Crop Production, the Pollinator Deficit and Land Use Management: UK Farm Level Survey Results

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Abstract

In this paper, we address a gap in the literature concerning pollination management, the pollinator deficit, and conservation objectives. By employing a farm level survey of UK farmers, we examine farmers' attitudes, understanding and management of pollinators. Based on descriptive statistics and regression analysis, we found significant variation in interest and understanding of the impact of pollinators on commercial crops meaning that many respondents did not consider they had a pollinator deficit in terms of crop quality, quantity, or financial impacts. At the same time, many farmers are willing to adopt environmentally beneficial land-use measures if suitable advice and financial incentives are offered. However, there is little evidence of coordination of actions between farms to support wild pollinators. These findings indicate a potential disconnect between a farmer's understanding of the impact on agricultural output from a pollinator deficit and the agricultural benefits from the adoption of specific environmental measures.

Key Words: agri-environment policy; bees; wildflower strips; soft fruit; top fruit; arable

JEL: Q15, Q576

1. Introduction

Ensuring sufficient crop pollination is essential if yields are to be maximised. This is particularly the case as we are seeing significant growth in demand for pollinator-dependent crops, at the same time that there is a decline in wild pollinators within the farming environment (Jordan et al., 2021; Gazzea et al., 2023) with research indicating that many crops may be experiencing a pollination deficit (PD) resulting in sub-optimal levels of production (Garibaldi et al., 2016; Reilly et al., 2020). For example, as part of an economic analysis of landscape configuration to support pollinators Kirchweger et al. (2020) assume that no insect pollination means that the optimal yield for oilseed rape (OSR) will be 79% of the maximum with pollination. Warnings about the economic impact of sub-optimal levels of crop pollination are frequent in the literature (e.g., Cardoso et al., 2020). Many studies examine the impact of pollination on the production of specific crops such as Perrot et al. (2018) (OSR), Fountain et al. (2019) (pears), Samnegård et al. (2019) (apples), Bishop et al. (2020) (faba beans), Eeraerts et al. (2019) (sweet cherry) and Garratt et al. (2023) for orchards (especially apples).

At the same time there are numerous studies examining farm level management options to support wild pollinators (Albrecht et al., 2020; Fountain, 2022; McHugh et al, 2022; Nicols et al., 2019 and 2023). In this literature, pollinator management can refer to measures that support both "managed" and "wild" pollinators. This distinction is important when considering how farmers think about the role of pollination in production. Managed pollination services (e.g. bee hives) which can be purchased or rented are equivalent to any other agricultural input and can reduce the uncertainty and risk of relying on wild pollinators. However, in many cases wild pollinators can provide the same or a better service than managed pollinators (e.g. Mateos-Fierro et al., 2022).

In response many governments including the UK have adopted pollinator friendly policy initiatives often embedded in agri-environmental policy (AEP) that explicitly aim to reverse the decline in wild pollinators in agricultural landscapes. For example, the UK government published the UK National Pollinator Strategy (NPS) in 2014, a 10-year plan to enhance and improve the status of all pollinating insects in England that includes the Wild Pollinator and Farm Wildlife Package (Defra, 2022).

Despite all this research and government policy it is somewhat surprising that there is limited research examining the knowledge and understanding that farmers have of the PD in crop production and the associated adoption of appropriate pollinator management activities (Hevia et al., 2021; Nalepa et al., 2021; Osterman et al., 2021). It remains unclear to what extent farmers consider or understand the potential for a PD to exist, and this is unlikely to change anytime soon because farmers rarely monitor the degree of crop pollination unlike yields (Garibaldi et al., 2020; Gemmill-Herren et al., 2021).

In this study, our key objective was to understand the degree to which UK farmers consider current levels and quality of pollinator activity and its impact on agricultural production, and to generate evidence on the extent to which farmers consider the PD to be a significant issue. In addition, we wish to examine the mix and type of management activities being implemented to support wild pollinators as well as the level of knowledge about pollinators. We also examine the degree to which AEP are enabling on farm management activities to support wild pollinators.

To address our research objectives, we developed a survey instrument that examine UK farmers knowledge of pollinator management for crop production together with wider environmental objectives. Our survey instrument was developed in collaboration with our project partners (academic and industry) from the North Sea Region Interreg project BEESPOKE.[1] In designing the survey, we took a bottom-up approach focussing on farmers to understand their knowledge of the PD as well as the use of AEP options. Our survey collected data (n=228) on farmers knowledge and understanding of the PD, pollinator habitat and management and AEP engagement. It was distributed to farmers growing at least one crop that is pollinator dependent in terms of yield. The survey yielded both qualitative and quantitative data.

By undertaking this survey our research contributes to the existing literature in several ways. First, we present evidence on the extent to which UK farmers perceive there to be a PD. Understanding farmers views about crop pollination and the associated, quality, quantity and financial implication reveals the extent to which they considered the PD to be important. Second, as noted there is limited existing research examining farmer understanding of pollinators and farmers' needs (e.g., Osterman et al., 2021; Busse et al., 2021; Nalepa et al., 2021). We add to this literature using our survey data for UK farmers. Third, within economics, much of the existing research has focussed on generating estimates of the value of pollination services (Feuerbacher et al., 2024) or the non-market values society derives from experiencing pollinators (use value), knowing that they exist (non-use existence value) as well as the indirect benefits they provide such wild-flowers and greater biodiversity (Moreaux et al., 2023). Therefore, there remains a need for more research examining on-farm adoption of pollinator conservation measures. Finally, there is a knowledge gap around our understanding of current levels of farm level pollinator management activities and whether this is driven by crop production and/or AEP.

The paper is structured as follows. In section 2, we briefly review the antecedent literature focussing on the significance of the PD, farmer knowledge and understanding of crop pollination, and AEP adoption. Next in Section 3, we describe our survey instrument and the statistical methods employed to analyse

[1] This research was funded by Interreg grant: Beespoke (Benefitting Ecosystems through Evaluation of food Supplies for Pollination to Open up Knowledge for End users) https://northsearegion.eu/beespoke

the data collected. Next, we present the results of our analysis and in Section 5, we discuss implications. Finally, in Section 6, we conclude.

2. Literature Review

2.1. Significance of the Pollinator Deficit

The potential for a PD or pollination limitation to exist in agricultural production has been a reoccurring theme with the literature (Garratt et al., 2014; Garratt et al., 2023). Identification and measurement of the PD has been examined in a wide array of crops in both field studies (Reilly et al., 2020) and meta-analysis of existing research (Gazzea et al., 2023). Economic research on the PD often reports the yield dependence ratios which measures how much of the crop (quality and quantity) is lost if there is no pollination (Feuerbacher et al., 2024). When a PD has been identified researchers typically express this in terms of sub-optimal production and consequent reduction in financial returns. For example, Garratt et al. (2023) report (for 24 commercial apple orchards in Kent, UK), that average PD was 22% in 2018 and 2.6% in 2019 which equated to an average reduction of £15,000 per hectare. The extent of the PD is also highlighted by Reilly et al. (2020) who report that five out of seven major pollinated crops in the USA exhibit a PD. And with this potential level of sub-optimal production being identified the economic consequences have also been examined (Jordan et al., 2021). However, Breeze et al. (2016) and Baylis et al. (2021), both note that economically valuing the PD or more generally valuing pollination services has proven to be complicated given the difficulties in identifying key parameters such as the extent to which crop output depends on pollination services.

2.2. Farmer Knowledge and Understanding of Pollinators

Despite the existence of a significant body of research examining and attempting to measure the PD there is far less research that considers the extent to which farmers knowledge and understanding of pollinators or the PD. A particularly relevant study is Osterman et al. (2021) who examined the decline of pollinators in agricultural landscapes highlighting the existence of a knowledge gap between understanding the issues around pollinator decline and farmer willingness to adopt science informed land use interventions. They interviewed 560 farmers across 11 countries all growing at least one of four pollinator-dependent crops (including 25 UK OSR farmers). Osterman et al. (2021) report that many survey participants know about non-bee pollinators via observation in the field but there remains a significant knowledge gap regarding non-bees and crop pollination (Rader et al., 2020). In terms of OSR and government incentives for AEP, they report that 70% of farmers implemented hedgerows when financial incentives are available and 20% without. They found similar results for floral strips. Clearly, the motivation for many famers to implement land use interventions such as flower strips is because they receive financial payments.

Another relevant study is provided by Hevia et al. (2021) who surveyed Spanish farmers in four areas to understand perceptions about pollinators and practices to promote them. They collected 376 face-to-face questionnaires, although between 59% and 87% of the responses collected are from respondents who are either part-time farmers or non-professional farmers. Like Osterman et al. (2021) honeybees, then bumble bees and wild bees are the main pollinators with other pollinators not viewed as being as important. Respondent attitudes about declines in pollinators informed their views about what needs to be done to reverse the decline. Employing stepwise multiple regression Hevia et al. (2021) examined what influenced knowledge about pollinators reporting that education, concern about the pollinator crisis and farmer type (i.e. full time) are positively correlated whereas age was negative. They also note that reported actions to promote pollinators are less use of insecticides, crop diversification and fallow fields, and that the level of education is positively correlated with maintaining wild-flowers and reduced spraying.

Similarly, Busse et al. (2021) report that adoption of insect-friendly farming measures, especially integrated pest and pollination management (IPPM) (Lundin et al., 2021) is only implemented if sufficient financial incentives are available. Also, farmers regard insect biodiversity typically in terms of ecosystems services as they relate to agricultural production and not as part of the wider ecosystem. Furthermore, farmers appear to implement specific types of agricultural practices without understanding the potential benefits they have on pollinators. For example, flowering catch cropping is used without many farmers realizing the benefits for pollinators. Cole et al. (2022) discusses how planting a legume mixture can help support wild pollinators. Improving farmers' understanding of this issue is, as Busse et al. (2021) argues, a precondition to the adoption of new land use management techniques that will support pollinators (and insects more generally).

Other relevant research is presented by Eeraerts et al. (2020), who surveyed 24 sweet cherry farmers in Flanders, Belgium employing semi-structured interviews. They report that the farmers understood the importance of insects as wild pollinators although as is common in the literature there was undue emphasis placed on the importance of specific types of bees. Eeraerts et al. (2020) also note that almost all respondents pay for honey beehives. This choice can be understood as a short-term solution to their crop pollination requirements whereas making changes to the landscape (e.g., the introduction of wildflower strips) are longer term strategies. More generally, the relationship between wild pollinators and the use of beehives can be understood as a pollination diversification strategy (Nalepa et al., 2021).

Finally, using an online survey of 75 Canadian apple growers Nalepa et al. (2021) examine the influence of farm characteristics and farmer perceptions about bees and how this influences the adoption of pollinator supporting management practices. Employing logistic and Poisson regression models they found a positive relationship between grower awareness of pollinators and the number of pollinator supporting practices adopted on-farm.

2.3. AEP and Pollinator Management

Agricultural production and land-use choices that necessitate the need for AEP to support wild pollinators is evidence that agricultural intensification is generally negatively correlated with pollinator diversity and associated services (Deguines et al., 2014). Increased intensification of crops that require pollination necessitates the need to support pollinators with suitable living habitats in the wider landscape. In addition, Kleijn et al. (2015) argue that society cannot rely on crop pollination as motivation for providing meaningful support for wild pollinators. Therefore, the importance of AEP in promoting and financially supporting wild pollinator management is clear. In the UK, there are a several AEP initiatives with specifically designed elements to support pollinators such as the Countryside Stewardship Scheme (CSS) that offers financial support for undertaking various pollinator supporting activities. Defra (2023a) report that popular CSS on-farm activities that support wild pollinators include management of hedgerows, the provision of winter bird food and flower-rich margins. The flower-rich margins option has been implemented on 32,000 hectares. Importantly, AEP pollinator options are targeted at conservation objectives and not agricultural production although there can be positive production externalities.

When it comes to AEP design, McCullough et al. (2021), Eeraerts (2023), and Pindar and Raine (2023) all conclude there needs to be more land maintained as natural/semi-natural habitat. Similarly, Image et al. (2023) argue that AEP needs to complement wildflower strips with other landscape features such as hedgerows and woodland margins. McCullough et al. (2021) suggested that planting small areas may provide some benefits for pollinators (bees) under specific settings but policy, with a focus on the landscape scale, is likely to be more important. Wood et al. (2015) also explains that an interaction between landscape features, AEP interventions and crops being grown needs to be considered when assessing landscape modifications to support pollinators. Gardner et al. (2021) note that wild pollinator populations are more stable in landscapes that have a greater number of boundary features and/or semi-natural features.

In terms of explaining adoption of AEP (in general) the literature frequently cites opportunity cost (Hejnowicz et al., 2016) and the fit of the AEP options with existing farm level practices (Bartkowski et al., 2023). Other explanatory factors identified in the literature as positively influencing adoption include tenure (Bartkowski et al., 2023), farm size (Wool et al., 2003) and farm type (grassland compared to specialized arable farms) (Paulus et al., 2022). In a systematic review of quantitative literature on AEP participation Canessa et al. (2024) report that binary choice models such as logits and probits are often used to explain adoption, although very few studies examine adoption in relation to biodiversity (7% of models). In these studies, frequently employed independent variables include age, education, farm size, farm type, information sources, and neighbour participation. However, it is noted by Tsakiridis et al. (2022) in studies that examine AEP and adoption that self-selection bias can be an issue in terms of sample composition. This in turn means that there will likely be higher levels of adoption in sample data such that any statistical signal will be likely stronger and positive.

2.4. Summary and Key Research Questions

Given our review of the antecedent literature and the objectives of our research, the following research questions will be addressed:

i. How important do farmers consider the PD to be for crop production?

Given the existing literature researchers consider the PD to be a significant issue, but it remains unclear if farmers share this view.

ii. What types of farm management actions and activities do farmers adopt to support pollinators?

The existing literature on the type of actions and activities that farmers adopt to support pollinators is limited and an enhanced understanding will give important insights into pollinator management. In particular, understanding the extent to which farmers employ short term (i.e., bee hives) versus long term (i.e., wild pollinators) solutions for pollination services is important. In addition, understanding the extent to which farmers employ AEP to supports pollinators and the reasons why. This will also enable us to better understand the degree to which farmers coordinate with neighbours in supporting pollinators.

iii. What knowledge do farmers have of pollinators?

A reoccurring theme in the literature is the limited knowledge and understanding that farmers appear to have regarding pollinators in terms of types and potential contributions to crop production.

iv. What do farmers consider to be their main pollinator management priorities and what advice and information sources will inform these priorities?

Finally, we examine key priorities in terms of pollinator management and who farmers turn to for advice and information.

3. Material and Methods

3.1. Survey Design and Implementation

Our data collection strategy involved the design and implementation of a farm level survey instrument that enabled us to address the research questions raised. The design of our survey enabled us to collect information to address the issues identified in the Introduction as well as key themes that emerged from the antecedent literature. In particular, the survey was designed to examine the extent to which farmers understand the required actions and activities to support pollinators and its impact on crop production, knowledge and understanding of pollinators, and appropriate management.

The survey (see Appendix C) began by requesting information for the most important pollinated crop from each respondent. We wanted to examine attitudes towards crop production and pollination. We asked a series of questions to reveal information regarding farm level production and the PD. The survey then asked about current levels of pollinator land management activities and how these are influenced by participation in AEP. We also sought information about farmer knowledge regarding pollinators as well as sources of advice and information used in crop production. Given the importance of landscape scale land use decision for wild pollinators, we asked about the extent to which respondents cooperate with neighbouring farmers regarding pollinators.[2]

The survey instrument was initially trialed by distributing to a small group of farmers involved with the BEESPOKE project who gave feedback. The final version was distributed online in two waves during

[2] The survey also collected qualitative information using open-ended questions. Although these are not referred to in this paper a small selection of responses are provided in Appendix B.

2021 and 2022 by an agricultural research company (i.e. Map of Ag Analytics Limited - https://mapof.ag/). To be included in the survey, we required respondents to grow at least one pollinator dependent crop. Survey participation was incentivized yielding 200 responses. In addition, to ensure adequate survey returns from soft and top fruit producers, we also distributed the survey via industry contacts, yielding a final sample of 228 responses.

3.2. Descriptive Statistics

Our sample of respondents (n=228) were drawn from farmers across England and Scotland with the largest number of responses being recorded for Kent (n=32), Scotland (n=14), Herefordshire and Norfolk (both n=13), North Yorkshire and Suffolk (both n=13), Lincolnshire (n=12), Shropshire and Cambridgeshire (both n=11). By mapping the survey data onto the International Territorial Levels (ITLs) adopted by the UK government we could assess the representativeness of our sample of farmers by crop (three most common reported) and region.[3] The results are shown in Table 1:

Table 1: Percentage of Survey Respondents by Region and Three Main Crops Compared Against England Farm Census Data for 2021.

	Sample Data			**England Census Data 2021[1]**		
Region	**OSR[2]**	**Apples**	**Strawberries**	**OSR**	**Apples**	**Strawberries**
South-East	17	43	6	14	44	50
East of England	19	8	35	25	7	14
West Midlands	14	33	12	11	30	21
Yorkshire	17	0	0	16	0	1
East Midlands	13	0	12	19	2	4
South-West	5	15	6	9	16	9
North-East	4	0	0	6	0	0
North-West	1	3	6	1	1	1

*Notes: 1 - Source: Defra (2024). Structure of the agricultural industry in England and the UK at June 2021 www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june; 2 – OSR = Oilseed Rape

The results in Table 1 reveal that in terms of regional distribution by crop type, our sample of respondents appears to be relatively similar in terms of OSR and apples. However, for strawberries our sample maps less well, however, as shown in Table 2, that presents sample descriptive statistics, strawberries only account for 7.5% of survey returns. We note, however, that the non-standard composition of the farms being surveyed means that it is difficult to accurately assess the representativeness of our sample.

The descriptive statistics shown in Table 2 present information for key variables side by side as well as by column.

[3] For details see: https://www.ons.gov.uk/methodology/geography/ukgeographies/eurostat#south-west-england-

Table 2: Descriptive Data

Variable	Categories	Percentage	Variable	Categories	Percentage
Years Farming	Less than 5	1.3	Age	Age Under 35	3.9
	5-10	3.9		36-45	12.3
	11-15	4.4		46-55	18.4
	16-25	11.8		56-65	39.0
	More than 25	78.5		Over 65	26.3
Farm Management	Farm Owner	75.4	Farm Type	Top Fruit	15.4
	Farm Manager	11.8		Mixed	15.5
	Tenant Farmer	9.2		Soft Fruit	7.3
	Other	3.5		Livestock	3.9
				Arable	57.9
How Crop Sold	Producer	19.3	Agri-Environmental Policy	Yes	54.0
	Organisation	22.4		No	46.0
	Contract	45.2			
	Spot Market	13.2			
	Other				
Crops Grown	Oilseed Rape	59.2	Crops Grown	Blackcurrants	0.9
	Apples	17.5		Blueberries	0.9
	Strawberries	7.5		Plums	0.4
	Cherries	2.6		Linseed	0.4
	Field beans	4.8		Spring Beans	0.9
	Pears	1.3		Borage	0.9
	Raspberries	0.9		Parsley	0.4
				Sunflowers	0.4

From Table 2, we observe that in terms of years of farming experience, it is unsurprising that almost 80% have more than 25 years given the age profile of respondents (median age of over 50 years). The age profile of our respondents is typical for England, although we have less farmers aged 65 and over compared to recent farm statistics (DEFRA, 2023b). In terms of farm management, 75.4% of respondents are farm owners and 9.2% are tenant farmers, which compares to 54% being owner occupied and 14% being tenanted in 2021 in England (DEFRA, 2023b). In terms of the area of pollinated crops grown, we have an average of 51 hectares with a median of 30 hectares.

Our sample has 54% of respondents participating in AEP. It is difficult to establish if this is high or low compared to national data. Within England in 2022, it is reported by DEFRA (2023c) that 34,500 AEP agreements were implemented. Given that there are almost 200,000 agricultural holdings in England this means 18% are participating, although 80,000 holdings are under 20 hectares and participation amongst small farms is known to be significantly lower. Also, the participation rate in our sample is significantly below the levels seen at the peak of earlier AEP e.g. Entry Level Scheme had 70% participation. Wool et al. (2023) report that in the Humber region of the UK AEP adoption rates are relatively low with only 11% of farms adopting.

Finally, the mix of crops reported in Table 2, shows that the most frequent is winter oilseed rape (59.2%), apples (17.5%) and strawberries (7.5%). Also, as we would expect, our sample does have a high proportion of arable producers which reflects current agricultural land use in England (DEFRA, 2021). In 2021, 3.7 million hectares of land was used to grow arable crops with cereals and oilseed crops (various) accounting for 80%. The area used to grow oilseed crops was 313,000 hectares in 2021. In contrast, horticulture accounted for 131,000 hectares of land. The land area devoted to orchards and small fruit was 31,000 hectares (DEFRA 2021) with orchards accounting for almost 70% of this area.

3.3. Data Analysis, Methods, and Statistical Software

We began by examining descriptive statistics for our survey for the set of questions we wished to address. In addition, we implemented a statistical test between pairs of proportions for responses by crop type. We also estimated several regression model specifications to further examine the questions we raised regarding attitudes and knowledge of the PD and pollinators, and farm management and pollinators.

In terms of regression model specifications, for example, when we had a binary dependent variable, we employed a logit specification. Most data collected by the survey, is either a yes or no responses (e.g., Is crop yield lower than expected? See Table 5). When employing a binary logit model, it utilises a latent variable approach to determine the probability of an event. This approach retains a linear regression model but utilises a framework to determine the value of a latent or unobserved variable (y^*) which in turn determines the outcome observed for the binary dependent variable y. Formally,

$$y_i^* = X_{ik}\beta_k + u_i$$

where

$$y_i = 1 \; if \; y_i^* > 0$$

$$y_i = 0 \text{ otherwise}$$

where $i = 1,\ldots,N$, X_{ik} is a i by k data matrix, β is vector of independent variables $(k=1,\ldots,K)$ to be estimated and u_i is the error term assumed to be independently identically distributed with mean zero and constant variance.

In contrast, when our dependent variable takes the form of a count variable, we employed a Poisson specification. An example is a count of the number of farm management practices adopted to support wild pollinators (see Table 7). In this case, the model is specified as

$$f(Y|y_i) = Pr(Y = y) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!} = \frac{e^{X_{ik}\beta_k}\lambda_i^{y_i}}{y_i!}$$

where λ is the Poisson distribution parameter. The Poisson regression model can be specified in log-linear form:

$$\text{Ln } \lambda_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k$$

Finally, when the dependent data was an ordered response, we estimated an ordered Probit model.

All regression models were estimated using LIMDEP Version 11 (Greene, 2016). Our regression analyses do not reveal causality, but potentially important correlations between aspects of farm level activities, crop types and pollinator management. The selection of explanatory variables we employ is informed in part by reference to the antecedent literature. For example, as noted by Canessa et al. (2024), experience, farm type, size and collaboration with neighbours are frequently employed in studies examining adoption of AEP. The set of explanatory variables used in the regression analysis are presented in Table 3.

Table 3: Explanatory Variables Used in Statistical Analysis

Variable	Description	Units
Experience	Number of years farming	Years*
Area	Size of farm	Hectares
AEP	In an AEP scheme supporting pollinators	Yes = 1, No = 0
Records	Keep records of crop pollination	Yes = 1, No = 0
Soft Fruit	Type of crop produced	Yes = 1, No = 0
Top Fruit	Type of crop produced	Yes = 1, No = 0
Arable	Type of crop produced	Yes = 1, No = 0
Low Yield	Farmer thinks current levels of pollination are negatively impacting crop yield	Yes = 1, No = 0
Collaborate	Collaborate with neighbours in supporting wild pollinators	Yes = 1, No = 0

Notes: * In some regression model specifications, we employed experience squared to capture the potential non-linear relationship between experience and the dependent variables.

4. Data Analysis

4.1. Attitudes About Crop Pollination

We first asked respondents' questions about their attitudes to current crop pollination (Table 4).

Table 4: Attitudes to Pollinator Management and Crop Production (%)

Question	Response	All Crops	Top Fruit	Soft Fruit	Arable
Do you believe the yield of your crop is currently lower than it could be because of a lack of insect pollination?	No Yes	84.2 15.8	92.0 8.0	79.2 20.8	83.2 16.8
Do you believe the quality of your crop is currently lower than it could be because of a lack of insect pollination?	No Yes	92.1 7.9	96.0 4.0	79.2 20.8	92.9 7.1
Do you believe the financial return of your crop is currently lower than they could be because of a lack of insect pollination?	No Yes	86.8 13.2	94.0 6.0	75.0 25.0	86.4 13.6

Many of the farmers in our sample do not consider a lack of pollination (i.e. PD) to be an issue that impacts yield, quality, or financial return (Table 4). However, by crop type, top fruit growers appear less concerned than either soft fruit growers or arable farmers, illustrating the issues confronting efforts to induce greater on farm pollinator management motivated by economic concerns alone. Furthermore, testing the null hypothesis of equality of proportions of responses by crop type, there is a difference at the 10% level of statistical significance between: soft fruit and top fruit (Z=2.18, p=0.074) for crop quality; between arable and soft fruit (Z=-2.136, p=0.055) for crop quality; and arable and soft fruit (Z=-2.34, p=0.052) for financial return. However, even for soft fruit producers the highest level of concern was only 25% for financial returns, meaning, either a large proportion of farmers are generally unaware of PD and its impact on production or PD is less important to farmers compared to other aspects of crop production.

To further examine the responses reported in Table 4, we estimated logit regression models (Table 5).

Table 5: Is crop yield, quality, or financial return lower than it could be, due to a lack of insect pollination? (Yes=1; No=0)

	Low Yield			Low Quality			Low Finance		
Variables	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**
Constant	-0.883	0.999	0.377	-1.332	1.220	0.275	-0.731	1.027	0.476
Experience	-0.313	0.198	0.114	**-0.406***	0.245	0.098	**-0.369***	0.204	0.071
Farm Area	**0.004***	0.002	0.079	**0.005***	0.003	0.064	0.003	0.002	0.214
Soft Fruit	0.138	0.591	0.816	**1.127***	0.644	0.080	0.641	0.563	0.255
Top Fruit	**-1.138***	0.636	0.074	-1.281	0.979	0.191	**-1.159***	0.704	0.100
AEP	0.567	0.411	0.168	0.114	0.546	0.835	0.455	0.431	0.292
Records	**1.27****	0.546	0.020	**1.638****	0.657	0.013	**1.177****	0.575	0.041
LL	-88.45			-53.21			-80.46		
Chi^2	18.6***			19.5***			16.6***		
McFadden Pseudo R^2	0.10			0.15			0.09		

Notes: Coeff = Coefficient; SE = Standard Error; ***, **, * Significance at 1%, 5% and 10% level; LL = Log-Likelihood.

Farm experience was negatively correlated with a positive response to the questions for crop quality and the impact on finance (Table 5), implying that older farmers appear less likely to express concern about aspects of insect pollination on production. In contrast, larger farms were more likely to respond 'Yes' to the question about the negative impact of insect pollination on yield and crop quality. For crop type (a dummy variable) the excluded category is arable meaning a negative estimate for top fruit (yield and finance) and a positive response for soft fruit (quality) are both relative to arable. These results indicate a mixed response for crop type and how insect pollination impacts crop performance. Next, if a farmer keeps pollinator records, then they are more likely to have responded 'Yes', such that recording crop pollination is likely to heighten awareness of potential issues stemming from crop deficiencies. Finally, we note that the McFadden Pseudo R^2 for all models is relatively low and as such we should treat these results with a degree of caution.

Finally, we also asked respondents if they hire contract pollination services. This was confirmed by 35% of respondents. To examine this decision in more detail, we estimated a logit regression model with the results shown in Table 6.

Table 6: Hire Crop Pollination Services (Yes =1/No=0)

	Pollinator Service		
Variables	**Coeff**	**SE**	**P value**
Constant	**-2.05****	0.95	0.03
Experience	0.07	0.19	0.71
Top Fruit	**1.33*****	0.36	0.00
Soft Fruit	**1.65*****	0.47	0.00
Low Yield	-0.19	0.47	0.69
AEP	0.44	0.32	0.17
Records	0.26	0.51	0.62
LL	-124.3		
Chi^2	23.96***		
McFadden Pseudo R^2	0.088		

Notes: Coeff = Coefficient; SE = Standard Error; ***, **, * Significance at 1%, 5%, 10% level; LL = Log-Likelihood.

The results in Table 6 reveal that soft fruit and top fruit producers are more likely to employ this type of service compared to arable farmers.

4.2. Farm Management and Wild Pollinators

Next, we asked respondents about farm management practices they employ to encourage and support wild pollinators (Table 7).

Table 7: Farm Management Supporting Wild Pollinators (%)

Farm Management Practice	Yes
Improve management of existing habitats	89.0
Establish new flower-rich habitats	73.2
Maintain hedgerows by not cutting annually	80.3
Time insecticide spraying to reduce impact on pollinators	93.9
Time pesticide applications to reduce impact on pollinators	81.6
Reduce number of chemical applications to protect beneficial insects	88.2
Spot spraying instead of treating an entire crop	46.1
Provide nesting and/or overwintering habitat	79.4

Most respondents undertake some type of activity to support wild pollinators (Table 7), although these estimates may be subject to a degree of selection bias i.e. responses from farmers interested in pollinators or biodiversity. Given the responses on crop quantity, quality and financial returns, the motivation for adoption of practice listed in Table 7 are unlikely to be driven by crop production and instead by environmental attitudes, AEP requirements, retailer requirements and insecticide container labelling that stipulates how to avoid impacts on pollinators. When we asked respondents their reasons for not adopting practices that support wild pollinators; time (28%), experience (20%) and cost (17%) were the main justifications.

To further examine adoption, we estimated a Poisson count data regression model by creating a dependent variable for the number of practices adopted/not adopted (see Table 7). These results are presented in Table 8.

Table 8: Adoption and Non-Adoption of Pollinator Supporting Activities

	Adopt			**Not Adopt**		
Variables	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**
Constant	**1.712*** **	0.156	0.000	**1.072*** **	0.306	0.001
Experience	-0.002	0.032	0.949	**-0.107***	0.063	0.089
Soft Fruit	0.119	0.085	0.159	-0.105	0.187	0.575
Top Fruit	0.086	0.065	0.187	**-0.693*** **	0.175	0.000
Low Yield	0.062	0.073	0.392	-0.105	0.166	0.527
Collaborate	0.107	0.068	0.118	-0.155	0.166	0.350
AEP	**0.147*** **	0.055	0.007	**-0.271** **	0.119	0.023
LL	-458.75			-356.74		
Chi 2	15.1***			25.8***		
McFadden Pseudo R^2	0.016			0.035		

Notes: Coeff = Coefficient; SE = Standard Error; P = P Value; ***, **, * Significance at 1%, 5%, 10% level; LL = Log-Likelihood.

The number of adoptions of pollinator beneficial on-farm management activities was only explained by whether a farmer was in AEP. In the case of not adopting practices, this was negatively related to farmer experience, if they produced top fruit, and if they were in an AEP. More analysis on the proportion of arable and fruit farmers in AEP is required. However, there is no published data available and only limited statistics regarding overall land use by farm type. This represents an important information gap.

We also examined the individual on-farm practices using logistic regression models. These results are presented in Table 9.

Table 9: Adoption of On-Farm Pollination Supporting Activities

	Improve Habitat[a]			New Flower[b]			Hedge[c]			Time Fungicide[d]			Spot Spray[e]		
Variables	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**
Constant	-3.12	2.754	0.257	-6.41**	2.665	0.016	-5.93**	2.515	0.018	1.26	2.585	0.625	-4.89**	2.259	0.030
Experience	3.24*	1.879	0.084	5.06***	1.722	0.003	3.93**	1.564	0.012	0.58	1.559	0.709	2.63**	1.305	0.043
Experience^2	-0.46*	0.275	0.092	-0.74***	0.245	0.002	-0.51**	0.219	0.020	-0.12	0.216	0.590	-0.36**	0.176	0.041
Soft Fruit	1.64**	0.787	0.037	0.27	0.389	0.494	0.85*	0.494	0.084	0.29	0.451	0.518	0.99***	0.352	0.005
Top Fruit	1.31	1.057	0.215	0.99	0.665	0.135	0.33	0.605	0.582	0.56	0.661	0.394	0.53	0.462	0.246
Low Yield	0.87	0.777	0.260	0.94*	0.553	0.091	1.39**	0.691	0.044	-0.82*	0.445	0.065	0.63	0.399	0.116
Collaborate	1.03	0.772	0.181	1.08**	0.523	0.039	0.55	0.528	0.299	1.18*	0.639	0.063	0.67*	0.378	0.075
Records	-0.26	0.814	0.751	0.64	0.667	0.337	0.69	0.794	0.379	0.29	0.680	0.670	0.47	0.503	0.352
LL	-70.3			-118.5			-104.1			-103.8			-147.9		
Chi^2	12.72*			25.79***			18.36**			10.12			18.9***		
McFadden Pseudo R^2	0.083			0.098			0.081			0.046			0.06		

Notes: Coeff = Coefficient; SE = Standard Error; ***, **, * Significance at 1%, 5%, 10% level; LL = Log-Likelihood; a = Improve management of existing habitats; b = Establish new flower-rich habitats; c =Maintain hedgerows by not cutting annually; d = Time insecticide spraying to reduce impact on pollinators; e = Spot spraying instead of treating an entire crop

Improved management of existing habitats was positively related to being a top fruit producer, and experience, but negative for experience squared, implying that as farmers gain more experience (i.e. years in farming) they have a decreasing likelihood of adoption. For those establishing new flower-rich habitats, experience was positively related, and experience squared negative. Farmers who considered levels of pollination to be having a negative impact on crop yield and who collaborated with their neighbours regarding pollinators are positively related. For farmers who maintain hedgerows, experience was positively related, but experience squared was negative. However, being a top fruit producer and considering existing levels of pollination as having a negative impact on crop yield were positively related. The timing of fungicide applications was negatively related for those farmers who consider that existing levels of pollination are having a negative impact on crop yield, but positive for those who collaborate with neighbours. Spot spraying was positively related to farmer experience and collaborating with neighbours if producing top fruit but negative for experience squared. Finally, when asked about reducing the number of chemical applications to protect beneficial insects, this was positively related to collaboration with neighbours. Similarly, farmers who provided nesting and/or overwintering habitat, were also likely to be collaborating with neighbours. Our results regarding any aspect of collaboration with neighbours could be a function of pre-existing farm clusters. Examining the influence of farm clusters on farm level cooperation warrants further examination.

4.3. Knowledge of Pollinator Types

We asked respondents if they knew which pollinators their crops depended on (Table 10).

Table 10: Which Types of Pollinators Do Your Crops Depend On (%)

Pollinator group	Overall Yes	Overall No	Yes if Top Fruit	Yes if Soft Fruit	Yes if Arable
Honeybees	80.3	19.7	88.0	87.5	76.6
Bumblebees	77.2	22.8	82.0	87.5	74.0
Solitary bees	53.9	46.1	80.0	50.0	46.1
Hoverflies	28.5	71.5	46.0	25.0	23.4
Flies	22.4	77.6	24.0	33.3	20.1
Butterflies	25.4	74.6	24.0	16.7	27.3
Moths	20.2	79.8	30.0	12.5	18.2

Most respondents indicated Honeybees, Bumblebees and Solitary bees were the main pollinators. The potential lack of understanding regarding the other pollinators, for example Syrphine hoverflies in strawberries (Hodgkiss et al., 2018) does indicate a need for greater provision of information for farmers. Also, the percentages of respondents indicating the specific type does not vary significantly by crop. Examining the average number of pollinator types by crop type reveals little variation: top fruit farmers identified 3.74 groups; soft fruit farmers 3.13 groups; and arable farmers 2.86 groups. One result of significance was the importance placed on solitary bees by top fruit producers, suggesting that efforts to increase awareness about the importance of solitary bees in pollinating top fruit is having an impact. For each pollinator type, we ran a logit regression and found that the only positive and statistically significant regressors were either being a top fruit producer or coordinating with a neighbour regarding pollinators, and only for Honeybees, Solitary bees, and Moths.

We next asked if respondents undertook any active monitoring of pollinators. Results indicated that most respondents relied on crop walks to assess crop pollination requirements (55%). There was also a significant proportion who relied on advice from agronomists and consultants (32%) but most farmers did not monitor pollinators using traps (13%). We also examined on-farm pollination monitoring by employing logit model specifications. These results are presented in Table 11.

Table 11: On-Farm Pollination Monitoring Activities (Yes =1; No=0)

	Traps in Crop			Walk Crop			Agronomist		
Variables	**Coeff**	**SE**	**Pvalue**	**Coeff**	**SE**	**Pvalue**	**Coeff**	**SE**	**Pvalue**
Constant	**-3.02****	1.22	0.01	-0.49	0.84	0.56	**-1.57***	0.90	0.08
Experience	-0.03	0.24	0.89	-0.01	0.17	0.93	0.05	0.18	0.80
Top Fruit	**0.90***	0.49	0.07	**1.07*****	0.37	0.00	0.55	0.37	0.13
Soft Fruit	0.73	0.64	0.26	0.72	0.48	0.13	0.72	0.48	0.14
Low Yield	0.58	0.54	0.28	-0.25	0.42	0.56	**0.91****	0.41	0.03
AEP	**0.83***	0.47	0.07	**0.68****	0.29	0.02	0.11	0.31	0.72
Records	**1.76*****	0.53	0.00	**2.11*****	0.77	0.01	**1.71*****	0.52	0.00
LL	-74.5			-142.4			-130.4		
Chi^2	24.68***			29.1***		25.18***			
McFadden Pseudo R^2	0.142			0.093			0.088		

Notes: Coeff = Coefficient; SE = Standard Error; ***, **, * Significance at 1%, 5%, 10% level; LL = Log-Likelihood.

Both crop walks and employing traps within crops are positively related with being a top fruit producer, AEP participation, and keeping pollinator records. The probability growers who took advice on pollination from agronomists and consultants was more likely if existing pollination levels are low, and they were keeping pollinator records. Overall, there was a strong and positive relationship between keeping pollination records and on-farm pollination monitoring activities.

We also asked farmers about other aspects of pollination management. 9.6% indicated that they collected records of crop pollination by pollinator type, 17.1% actively managed their farm for wild pollinators in collaboration with neighbours and 49.1% think that they benefit from pollinators by the actions being undertaken by their neighbours. These findings are important given that accurate records of crop pollination are required if changes to production or land use are to be evaluated in terms of supporting wild pollinators.

4.4. Pollinator Management Priorities

We next asked respondents their priorities in relation to pollination management (Table 12).

Table 12: Main Priorities for Pollination Management (%)

Pollination management main priorities	Always	Often	Maybe	Never
Consistent and reliable crop pollination	67.5	18.9	10.5	3.1
Increased economic return	62.7	22.4	12.3	2.6
Availability of managed pollinators for rental or purchases	14.9	13.2	31.1	40.8
Reported declines in wild pollinator populations	20.2	28.5	26.8	24.6
Diversification of pollination strategies	22.4	25.9	33.8	18.0
Minimising uncertainty and risk in crop pollination	43.0	27.6	22.8	6.6
Effectiveness of pollinator species	36.4	24.6	30.7	8.3

Many respondents indicated “Always” or “Often” in terms of priorities for pollination management regarding consistent and reliable crop pollination and increased economic returns (Table 12). This contradicts the answers reported in Table 4 about understanding how crop pollination relates to quantity, quality, and financial returns. These results are also hard to reconcile with data around maintaining records about crop pollination. Potentially, it is correlated with crop pollination monitoring and walking the crop, but unless a coherent and meaningful assessment of pollinator presence is related to crop quality/quantity it remains unclear how informative walking a crop can be regarding pollination requirements. Thus, whilst most respondents understand the economic significance of crop pollination it is unclear how this is manifesting in current agronomic practices. For the other types of pollination management priorities, there were much lower levels of importance. Given the clear correlation between these priorities and the supply of pollinator services either from wild or managed pollinators, these results provide more evidence of inconsistent understanding regarding crop pollination and farm level activity.[4]

4.5. Advice and Investment in Pollination Services

Our survey revealed that by far the most important source for seeking advice on crop pollination were agronomists and other commercial suppliers (74%). Next were published advice (33%) and sources including government, NGOs and local environmental groups (at or below 25%), partly relating to the answer about the role of agronomists in monitoring pollinators. For the crop pollination information source, we estimated logit model specification. These results are presented in Table 13.

[4] We also analysed these responses employing an ordered probit where the dependent variable was coded: Never = 0, Maybe =1, Often = 2 and Always =3. All models yielded relatively weak statistical results. See Appendix A for details.

Table 13: Sources of Advice Used by Respondents

	Published			Government			NGO			Local Groups		
Variables	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**	**Coeff**	**SE**	**P value**
Constant	3.739	2.447	0.127	**5.275***	2.705	0.051	-0.674	1.980	0.734	**4.189***	2.275	0.066
Experience	-1.876	1.424	0.188	**-2.916***	1.586	0.066	0.217	1.216	0.858	**-2.337***	1.367	0.087
$Experience^2$	0.179	0.193	0.353	0.309	0.215	0.151	-0.102	0.170	0.550	0.246	0.189	0.192
Low Yield	**1.011****	0.407	0.013	0.315	0.447	0.481	**1.132****	0.418	0.007	-0.333	0.464	0.473
Top Fruit	-0.466	0.522	0.372	0.174	0.526	0.741	-0.131	0.562	0.816	-0.646	0.582	0.267
Soft Fruit	-0.487	0.406	0.231	-0.436	0.467	0.351	0.389	0.411	0.344	-0.692	0.445	0.120
Records	-0.220	0.539	0.683	0.513	0.546	0.347	0.121	0.538	0.822	**1.258****	0.507	0.013
AEP	0.452	0.312	0.148	0.133	0.352	0.705	**0.767****	0.353	0.030	0.314	0.337	0.351
LL	-130.69			-122.42			-127.1			-129.29		
Chi^2	27.45		0.000	22.98		0.000	26.82		0.002	21.54		0.003
McFadden Pseudo R^2	0.095			0.094			0.11			0.083		

Notes: Coeff = Coefficient; SE = Standard Error; ***, **, * Significance at 1%, 5%, 10% level; LL = Log-Likelihood.

The results shown in Table 13 reveal that there is only weak statistical evidence between the source type of information and the set of explanatory variables. For example, published sources were positively related to reporting a negative yield effect from a lack of pollination. When asked about government sources of information we found only a negative result for experience. For NGOs we found a positive relation for AEP participation and reporting a negative yield effect.

Finally, we asked what would make a farmer increase investment in pollination services (Table 14).

Table 14: Increased Investment in Pollination Services (%)

Invest in Pollination Services	Yes
Research Evidence on Financial Benefits	63.2
Research Evidence on Environmental Benefits	60.5
Research Evidence on Landscape Benefits	28.9
Farm Assurance Schemes	31.6
Customer Assurance Schemes	22.8
Higher Payments for AEP	54.8
Decrease in Natural Pollinators	39.0

Evidence regarding financial benefits, higher payments associated for AEP participation and evidence on environmental benefits will all lead to an increase in investment of pollination services (Table 14).

5. Discussion

5.1. The Significance of the Pollinator Deficit

Our survey results indicated that most respondents were not concerned about the financial consequences of inadequate pollination (i.e. the PD). This means that the answer to our first question (How important do farmers consider the PD to be for crop production?) is not very much, there are only low levels of concern about crop pollination and the associated PD. This result is somewhat surprising given the apparent importance of the of the PD within the existing literature. There are several possible explanations for this result.

First, any variation in crop yield and/or quality that occurs because of the PD are small and as such considered negligible compared to other factors. Within the extensive economic efficiency literature and related farm level benchmarking literature, it was very difficult to identify existing research considering pollination . Examples include Tariq et al. (2018) and Wijayanti et al. (2020) who consider strawberry production and note that variation in pollination as a possible reason for differences in farm level performance. However, the lack of literature on farm level efficiency and productivity that mentions pollination or pollinators likely occurs either because pollination is assumed to be constant, or that the importance of pollination in commercial systems has not been investigated sufficiently to know whether it is optimal and so it has generally been overlooked.

Second, 35% of our sample of respondents employ crop pollination services (i.e. honeybee hives). As observed by Garibaldi et al. (2020), if there are too few pollinators this could be resolved using managed hives in the short term with longer term landscape planning including enhancement and conservation of semi-natural habitats and flower strips. In fact, a decision to deploy honeybee hives can be understood as a risk averse approach to pollination, and many farmers see wild pollinators as additional (or secondary) to honeybees (Eeraerts et al., 2020), even when honeybees are not the most effective or efficient pollinator.

Third, there are trade-offs in land use as it relates to agricultural production and pollination management that means that a PD will always occur. Micro economic analysis assumes that economic agents will equate net marginal benefits from all activities such as crop production and provision of landscape (e.g. wildflower strips) to support wild pollinators that in turn enhance crop returns (Fezzi and Bateman, 2011). Assuming we have a single farm, and they can allocate a small land parcel to either production of apples or production of pollinators (e.g., wildflower strips). On this piece of land farmers are equating the return from the crop and the return from supporting pollinators. If the increase in production on the marginal piece of land more than compensates for the reduction in yield from lower pollinator numbers, then the farmer will plant the crop.

Fourth, our results reveal that the current levels of monitoring and record keeping about crop pollination and pollinators are limited. This means that awareness of the existence of a PD is likely to be low. In addition, this result also answers our third question regarding knowledge of pollinators (What knowledge do farmers have of pollinators?). As noted from the literature, limited knowledge and understanding of pollinators by farmers is frequently reported. In part this could be a result of there being too little monitoring of pollinators, without which it will be difficult for farmers to fully appreciate if existing levels of crop pollination are sufficient. To enable farmers to monitor pollinators requires them to understand how to measure pollination activity as well as be able to identify pollinators. Garibaldi et al. (2020) have described a protocol that farmers could employ to assess if current levels of pollination are too low and research projects such as Beespoke provide extensive guidance on pollinator identification and land management options.[5] The need for this type of protocol is supported by our results in that respondents consider bees to be the most important pollinator, even though many other insects play a significant role in crop pollination. There is a significant body of research demonstrating that insects, in general, are in decline (Cardoso et al., 2020; Mancini et al., 2023). Hall and Martins (2020) note that although pollinator decline and its consequences are understood, and bees have played a key role in knowledge enhancement, there is a need enhance understanding to include insects in general. Basset and Lamarre (2019) and Goulson (2019) argue that we require adoption of activities to protect all insects given the rapid declines in population levels being observed. Basset and Lamarre (2019) also observe that specific species i.e., bees and butterflies have provided an initial focus, but protection needs to go beyond a small group of iconic species. Potentially, bees could be a "flagship species" as happened with the short-haired bumblebee project in south-east England (Gammans, 2013). Conversely, flagship species can mean that other insects are marginalized in terms of conservation efforts and understanding other insects that are critical to ecosystem survival.

Finally, benefits of pollinator monitoring are not confined to individual farmers. There is the need for more general pollinator monitoring such as advocated by Breeze et al. (2021). They demonstrated that costs of monitoring are significantly less than losses from poor pollination. Identifying the potential economic benefits of monitoring needs to examine if the costs of dealing with sub-optimal levels of pollination are economically meaningful.

5.2. Farm Level Management to Support Pollinators

In relation to our second question (What types of farm management actions and activities do farmers adopt to support pollinators?) our results align with the existing literature. We find that participation in AEP is positively correlated with the adoption of pollinator supporting activities such as habitat improvements, establishment of flower strips and hedgerow management. There are several reasons why AEP is so important for supporting pollinators on farms.

First, when it comes to key farm level priorities to support pollinators financial reward is the most important motivation for adopting appropriate practices. However, the financial driver is unlikely to be because of agricultural production and the PD given our results. That said, our results also reveal that if the financial benefits in terms of crop production from greater levels of pollination can be shown then farmers would invest in pollination services. Without this evidence payments offered for AEP participation will continue to be the main motivation for adoption. Existing research unambiguously demonstrates that higher AEP payments attract great levels of participation as there are clearly significant costs involved in creating habitats that support pollinators. If we assume that a farmer creates a wildflower strip, then they will incur costs in terms of soil preparation prior to planting the seed which

[5] Beespoke (https://northsearegion.eu/beespoke/) has developed protocols to enable farmers to measure insect pollination by crop type. Other examples of research projects supporting farmers in understanding how to count pollinators are the Flower-Insect Timed (FIT) Counts app (https://fitcount.ceh.ac.uk/) that is part of the UK Pollinator Monitoring Scheme (PoMS: https://ukpoms.org.uk/).

also needs to be bought as well as ongoing management to ensure the wildflower strips yields sufficient flowering plants that will attract and support pollinators. There may also be an opportunity cost where the land used to produce the flower strip is no longer in conventional production (Silva et al., 2023). These costs can reduce the attractiveness of allocating land for pollinators. There may be land that is not currently in production that can be used to support pollinators. In this case, when there is minimal opportunity cost, planting wildflower strips may be an appropriate land use choice, especially if there is also an increase in crop yield (Blaauw and Isaacs, 2014).

Second, even though higher rates of payment for AEP will likely induce higher participation, not all farmers will participate in AEP. As explained by Gaines-Day and Gratton (2017), there may be factors that prevent participation including awareness of policy options, a lack of knowledge to enable participation and a need for farmers' *"to experience a shift in their beliefs, values, or attitudes regarding environmental conservation"* (p. 2). Nalepa et al. (2021) also argue that increasing farmer awareness and understanding of wild pollinators could see increased levels of adoption of appropriate land use practices. An important element that is required to ensure improved identification of pollinators, is more emphasis on farmer education and extension service to enable them to monitor pollinators and undertake land management practices that support pollinators (Nichols et al., 2022). Clearly, AEP design and implementation needs to recognize the important role that education and extension services play if AEP is to be successful. Much in the same way that there is growing evidence about the PD, greater efforts are still needed to communicate scientific research findings to farmers such as the importance of specific wildflower seed mixes, appropriate management for floral establishment and on-going management to ensure longevity of the resource (Nichols et al., 2022).

Third, another important finding regarding farm level management emerged when we asked respondents about the extent to which they coordinate activities in support of wild pollinators. Only 17% responded positively whereas almost 50% acknowledged that they benefited from the actions of neighbouring farmers. There is significant evidence that many pollinator species are reliant on landscape management and therefore require land-use management at a scale beyond an individual farmers' control. From a policy perspective, given that many pollinator species are reliant on wider landscape features, and this requires management at a scale beyond an individual farmers' control, collective action is needed, with policy support. Therefore, there is a need to align wild pollinator management with AEP design. From an economic perspective, Cong et al. (2014) show, using an Agent Based Model (ABM), that an individual farmer will have little incentive to manage their farm for wider landscape objectives that can support wild pollinators. A solution to this problem, proposed by economists, is the agglomeration bonus (Bareille et al., 2020, 2021). This is a payment, that could be made via AEP, that increases as the number of farmers coordinating increases. On a practical level, farm level coordination could be enabled by the development of farm cluster groups and these groups have been growing in importance in the UK (Prager, 2022). If the focus of a farm cluster is based purely on pollinators it might not be induce sufficient participation, whereas improving wider biodiversity, and/or pest control, may be more of an incentive. Interestingly, the reintroduction of the shorthaired bumble bee (*Bombus subterraneus*) into south-east England does suggest that focusing on a single species can work and in turn yield wider biodiversity benefits (Gammans, 2013; Sampson et al., 2020). However, the current prescriptive nature of AEP design has been noted by Arnott et al. (2019) as a limitation enabling longer-term behavioural change. By allowing AEP implementation to be more flexible not only might this induce higher levels of participation, but it may also support farm level coordination that in turn generates a landscape that is beneficial for wild pollinators.

5.3. Limitations of the Current Research

Although our research has revealed important insights into farm level knowledge and understanding of the PD and pollinators within the UK there are several limitations that need to be acknowledged. First, although our regression models yielded interesting results, in general statistical significance is quite low (e.g., low McFadden Pseudo R^2 values). Therefore, our results do need to be treated cautiously and would be best interpreted as exploratory as opposed to definitive. One way to address this limitation would be to collect a bigger sample of data. It would also be important to ensure that the sample is representative of the type of farm level behaviour and practices we are focussing on. To be able to statistically demonstrate sample representativeness would constitute an important development on the research presented here. Second, our sample although does not capture the regional variation in strawberry production as well as that for OSR and apples. In part, this limitation could again be addressed by increasing sample size but with a clear emphasis on mapping crop composition by regional production. Third, with a different approach to sampling it would be possible to deal with the issues arising from sample selection bias in relation to AEP participation.

6. Conclusions

In this paper, we present findings from a farm-level survey undertaken to examine farmer knowledge and understanding of the PD, and pollinator management. Overall, our results indicate that identifying a PD at the farm level is difficult and is maybe considered less important than other yield limiting factors that can affect output on an annual basis. Our findings also indicate that many respondents are actively undertaking farm level management activities that support wild pollinators. Therefore, although respondents recognize the importance of pollinators in crop production, they do not seem as concerned with pollination management in relation to crop production, and the PD. This may be because many do not consider there to be issues around crop production and existing levels of crop pollination. Or it could be because pollinator monitoring is too difficult or time consuming or that the benefits from monitoring are not understood. There are clearly some crops for which the relationship between crop quantity and quality is positively correlated with levels of pollination, e.g. apples and strawberries. Potentially, with an enhanced understanding of crop pollination and provision of simple protocols for assessing levels of pollination (such as those developed by BEESPOKE) farmers might begin to actively monitor pollination of crops. Even if the extent of the PD becomes more widely understood, how farmers use their land, and the associated marginal costs and benefits means that increasing pollination levels may not be considered of sufficient economic importance. This land-use trade-off makes pollination decisions more complex than simply looking for margins of improvement in crop production from applying agricultural chemicals.

Given the existing set of financial incentives determining production there is a negative externality in terms of biodiversity provision which in turn necessitates the need for AEP. The challenge in this context is that the land-use activities that support wild pollinators are only part of a wider mix of policies that farmers can adopt. Evidence to date suggests farmers are not adopting the right mixes and as such there is an under provision. This implies that the relative "prices" for the mix of land use options is "wrong". This can be rectified if the relative prices are changed or if some additional benefits from the land use management can be perceived or achieved by farmers.

Our findings confirm that efforts to inform and provide incentives to farmers to adopt farm management practices that support pollinators will likely be more successful if channeled via AEP rather than appealing to the profit motive. If farmers are experiencing PDs, then there is likely to be a high correlation with it and potential exit from the industry. However, there is little or no research pointing to a serious PD in crop production and resulting farm level industry exit. Until such evidence is forthcoming the desired changes in land-use practices that will support wild pollinators will have to come via AEP.

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Appendix A

Table A1: Priorities for Pollination Management (Ordered Probit - dependent variable: Never = 0, Maybe =1, Often = 2 and Always =3) Only statistically significant estimates and associated marginal effects are reported

	Reliable Crop[a]	**Managed Pollinators[b]**	**Declines Pollinators[c]**	**Diversify Management[d]**	**Minimise Risk[e]**	**Effectiveness Pollinators[f]**
Variables	**Coeff/ME**	**Coeff/ME**	**Coeff/ME**	**Coeff/ME**	**Coeff/ME**	**Coeff/ME**
Top Fruit Y=0 Y=1 Y=2 Y=3	1.07*** -0.03*** -0.01*** -0.15*** 0.28***	1.36*** -0.38*** -0.12* 0.07*** 0.43***				0.47* -0.05** -0.12* -0.02 0.18*
Soft Fruit Y=0 Y=1 Y=2 Y=3	0.48** -0.02** -0.06** -0.08** 0.16**	0.5*** -0.18*** 0.004 0.06*** 0.12**		0.55*** -0.12*** -0.1*** 0.04*** 0.18***		0.71*** -0.07*** -0.17*** -0.03 0.27***
AEP Y=0 Y=1 Y=2 Y=3	0.31 -0.02* -0.04* -0.05* 0.11*		0.25* -0.08* -0.02* 0.03* 0.07*	0.43*** -0.11*** -0.06*** 0.05*** 0.12***	0.52*** -0.06*** -0.11*** -0.02* 0.2***	
Records Y=0 Y=1 Y=2 Y=3				0.44* -0.09** -0.08 0.03*** 0.14		
LL	-201.4	-273.5	-311.3	-298.9	-274.6	-292.3
Chi^2	18.3**	36.4***	5.89	22.3***	13.79*	20.28***
McFadden Pseudo R^2	0.043	0.062	0.01	0.036	0.025	0.035

Notes: Coeff = Coefficient; ***, **, * Significance at 1%, 5%, 10% level; ME = Marginal Effects [Y=0,1,2,3]. MEs for dummy variables are Pr[Y|X=1]-Pr[Y|X=0]; LL = Log-Likelihood; a=Consistent and reliable crop pollination; b=Availability of managed pollinators for rental or purchases; c=Reported declines in wild pollinator populations; d=Diversification of pollination strategies; e=Minimising uncertainty and risk in crop pollination; f=Effectiveness of pollinator species.

In terms of delivery of consistent and reliable crop pollination, top fruit, soft fruit, and AEP participation was positively related. For availability of managed pollinators for rental or purchase, and effectiveness of pollinator species, both top fruit and soft fruit growers are positively related. Declines in wild pollinator populations and minimizing uncertainty and risk in crop pollination were positively related to AEP participation, indicating that either these farmers have an increased awareness of crop pollination or because farmers are more likely to participate in AEP if are interested in the environment. For diversification of pollination strategies there was a positive association with soft fruit, AEP participation and keeping pollinator records but increased economic return yielded no statistically meaningful results.

Appendix B: Examples of Qualitative Responses

To further investigate this issue, we sought feedback on each of these questions raised. Several respondents assess yields (compared to historical levels or national averages) and suggest deficit might be due to a PD, although several noted that measuring a PD is difficult in practice.

- "Very difficult but think that the crop could always yield better and maybe it is down to not enough pollinators"
- "I think it is very difficult to assess how I can say how much the yield is down due to pollinators"
- "I don't think you can truthfully"
- "Very difficult to assess yield deficit"
- In addition, a few respondents indicated that they employed measures to support pollinators (floral strips, and honeybee and bumblebee hives) and some examined seed set and flower counts. In terms of the crop quality and pollination the responses were like those for crop production. Most respondents provided no specific feedback although a few indicated that it is difficult to assess the pollination/crop quality relationship and a couple suggested that fruit shape and crop quality indicate issues regarding lack of pollination.
- These results echoed many of the qualitative comments for increased investment in pollination services. Increased payments for AEP for an increase in pollinator beneficial land use management was a frequently articulated response:
- "If there was more financial rewards for providing habitats for pollinators, no questions it would be more poplar. Money always talks."
- "If there was financial help to allow us to not grow as many crops and put it down to wild flowers."
- "More finical support and advice."
- "Help with a grant."
- "Grants or financial support."
- "Financial incentives to purchase wildflower seed, and schemes to reward farmers for leaving dedicated habitats for wild pollinators."

Appendix C: Copy of Survey Instrument

Attached as separate file.