to drill the subsequent crop. Although the maize yield was reduced in the two strip tillage cultivation methods compared with the conventional and minimum tillage cultivation methods (Table 1), in the second year early competition of the intercrops with maize was reduced, increasing maize yields without significantly reducing the richness, density or diversity of pollinators (Table 1). This result confirms that flowering plant availability is a key driver of pollinator abundance and diversity. At the landscape scale, increasing the density of flowering species within arable systems could provide greater resource complexity and stratification to help support pollination and pollinator communities (Roy *et al*., 2003; Potts *et al*., 2006).

Separate analysis of the BSM cultivation technique showed that vegetation richness and cover are positively correlated under BSM and vegetation cover was a key factor influencing the composition of pollinators utilising these resources (Table 3) suggesting that where there was a greater cover and richness there was greater variety of plant species for pollinators to forage upon.

The separate analysis of the data from the BSM plots (Table 3) showed that the composition of the pollinator community differed between the two sites. Others studies have shown that this may be attributed to natural variation in the surrounding local pollinator populations from which communities were able to recruit (Baur *et al*., 1996; Tsiafouli *et al*., 2015). Although not measured in this study, differences between communities over large spatial scales have been shown to be linked to the surrounding vegetation and the extent of isolation from natural vegetation (Altieri, 1999; Roy *et al*., 2003). Despite the differences in community composition at the two sites (Table 3), greater richness, density and diversity of pollinators was associated with an increase in the cover of flowering plants (Table 1). Of all the observed pollinators, *Apis* was found to be particularly sensitive to increases in vegetation cover, which correlated with greater numbers of *U. urens* (Fig 1). In contrast, *B. terrrestris/lucorum* abundance was correlated with greater numbers of *T. repens* (Fig 1). These results suggest that different pollinators may be associated with different plant species, altering foraging strategies among pollinator species; supported by evidence of site choice by pollinators being related to the number, size, colour, scent of flowers present (Schlinkert et al., 2015) as well as morphological traits of pollinator species such as tongue length (Hegland et al., 2005).

These results show that it is possible to support greater pollinator populations than are currently supported under conventional maize systems by including only a few species of flowering plants (Table 3). However, plots with greater cover of flowering plants supported more diverse pollinator communities (Fig 1; Schlinkert *et al*., 2015).

Although this study shows that it is possible to increase the biodiversity of pollinators in maize systems by increasing the number of flowering plants (Goulson, 2015), these benefits to pollinators must be balanced with the yield penalties to farmers. At both sites, the greatest dry matter yields were measured on the conventional and non-inversion cultivation methods, with a mean dry matter yield of c.11 t/ha. However, yields from the strip tillage-ryegrass (RGS) and strip tillage-biodiverse mix (BSM) were as much as 80% and 90% lower than the conventional treatment at Norfolk and Devon respectively (Table 1). Increased herbicide application rate to the intercrop in 2014 reduced early competition with maize and improved yields (Table 1), however, yields on the strip tillage-ryegrass and strip tillage-biodiverse mix were still approximately 45% lower compared to the conventional treatment. Despite reductions in yield, this study suggests that even a relatively low richness of flowering plants will attract pollinators, supporting populations and the services they facilitate. Despite increases in pollinator richness and diversity a maize system with diverse intercrops may make it possible for pollinators to thrive, however, these systems may only be attractive enough to bring pollinators in temporarily from the surrounding areas.Agricultural schemes to secure the important ecosystem services such as pollination are critically important for sustainable crop production. Further work should focus on investigating the proportions of the cultivated area that needs to be sown with flowering plants to support greater numbers of pollinators in arable systems, how this affects pollinator diversity on a landscape scale and the longevity of these effects.

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Abbreviations

Conventional plough-based maize cultivation (PGH), minimum tillage maize cultivation (MNT), strip tillage into a biodiverse seed mix ground cover (BSM), strip tillage into a perennial ryegrass ground cover (RGS), Non-metric multidimensional scaling (NMDS).