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REVIEW

Trees for Climate Change, Biodiversity and People

Farmland trees and integrated pest management: A review of current knowledge and developing strategies for sustainable systems

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Abstract

1. Climate change and the withdrawal of several classes of agrochemicals from use are intensifying the challenges faced by food producers in controlling pests in crop systems. Integrated pest management (IPM), which uses a combination of pest control approaches, is therefore a focus in international initiatives to improve the resilience of food production.
2. Integrating the greater use of trees and shrubs on farms within IPM frameworks offers a biodiversity-positive contribution to crop protection. For example, trees can modulate the prevalence and impacts of agricultural pests and their natural antagonists through direct and indirect interactions. The beneficial impact of farmland trees and shrubs on pest management in arable or grassland fields can be enhanced from an analysis of variables such as tree species and their spatial distribution on farms, insect-plant dynamics, population behaviours and soil management practices.
3. The aim of this study is to synthesise existing knowledge and to assess the benefits and trade-offs between farmland trees and IPM strategies, building on gaps in knowledge identified by a stakeholder survey. Through this targeted review, we delineate the future evidence required to define and quantify the advantages that farmland trees offer as an element of IPM strategies.
4. *Practical implication*. The development of regional biodiversity monitoring tools, which integrate landscape features such as trees, shows promise for shaping national policies to increase the adoption of IPM. There is a demand for user-friendly on-farm tools, adaptable to changing crop and pest priorities, that can support the alignment of the management of farm trees with IPM. However, basic

and applied biological and ecological research are needed to inform and validate these decision-support tools and the capability to inform landscape-scale models.

KEYWORDS
agroecology, conservation biological control, farmland trees, integrated pest management, multifunctional landscapes, natural enemies

1 | INTRODUCTION

Agricultural intensification, aimed at ensuring affordable, safe and abundant food supplies, has been implicated in the decline of on-farm biodiversity and the disruption of essential ecosystem services such as pollination and natural pest control (Benton et al., 2003). The prolonged use of a limited range of conventional chemical pesticides has further exacerbated these issues by negatively impacting non-target species and increasing the risk of human exposure to these chemicals (Whelan et al., 2022). Integrated pest management (IPM) presents a sustainable alternative, emphasising low-input, preventative approaches (Birch et al., 2011; Deguine et al., 2021; EPA, 2022). As defined by the European Commission's Sustainable Use of Pesticides Directive (Table 1; European Commission, 2009), IPM adheres to eight core principles applicable to arable cropping systems (Barzman et al., 2015). A fundamental aspect of IPM involves the protection and enhancement of beneficial organisms through the establishment of ecological infrastructures within and surrounding crop production areas (Gurr et al., 2017; Holland et al., 2016; Tscharntke et al., 2005). Additionally, IPM advocates for the preferential use of biological, physical and other non-chemical methods over chemical interventions, where evidence suggests the former provide satisfactory pest control, or where significant pest suppression occurs leading to reduced use of conventional control application (Figure 1).

Farmland trees and shrubs are perennial structures in agricultural landscapes which provide a range of ecological services delivered both spatially and temporally (Kuyah et al., 2016). For example, trees support beneficial arthropods including pollinators and natural enemies of crop pests, directly contributing to crop production and resilience (Kletty et al., 2023; Udawatta et al., 2019). Trees support beneficial species in temperate habitats by providing pollen and nectar early in the year when herbaceous flowering plants remain dormant, and additionally offer habitat niches and nesting sites all year round (Donkersley, 2019). Shelterbelts planted to protect crops from wind can provide additional refuges to beneficial arthropods and serve as barriers to insecticidal drifts from adjacent field crops (Holland et al., 2016; Longley & Sotherton, 1997; Ucar & Hall, 2001). For these reasons, farmland trees and shrubs can be considered a component of conservation IPM planning. Young trees can provide immediate beneficial functionality that, if appropriately maintained, can continue throughout their life-span providing benefits for future generations (Pywell et al., 2005).

Within Europe, IPM principles and technologies have attracted increased interest because they can fill gaps created by the removal and restricted use of chemical controls, as well as complying with imposed legislation driven by new national agendas, policies and funding strategies (HSE, 2021). However some argue that the implementation of IPM remains limited and that the 2014 goals set by the Sustainable Use Directive (SUD) (see The Voluntary Initiative, 2024a) have been missed. A key objective of the UK Government's 25-year Environment Plan and initiation of various incentive schemes that followed (DEFRA, 2024a; Gov.UK, 2018, 2023a) aimed to 'use resources from nature more sustainably and efficiently' and manage pressures on the environment by managing exposure to chemicals and enhancing biosecurity (DEFRA, 2023; Wentworth, 2023). Within the European Union, the EU Green Deal with integral Farm to Fork and Biodiversity initiatives (TEEB, 2018) have also raised the profile of IPM methodologies and the need for policies and funding to bring evidence-based IPM solutions into practice.

In this context, the broad question 'Can farmland trees contribute to IPM strategies in agricultural landscapes?' formed the basis of our literature review. We invited 50 professionals working in areas of UK agriculture, forestry, conservation, plant health and IPM to guide us in narrowing down the scope our literature review. We identified the key subject areas that were deemed highly relevant to our question and establish current views on what evidence and resources are needed to support knowledge exchange and promote the benefits of trees for contributions to IPM on arable farms.

2 | SURVEY METHODS

We used an online survey approach, adapting methods established for iterative voting processes in agricultural and science-policy (Ingram et al., 2013; Pretty et al., 2010; Sutherland et al., 2012) to circulate a list of suggested research questions aligned with our overarching theme of enquiry, IPM and farmland trees. The questions were divided into three themes: (i) components (trees, pests and beneficial invertebrates), (ii) interactions between these components and management practices, and (iii) monitoring, promotion, and regulation (Table 2). The survey was circulated to a group of 50 experts working in agriculture, forestry, conservation, plant health and IPM, based in UK research organisations, government departments and advisory services. Individuals were selected based on their expertise in one or more of these areas while ensuring a

TABLE 1 Definitions of integrated pest management, trees outside of woodland, farmland trees, native species and natural enemies.

Term	Definition
Invasive species and plant pest	*Invasive species* are those that are not native to the ecosystem under consideration and that cause or are likely to cause economic or environmental harm or harm to human, animal or plant health (Beck et al., 2008). *Plant pests* include insects, other invertebrates, bacteria, fungi, viruses and other pathogens which affect the health of plants or plant products by feeding on them or causing disease (DEFRA, 2024b)
Integrated pest management (IPM)	*Integrated pest management* means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms (European Commission, 2009)
Trees outside woodland	*Trees outside woodland* are trees that exist outside of woodland both in rural and urban areas. 'Woodlands are defined as land with a minimum area of 0.5 ha under a stand of trees, and a tree crown cover of at least 20% or the potential to reach this. The minimum width for a woodland is 20 m' (Brewer et al., 2017)
Farmland trees	*Farmland trees* are trees that are intentionally maintained or allowed to grow on farmland. A framework for classifying agroforestry types that includes trees on farmland is provided by Sinclair (1999), and Lawson et al. (2016) as reported by Burgess (2019)
Native species	*Native species* have been defined as those which have occurred in an area continuously since the last glaciation, or have subsequently colonised naturally, although sometimes this can be difficult to demonstrate (Crees & Turvey, 2015)
Natural enemy	*Natural enemy* is a collective term for parasites, parasitoids, pathogens, predators and competitors that inflict mortality on a population of a species. Arthropods (including insects, spiders, predatory mites and nematodes that parasitise insects) that are natural enemies of pests are termed *beneficials* (sources from Frank & Gillett-Kaufman, 2021)

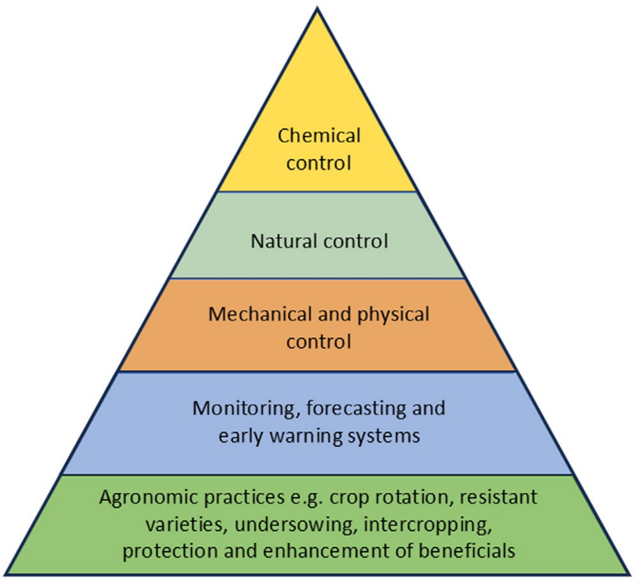

FIGURE 1 Physical, biological and chemical components of IPM, highlighting the role of the enhancement of beneficials and natural control (IBMA, 2021). Priority is given to actions at the base of the triangle, moving upwards, as necessary. IPM, integrated pest management.

widespread of organisations were represented. The expert group was asked to rate each question on a five-point scale to indicate the sufficiency of existing information and the priority for further research and were encouraged to comment and include additional questions they felt were needed.

Responses were scored from a scale of 0 to 1, where 0 represented 'no priority' or 'no information', and 1 represented the highest availability of information or highest research priority. To rate the 'Existing knowledge' (Table 2, column 2), the number of responses per question were normalised to a scale from 0 to 1, with scores greater or equal to 0.75 signifying strong evidence, between 0.55 and 0.74 moderate evidence (or 'Some'), between 0.25 and 0.54 weak evidence (or 'Little') and negligible evidence was associated with scores of less or equal to 0.24. The same grouping of normalised scores, was also applied to the 'Priority for research' column, with values signifying 'High priority' ($1 < 0.75$), 'Moderate priority' ($0.74 < 0.55$) and 'Low priority' ($0.54 < 0.25$). Responses including 'Do not know' were removed from the analysis, but values are illustrated for clarity.

Survey participants received a preliminary report summarising the survey results, which initiated a second round in the consultation process, providing participants with the opportunity to again review and amend their initial responses or pose additional questions based on the collective feedback circulated (Hsu & Sandford, 2007).

The survey was conducted in accordance with the School of Animal, Rural and Environmental Sciences' Research Ethics Committee, Nottingham Trent University. All submitted responses and comments were treated anonymously, with agreement that the survey results would be made openly available.

3 | SURVEY RESULTS

Of 50 stakeholders approached, 36% (18) participated in the initial survey poll. Among the respondents who confirmed the sector

TABLE 2 Participants' responses ($n=20$) on the level of existing knowledge and prioritisation for research related to trees as a component of IPM strategies across farms in England and Wales.

Survey section	Survey questions	Existing knowledge	Do not know (%)	Priority for research/action	Do not know (%)
A. IPM components: trees, pests and beneficial invertebrates					
A.1	Is information on the principal farmland trees and shrub species available?	Limited	13	Moderate	13
A.2	What are the main forms of the layout and management of farmland trees and shrubs?	Limited	14	Moderate	20
A.3	Which invertebrate groups are key economic pests of arable farms?	Some	0	Moderate	7
A.4	Which invertebrate groups are key economic pests of livestock farms?	Some	13	Low	7
A.5	Which invertebrates are natural enemies of pests?	Limited	13	**High**	7
B. Interactions between trees, pests, beneficial invertebrates and management practice					
B.1	Which species of trees and shrubs directly affect the diversity and abundance of pests?	Limited	8	Moderate	7
B.2	Which species of trees and shrubs directly affect the diversity and abundance of beneficial invertebrates?	Limited	13	**High**	7
B.3	How does layout and management affect diversity and abundance of pests?	Limited	20	Moderate	7
B.4	How does layout and management affect diversity and abundance of beneficial invertebrates?	Negligible	20	**High**	7
B.5	How does the distribution of beneficial invertebrate groups affect the importance of farmland trees for IPM?	Negligible	47	Moderate	20
B.6	What local factors affect the association between farmland trees and economically important invertebrates?	Limited	29	Moderate	7
B.7	What key farm management actions affect invertebrate-tree relationships?	Limited	14	Moderate	7
C. Monitoring, promotion and regulation					
C.1	Does a standard typology for IPM exist across research disciplines and industrial sectors?	Limited	33	Low	13
C.2	Do we know how to measure IPM benefits?	Limited	7	**High**	7
C.3	Do we know the best ways to promote farmland tree species and arrangements that provide IPM benefits?	Negligible	33	**High**	7
C.4	Do useable resources exist to guide the use of trees to promote IPM?	Negligible	33	**High**	13
C.5	Do farmer-led research or demonstration sites exist to test and explain the implications of farmland trees for IPM?	Limited	33	**High**	20
C.6	Do we understand how voluntary initiatives and government regulation can best be used to promote the use of trees to provide IPM on farms?	Limited	33	Moderate	13

Abbreviation: IPM, integrated pest management.

which most closely aligned to their area of expertise, 22% (8) were from research sectors, while others were aligned with policy (2), industry (1) or conservation organisations (4). We analysed the participants survey responses using the scoring system defined in the methods section to identify the themes this group perceived to be insufficiently studied (negligible or limited existing knowledge) and where there was a moderate to high priority for further research (Table 2).

A preliminary report summarising the survey results was circulated to the participant group, which included their comments, references and links to relevant open-access resources (Data S1). No further additional comments were received from the survey participant group during the second round in the consultation process.

Participants' scores and comments were used to assign the questions into three sections illustrated in Figure 2 and Table 2, and these were considered alongside published information to develop the background context, therefore incorporating views of the group of participants who responded. The first section addresses the component elements relevant to our overarching question, focusing on

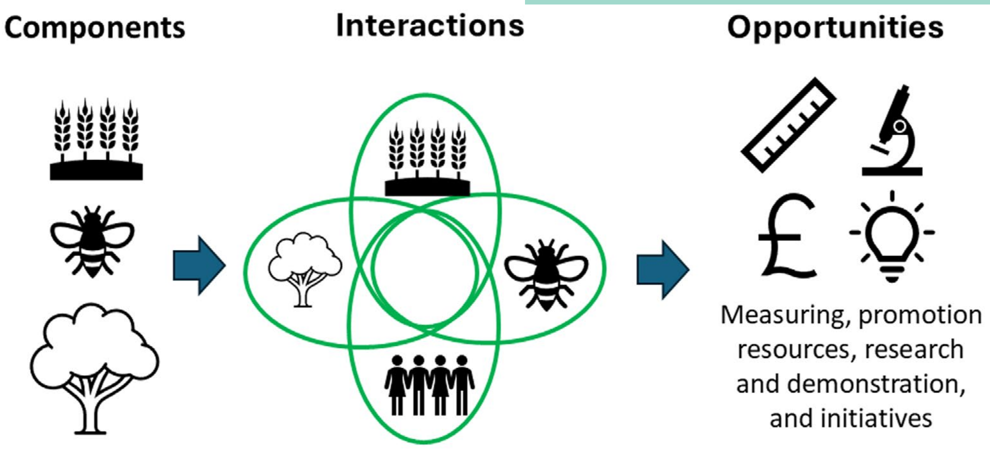

FIGURE 2 Conceptual framework illustrating the three core topics in scope of this literature review —(i) components (crops, invertebrates and trees with their spatial arrangements), (ii) interactions (how these components interact with management practices) and (iii) opportunities (strategies for measurement, promotion, resource optimisation, research, demonstration and new initiatives).

tree species and layout (Table 2; A.1 and A.2) and significant natural enemies of pests (Table 2; A.5). The second section examines the interactions between trees, pests, beneficial invertebrates and management practices (Table 2; B.1–B.7). The final section explores questions related to monitoring, promotion and regulation (Table 2; C.2–C.6).

4 | DISCUSSION

4.1 | Components: Trees, pests and beneficial invertebrates

4.1.1 | Farmland trees: Distribution and composition

Our survey highlighted that the distribution and composition of farmland trees are relevant to current investigations and limited knowledge exists (Table 2; A.1 and A.2). Farmland trees can be classified as either Woodland Trees (WT) or Trees outside Woodlands (ToW) (Table 1). Hill et al. (2017) refined methods for estimating tree abundance and distribution within Great Britain's woodlands, utilising resources from the Sylva Foundation Suite (Sylva Foundation, 2023) and Oxford University Research Archive (Hill, 2016). The European Agroforestry Federation has also recently reviewed methods for classifying tree cover in Europe (Lawson et al., 2024).

More recently, Forest Research's Earth Observation for Trees and Woodlands (EOTW) project identifies tree canopy cover outside the National Forest Inventory. In England, trees outside woodlands have been mapped, showing that these trees make up nearly a third of the nation's tree cover (Hunter et al., 2025). It categorises trees (over 3 m tall, covering an area of 5 m^2) into lone trees, groups of trees and small woodlands, using lidar, Sentinel-2 imagery and OS mapping. Brewer et al. (2017) reported that in England and Wales, such trees occupy an area of 658,000 ha or 28.5% of the total tree cover in 2016, comprising small woods (14.9%), groups of trees (9.8%) and lone trees (3.8%) (Figure 3). Regarding linear features, maps combined with LiDAR data collected between 2016 and 2021 estimate 390,000 km of hedgerows up to 6 m tall and 185,000 km above 6 m tall, the latter include mature hedgerow trees (UKCEH, 2024).

In Great Britain, resources such as the National Inventory of Trees in England and Wales (Forestry Commission, 2001, 2002) indicate that 93%–95% of trees outside woodlands are broadleaf, with ash (*Fraxinus excelsior* L.) and oak (*Quercus robur* L.) being the most common species. Hawthorn (*Crataegus* spp.) and blackthorn (*Prunus spinosa* L.) dominate two-thirds of British hedges (Montgomery et al., 2020). In the past, comprehensive information on managing farmland trees and shrubs has been more limited. Carey et al. (2008) noted a 6% reduction in managed hedgerow length in Great Britain from 1998 to 2007, with many transforming into lines of trees and relict hedges.

4.1.2 | Arable invertebrate pests and natural enemies

Trees on farms support IPM strategies by reducing pesticide drift (Ucar & Hall, 2001) and acting as sentinels in pest surveillance (Morales-Rodríguez et al., 2019; Way & Cammell, 1982). Here, we focus on their role in providing resources for invertebrate natural enemies that forage in adjacent crops (Iuliano & Gratton, 2020), in response to comments by survey participants who highlighted the need for a comprehensive source of information on the interactions of pests and their natural enemies in arable systems (Table 2; A.5). The lack of information about natural enemies in arable crops contrasts with horticultural crops, where decades of research have developed mass-reared predators and parasitoids. In the orchard and fruit-growing sectors, native natural enemies are considered an integrated solution for pest control, though participants commented that their biology and interactions in these systems are still not fully understood.

Survey respondents reported some existing knowledge of invertebrate groups which are key economic pests (Table 2; A.3). An

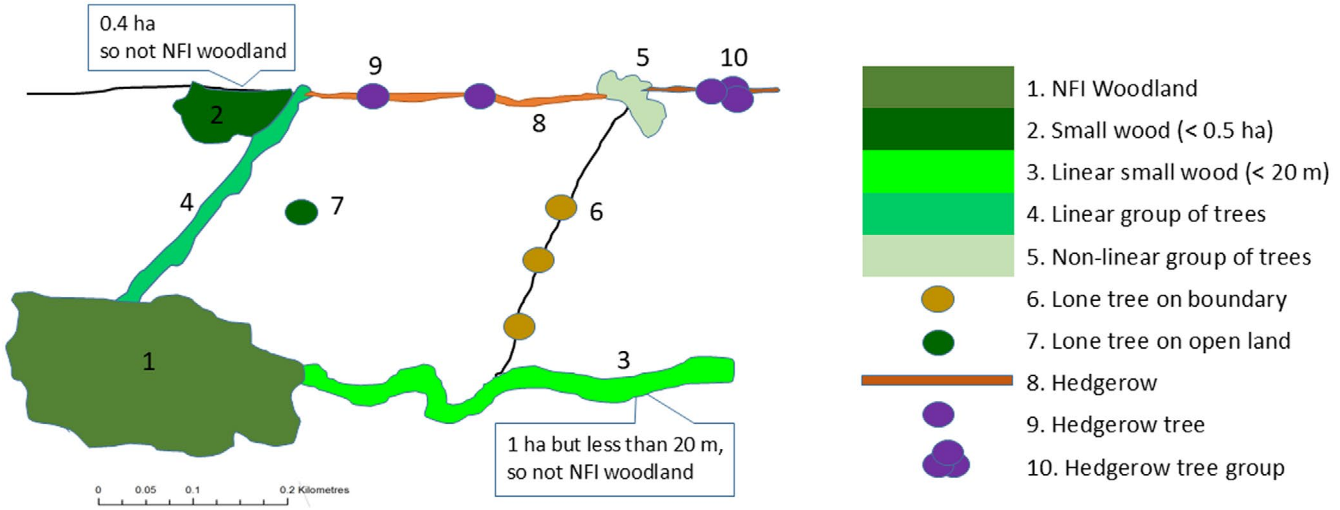

FIGURE 3 Farmland trees exist in a range of forms beyond woodland, as defined by the National Forest Inventory (NFI), including lone trees and hedgerow trees, linear groups and small woods.

example includes a study by Lamichhane et al. (2017) which identifies common priority pests of field-grown crops, ranked by order of importance at the European level. However, ongoing research is needed because pest control requirements may vary with new crops, the arrival of new invasive species, or increasing threats from minor or endemic pests as climate and associated factors change over time (Mumford et al., 2017; Skendžić et al., 2021). Regional threats from pests and diseases are available online via national plant health risk registers and databases supported by national and regional plant health authorities (e.g. DEFRA, 2024b; EPPO, 2024; Ministry for Primary Industries, 2024; USDA APHIS, 2022). Additionally, long-term datasets, such as the Rothamsted Insect Survey (RIS, 2022), offer national resources for developing and testing models to forecast and evaluate pest management options under changing conditions (Redhead et al., 2020; Webb et al., 2023).

IPM solutions typically seek to complement crop pest control activities by promoting wild predatory and parasitic invertebrates present in cultivated landscapes (Daniels et al., 2017; Losey & Vaughan, 2006). Information on conservation biological control for pest suppression can be obtained via the BioProtection Portal, where users can seek details on biological control agents by entering pest location and cropping system (CABI, 2024a). With relevance to field-grown crops, the Agriculture and Horticulture Development Board's 'Encyclopaedia of pests and natural enemies in field crops' provides efficacy data on specialist and generalist natural enemies (Data S2; AHDB, 2021). An IPM online tool provide by the National Farmers' Union provides one of the few resources that support the development of IPM strategies tailored for use on arable and pasture farms (NFU, 2023). However, the economic benefits and trade-offs associated with practices to conserve and integrate natural enemies into crop protection remain underexplored (Tamburini, Bommarco, et al., 2020), potentially hindering the adoption of new IPM methods.

Identifying key invertebrates associated with farmland trees that benefit arable crop protection is challenging due to the dynamic nature of these systems (illustrated in Figure 4), (Begg et al., 2017; González et al., 2022; Tscharntke et al., 2016). Advances in conservation biocontrol methods are addressing these complexities, providing valuable data such as dispersion distances for tree-associated natural enemies, which can improve pest management (Boller et al., 2004; Staton et al., 2019, 2021a). Enhancing pest control during vulnerable crop phases involves promoting diverse natural enemy guilds with different hunting strategies (Greenop et al., 2020; Woodcock et al., 2016).

Recent advances in artificial intelligence, molecular technologies and remote sensing (e.g. radar, LiDAR, high-resolution drone imagery) are revolutionising field-based surveillance and providing new methods to monitor pest and natural enemy abundance, movement and behaviours in agricultural systems (Badirli et al., 2023; Besson et al., 2022; Høye et al., 2021; Rhodes et al., 2022). These technologies are crucial for supporting integrated modelling systems that account for interactions between natural enemies, agricultural yields and landscape composition. This approach will significantly enhance our ability to demonstrate and optimise the impact of natural enemies on food production and profitability across diverse management practices and environmental conditions (Sponagel et al., 2025).

4.2 | Interactions between trees, pests, beneficial invertebrates and management practices

4.2.1 | Field-scale: Ecological associations

A number of studies have investigated the role of adjacent semi-natural vegetation, field margins and intercropping systems in conserving natural enemies for crop pest suppression (Bianchi

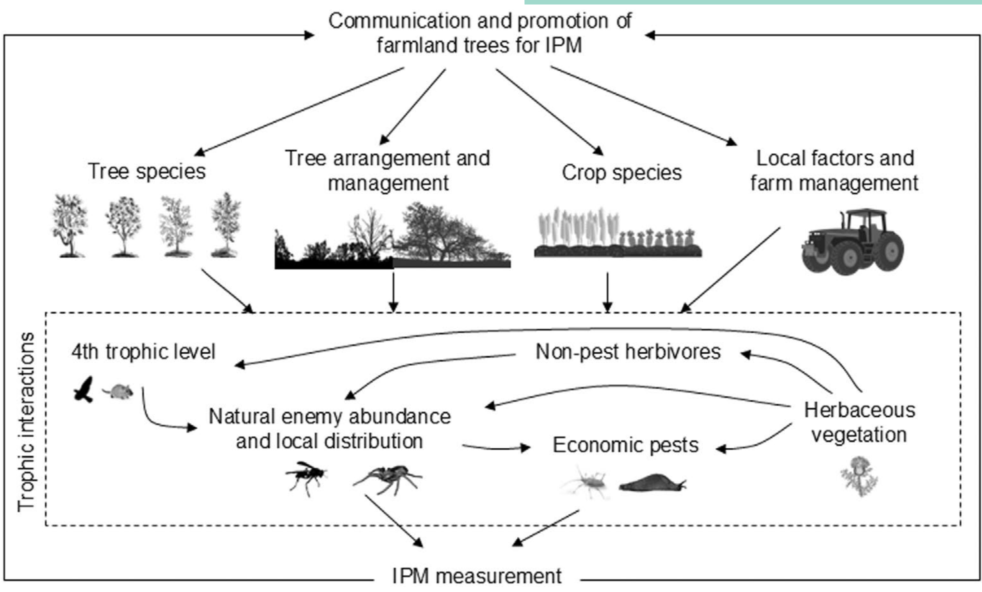

FIGURE 4 Illustrative summary of the key components, interactions and need for measurement and promotion of farmland trees for IPM (adapted from Staton et al., 2019). IPM measurements depend on complex community interactions (dashed box), which in turn depend on farm planning and management. Effective communication and promotion of farmland trees are crucial for successful IPM.

et al., 2006; Haaland et al., 2011; Wolz et al., 2018). However, survey participants commented on the lack of detailed ecological studies that link temperate farmland trees with natural enemy taxa that prey on economically important pests in adjacent crops within temperate climates (Table 2; B.1 and B.2). They regarded this knowledge as essential for a broader analysis, linking tree species with pest suppression at farm level.

An initial examination of the availability of published literature detailing interactions between 15 widespread native trees and shrubs and arthropods in Web of Science revealed that woody perennials are underrepresented in research on natural enemies and crop pests, with studies on 'pests' more frequently focusing on tree pests (Table 3; Data S3). Notably, a paucity of studies on species such as blackthorn (two studies), one of three of the most common species found in hedges across the British mainland (Dover, 2019) suggests there is a need for more research to help define how arthropods interact with this species. In contrast, other common hedgerow species such as hawthorn, hazel (*Corylus avellana* L.) and common elder (*Sambucus nigra* L.) appear to be more often studied in this context, with a total of 23 studies (Bennewicz & Barczak, 2020; Lee et al., 2015; Peñalver-Cruz et al., 2020; Wojciechowicz-Zytko & Jankowska, 2016), in addition to iconic species such as English oak (9 studies) (Ekholm et al., 2020, 2021; Van Dijk et al., 2022).

Online sources, such as the national plant health risk register, offer insights into tree species that host invasive arthropods (e.g. DEFRA, 2024b). CABI's Compendium of Invasive Species (CABI, 2024b) offers detailed insights into hedge species like the Spindle tree (*Euonymus europaeus* L.), commonly used as a sentinel species to monitor aphid and natural enemy populations in central and eastern England's field crops (Way & Cammell, 1982). Conversely, we found that information on tree hosts of key natural enemy groups (Coleoptera, Arachnida, Diptera, Homoptera and Hymenoptera) is not readily accessible due to the lack of dedicated online resources. This gap may pose challenges for non-research users seeking to identify tree species that support natural enemies of agricultural pests, which contribute to effective crop pest suppression.

Survey participants also noted that certain tree species can harbour arthropod groups associated with crop damage (e.g. *Aphididae*, *Drosophila suzukii* Matsumura) and livestock disease (e.g. *Culicoides* spp.). Kletty et al.'s (2023) systematic review of silvoarable systems' impact on biodiversity indicates evidence of disservices that tree planting may have on pest abundance. For example, agroforestry systems tend to have higher slug densities than arable fields, likely due to higher soil moisture levels (Burgess et al., 2003; Staton et al., 2021a, 2021b). Additionally, farmland trees can harbour crop pests and bacterial diseases such as canker and fire blight (Dailey O'Brien, 2017; Staton et al., 2024). Understanding these trade-offs is crucial for maintaining stable species mixes that provide pest-control services beyond tree lines (Barczak et al., 2014). Recent models, integrating expert opinion and field data, have demonstrated the potential to understand these trade-offs in silvoarable systems (Tosh et al., 2024). However, given their longevity, diversifying tree species to adapt to changes in natural enemies, pests and new crops may be a secondary factor when selecting a climate-resilient species mix (Broadmeadow et al., 2005).

Understanding how natural enemies move from tree habitats to crops and their impact on ecosystem services is crucial for precision farming in IPM (Saunders & Luck, 2014; Stafford, 2000; Woodcock et al., 2016), yet quantifying spillover for pest control remains poorly defined (Bailey et al., 2014; Morandin et al., 2014; Saunders & Luck, 2014). Boller et al. (2004) categorise natural enemies into two groups to illustrate the link between functional infrastructure and cropping area based on their 'operational distance', indicating

TABLE 3 Publications on farmland trees' associations with (a) arthropods, (b) pests and (c) natural enemies, aiming to identify the overall supply of natural enemies and pests from trees, with (d) additional specific search terms for agricultural settings.

Tree or shrub species[a]	Number of publications describing			
Tree or shrub	(a) Association with all invertebrates, Search term: {English OR Latin names of tree} AND (arthropod* OR insect* OR invertebrate*)	(b) Association with pests, Search term: As (a) AND ("pest*" OR "herbiv* insect*")	(c) Association with natural enemies, Search term: As (a) AND ("natural enem*" OR "predator*" OR "parasitoid*")	(d) Association with arable pests or natural enemies[b]: As (a), (b) and (c), AND ("agricultur*" OR "arable" OR "farm*" OR "crop*")
English oak, Pedunculate oak, *Quercus robur* L.	395	87	52	25 (9)
Common beech, *Fagus sylvatica L.*	308	39	39	19 (6)
Silver birch *Betula pendula* Roth	250	41	20	9 (2)
Hawthorn, common hawthorn, *Crataegus monogyna* Jacq.	241	46	24	21 (14)
Black alder, common alder, European alder, *Alnus glutinosa* (L.) Gaertn.	169	22	11	9 (3)
Hornbeam, common hornbeam, *Carpinus betulus* L.	115	16	18	7 (4)
Common ash, European ash, *Fraxinus excelsior* L.	114	27	14	7 (5)
Common hazel, *Corylus avellana* L.	68	30	11	12 (9)
Common elder, European elder, *Sambucus nigra* L.	59	23	9	20 (9)
Small-leaved lime, *Tilia cordata* Mill.	55	10	4	5 (2)
White poplar, *Populus alba* L.	55	19	2	4 (2)
Blackthorn, sloe, *Prunus spinosa* L.	41	5	2	4 (2)
Goat willow, *Salix caprea* L.	39	6	5	0
Common spindle, *Euonymus europaeus* L.	18	1	0	0
Field maple, *Acer campestre* L.	11	2	1	1 (1)

Note: Conducted using Web of Science (core collections), using Boolean terminology on 19 November 2024 (Data S3).

[a]15 representative common native tall trees, small trees and woody shrubs found on farmland across England and Wales, selected on the basis of abundance (Dover, 2019). We include one widespread, naturalised species *P. alba* (Woodland Trust, 2024).

[b]The number in parentheses represents the actual number of publications relevant to tree host, pest or natural enemies and agricultural landscapes.

habitats within 100 m suit flying or wind-borne species (e.g. syrphids, parasitoids and some mites, spiders and predatory beetles), while distances of 100–500 m may reduce effectiveness for short-range dispersers, affecting seasonal distribution and species richness (Knapp et al., 2019). The ability and scale of movement of natural enemies, spatially and temporally, has become increasingly important in efficacy studies which aim to quantify the control of arable pests (Clobert et al., 2012; Shepard et al., 2013; Stephens et al., 2007).

4.2.2 | Farm-scale: Impact of tree layout, tree management and farm management on pest control services

At farm and field scale, many studies emphasise the importance of vegetation management within IPM for controlling arable pests (Franks et al., 2016; Haaland et al., 2011; Holland et al., 2013), although our survey results indicate that this remains a priority research area (Table 2; B.3 and B.4). Hedgerows, protected from insecticides and tillage, serve as refuges for beneficial insects, providing food sources and alternative prey (Montgomery et al., 2020). Structural and floristic diversity of hedgerows benefits invertebrate diversity and certain natural enemy groups (Garratt et al., 2017; Wolton et al., 2014), with frequency and timing of management practices such as hedge cutting playing a key role in determining their diversity (Staley et al., 2012, 2016).

The structure of field-boundary trees and shrubs can influence the distribution of aerial invertebrates (Holland et al., 2016, 2021). Graham et al. (2018) identified that height, width, woody biomass, nativeness, foliage quality, age structure, branching architecture and hedgerow continuity can impact the abundance, survival or fecundity of associated taxa. Amy et al. (2015) also found herbivores and predators' abundance was influenced by foliage density, while detritivore abundance correlated with hedge gap size.

Edge density of tree formations, i.e. the length of edges along treed habitats within a given area, is reported to impact natural enemy abundance and their ability to suppress crop pests (Bianchi et al., 2006; Burgess et al., 2003; Staton et al., 2021b). In an analysis of 49 studies from European agricultural landscapes, natural enemies which overwinter in non-crop habitats responded positively to high edge densities, in contrast to natural enemies that overwinter in cropped habitats (Martin et al., 2019). High edge densities also increased pest suppression and reduced pest abundance (Martin et al., 2019). The benefits of fine-grained landscapes with high edge densities are attributed to spillover effects from overwintering habitats, where natural enemies and associated pest control services disperse into adjacent farmed areas (Albrecht et al., 2020; Garratt et al., 2017).

Survey respondents pointed out the need for studies to address how farm management practices impact invertebrate-tree interactions, which could contribute to the observed heterogeneity in natural pest regulatory ecosystem services (Table 2; B.7; see Kletty et al., 2023; Staton et al., 2019). A common theme was the application of synthetic insecticides, with evidence that certain classes can detrimentally affect the activity of natural enemies, including lethal or sublethal effects (Sánchez-Bayo, 2012), as well as inducing behavioural avoidance responses (Singh et al., 2001, 2004; Thornham et al., 2007). The sensitivity to pesticides, however, differs among natural enemy species (Greenop et al., 2020; Guedes et al., 2016) and across diverse agroecological systems (Boinot et al., 2020; Gagic et al., 2019; Ricci et al., 2019). While the impacts of pesticide drift on surrounding invertebrate populations are relatively well documented (Gagic et al., 2019), it is apparent that more field studies would enhance our understanding of the resilience and recovery rates of natural enemy populations following management interventions (Beers et al., 2016).

Management interventions such as crop fertilisation and increasing investment in agrobiodiversity can also influence crop pests and their natural enemies (e.g. Albrecht et al., 2020; Tamburini et al., 2016). A broad study across different regions and farming systems shows that diverse flower mixes enhance natural pest control in adjacent fields (Albrecht et al., 2020). This suggests that managing and restoring perennial floral plantings can boost pest regulatory services by providing high floral diversity for beneficial arthropods. However, few studies explore the benefits of healthy soils for perennial hosts, such as trees and shrubs supporting natural enemies at the periphery of arable crops. While nitrogen accumulation in soils can reportedly harm pollinators (Stevens et al., 2018), certain fertilisers may benefit some natural enemy taxa (Garratt et al., 2011).

In accordance with IPM principles set out by the EU Directive (European Commission, 2009), the strategic application of effective pesticides remains an essential option in reducing economic losses due to pest and disease damage. There is a critical need for a suite of target-specific compounds that are compatible with the life stages and foraging behaviours of both beneficial and non-target organisms. To address the variability in the abundance and efficacy of natural enemies in suppressing crop pests, it is essential to investigate and optimise spatial and temporal farm management practices to mitigate negative impacts. Balancing product selection, application frequency and enhancing agroecological conditions is key to supporting the resilience and stability of predator and parasitoid populations in farmland trees.

4.2.3 | Landscape-scale: Distribution and resilience of pest regulatory services under climate change

Associations between insects and their tree hosts can be impacted by a range of factors beyond those imposed through tree arrangement and farm management measures (Table 2; B.3–B.6), potentially affecting the quality and flow of pest regulation services for IPM. Studies have assessed the distribution of semi-natural habitats in order to evaluate the impact on the abundance of beneficial organisms and the effectiveness of pest control (Alignier et al., 2014; Hatt et al., 2018). Strategically arranging trees in linear corridors or as 'stepping stones' can amplify their impact on pest control by connecting functional habitats with arable fields. Studies have provided evidence that enhancing agricultural landscape diversity increases the abundance and diversity of natural enemy groups (Marshall, 2004; Marshall et al., 2006), although gaps remain in demonstrating how this relates to reduction in pest damage in adjacent crops (Tscharntke et al., 2016).

For farmland trees to effectively promote IPM, the phenologies of natural enemies must align with tree resource availability and coexist with arable pests both spatially and temporally. Otherwise, the effectiveness of trees in IPM strategies will be diminished (Ramos Aguila et al., 2023). The development of innovative tools to map and predict biodiversity supported by farmland trees at a regional scale represents a significant advancement in ecological research (Harrison et al., 2021). Nevertheless, the accuracy of these tools in forecasting natural enemies of crop pests at catchment or farm levels remains to be validated.

The dynamic nature of ecosystems, especially under the influence of climate change and human actions, calls for long-term studies into the resilience of trees to pest pressure, to ensure a sustainable IPM framework in the broader agricultural landscape (Baker et al., 2000; Panzavolta et al., 2021). Abiotic and biotic factors can affect host-insect level interactions through diminishing or enhancing the availability or suitability of the host plant. Soil properties, hydrology, aspect and elevation are reported to alter plant-tissue chemistry (Karolewski et al., 2013; Pichersky & Raguso, 2018) and morphology, food-reward attractiveness and 'host apparency' (Zverev et al., 2017).

Frameworks that demonstrate the current and predicted geographic range shifts of multiple taxa have been adopted for conservation assessment (Natural England and RSPB, 2019), explaining the vulnerability of species and species groups associated with specific habitat types studied in the UK (Pearce-Higgins et al., 2017). Additionally, climate-suitability analysis has been extended to predict where invasive forest insect species may expand their range and threaten tree hosts (Venette, 2017). However, there is a concern that the predicted climate distribution matches of pests with their natural enemies may be jeopardised if the populations of the latter fail to establish successfully due to other factors such as asynchrony (Fischbein et al., 2019). Developing and validating models to understand interactions among trees, crops, pests and natural enemies at multiple scales remain an important area of research to answer questions on the role of farmland trees in IPM.

4.3 | Monitoring, promotion and regulation

4.3.1 | Measuring IPM benefits for trees

In this study, participants highlighted the need for a comprehensive system-based approach in IPM to evaluate the role of trees in pest control (Table 2; C.2). Johnson et al. (2021) also note that few studies address crop-related outcomes or economic impacts. Creissen et al. (2019) proposed a framework to capture multiple IPM activities simultaneously. Multi-attribute, flexible metric frameworks can be adjusted based on expert opinion, reflecting the spectrum of IPM adoption across farming practices and locations, potentially including components such as farmland trees.

The availability of data remains a significant limitation in measuring and evidencing the beneficial effects of semi-natural habitats on biological control (Holland et al., 2016). The reliability of using natural enemy abundance or diversity as proxies for natural pest control has been questioned, given the context-dependent nature of these relationships (Jonsson et al., 2017; Perović et al., 2018; Tamburini, Bommarco, et al., 2020). Consequently, recent research has shifted towards a trait-based approach, finding that the diversity of functional traits among natural enemies is a more robust predictor of pest suppression (Jonsson et al., 2017; Perović et al., 2018; Tamburini, Santoiemma, et al., 2020). Combining single-trait identities and multi-trait complementarity offers greater explanatory power for ecosystem functioning than traditional taxonomic approaches (Gagic et al., 2015). For instance, Greenop et al. (2018) demonstrated that functional trait diversity of natural enemies was the best predictor of prey suppression in a meta-analysis of mesocosm experiments. Trait-based approaches can also enhance our understanding of how farmland trees influence pest management needs (Staton et al., 2021a). Developing a trait-based approach could establish a predictive framework for the effects of farmland trees on pests. However, intraspecific trait variability in trees, which could be crucial for plant-insect interactions, has received little attention.

Advancements in techniques and technologies are broadening the scope for accurately assessing the effectiveness of natural enemies in IPM settings. For instance, the use of sentinel prey, such as live, dead or artificial prey, enables detailed quantification of predation or parasitism rates (Chisholm et al., 2014; Howard et al., 2024; Lövei & Ferrante, 2017), although the effectiveness can vary by the type of sentinel used and the predator species involved (Greenop et al., 2019; McHugh et al., 2020; Nagy et al., 2020). Exclusion methods compare pest levels with and without natural enemies, but applications are often labour intensive and have practical difficulties (Chisholm et al., 2014). Additionally, molecular methods provide a sophisticated means of analysing the diets of natural enemies, thereby pinpointing their roles within IPM frameworks (Furlong, 2015). On a larger scale, precision monitoring of tree cover on farmlands could refine evaluations of how trees contribute to IPM, offering insights into potential yield benefits from microclimate moderation (Redhead et al., 2020), while also considering the trade-offs due to resource competition (Ivezić et al., 2021). These developments highlight the complex but critical nature of optimising IPM strategies to balance ecological benefits with agricultural productivity.

4.3.2 | Regulation and initiatives to promote trees for IPM

The EU set the IPM agenda in Europe, mandating all member states should adopt IPM strategies by January 2014 through the Sustainable Use Directive (European Commission, 2009). The Common Agricultural Policy (CAP) and the Farm to Fork and Biodiversity initiatives aim to support a 50% reduction in pesticide use by 2030, and promote sustainable agriculture practices (European Commission, 2009, 2020; TEEB, 2018). In England, the Environmental Land Management (ELM) strategy aligns with the EU vision, setting out a pathway to enhance biodiversity and minimise pesticide use (Gov.UK, 2023b). Specifically, the Sustainable Farming Incentive (SFI) schemes implemented between 2022 and 2025 included several key actions to support the voluntary uptake of IPM (DEFRA, 2024a, 2025). Within this framework, farmers were encouraged to develop IPM plans with qualified advisors (BASIS, 2024; The Voluntary Initiative, 2024b) to establish habitats for natural enemies and pollinators through establishing flower-rich grass margins, blocks or strips, to plant companion crops, and avoid or limit the use of insecticides (DEFRA, 2024a, 2024b; Gov.UK, 2024).

While industry advocates for incentivising farmers to adopt IPM, with progress tracked and biological crop protection solutions defined in national legislation (IBMA, 2021), inconsistencies in the methods to monitor the effectiveness of these efforts across the EU or the UK remain a challenge (Helepciuc & Todor, 2022).

At present, there are substantial national and international initiatives to increase the rate of tree establishment, such as the Nature for Climate fund in the UK dedicating over £500 million to tree planting and management (Gov.UK, 2021) and the EU Biodiversity Strategy for 2030 aiming to plant three billion more trees across the EU by 2030 (FISE, 2022). In England, various incentive schemes support woodland creation, agroforestry systems and the planting of farmland hedge shrubs and trees (Gov.UK, 2025b, 2025c, 2025d), with regulations in place to protect existing trees and hedgerows on farmland (Woolford & Jarvis, 2017). However, developed guidelines tend to lean towards the role of hedgerows or trees as providers of biodiverse habitats for woodland and farmland species rather than focusing on the contribution to farm IPM (Gov.UK, 2025a).

Survey participants emphasised the importance of effectively communicating the commercial viability and reliability of IPM innovations to enhance their adoption (Table 2; C.3–C.5). Assessment toolkits were highlighted as essential for integrating tree benefits into IPM, allowing for pest control scenarios by adjusting layout, species and tree management based on pest traits. This aligns with a consultation by Walters et al. (2024), where 130 UK stakeholders recommended enhancing IPM knowledge exchange through diverse methods, including decision support tools, professional training, demonstration farms and farm-to-farm engagement hubs. Recommendations included the need to integrate trees into IPM strategies and called for a national action plan to coordinate efforts (Walters et al., 2024). Significant advancements in creating accessible toolkits for IPM in field crops include the IPMWORKS Resource Toolbox and online self-assessment platforms (IPMWORKS, 2024), developed through partnerships with ADAS, NFU, SRUC and the Voluntary Initiative (NFU, 2023).

The implementation of IPM practices must also consider future climate compatibility (Roncoli, 2006), informed by a co-design and participatory approach (Lamichhane et al., 2018). Our survey group emphasised the importance of local knowledge in developing analytic tools to measure IPM benefits (Data S1, C.2). In this context, demonstration sites are highly effective for facilitating knowledge exchange and the adoption of conservation practices, especially when well funded (Singh et al., 2018) (Data S1, C.5). In England and Wales, demonstration farms serve as crucial links between research and practical application (AHDB, 2024). The LEAF partnership in the UK established demonstration farms and research centres to promote IPM using environmental self-audit tools (LEAF, 2024). A large network of demonstration farms in Europe, coordinated by IPMWORKS (2024), also aims to expand its network of farms, representing 26 countries across the EU and the UK. This project seeks to standardise successful IPM strategies, reporting management details, pesticide use and profitability, with the goal of halving pesticide use in European agriculture by 2035.

Few resources explicitly address the crop protection benefits of farmland trees. The Soil Association's UK Agroforestry Handbook is a notable exception, providing non-experts with methods to reduce pest competition by integrating trees into farm landscapes (Raskin & Osborn, 2019). Earthwatch Europe's report highlights the economic and sustainability benefits of tree planting in agriculture but calls for further research to enhance environmental impacts (Cardenas et al., 2021). Recently, Natural Resources Wales has developed guidance on managing natural resources, including the Ancient Woodland Inventory and the National Survey for Wales (Natural Resources Wales, 2020).

While promoting biodiversity in natural and agricultural settings is on the political agenda, there is an opportunity to increase the prominence of IPM principles through higher education curricula. However, the eight principles of IPM currently overlook the social and economic dimensions of implementation and the organisation of farm advisory services (Deguine et al., 2021). Effective IPM deployment depends on these non-technical factors, including economic conditions, social contexts of farmers, the efficacy of advisory services and collaborative multi-actor strategies, all of which require greater focus.

Addressing critical areas highlighted by our expert group, we emphasise the complexity of socioeconomic, environmental and ecological factors in future research to quantify trees' contributions. With increased attention on ecological and tree distribution at all scales, the valuable services provided by farmland trees can be measured, sustained and enhanced, reducing chemical pest control reliance and boosting productivity. This will enable growers to adopt more sustainable agricultural practices, reduce reliance on chemical pest control and potentially increase land productivity. Research to understand how incentive schemes and private financial mechanisms can support land management for increasing benefits from tree-natural enemy associations for crop protection will markedly increase the understanding and implementation of IPM on arable farmland (Grigoriadis et al., 2023). Given the interest in planting trees across European farmland for pest control, increased investment in optimising these services for IPM would be well justified.

5 | CONCLUSIONS

'Can farmland trees contribute to IPM strategies in agricultural landscapes?' We adopted a participatory approach to this broad question in light of the complex interactions in delivering multiple ecosystem services (Fagerholm et al., 2012; Jacobs et al., 2015; Krueger et al., 2012), specifically associated with integrating trees within IPM frameworks (Ambrose-Oji et al., 2022; Blanco et al., 2020; Brown et al., 2022). Individual trees and tree configurations, such as windbreaks and hedges, provide critical seasonal resources for beneficial arthropods, offering food, shelter and sites for reproduction. Advances in remote sensing technologies, including satellite imagery, aerial photos and drone data, have greatly improved the mapping and management of trees across landscapes (Hunter et al., 2025). Advanced mapping tools and modelling systems are now enabling assessment of management strategies at field, farm and regional scale (Burgess et al., 2019; Harrison et al., 2021; Schneider et al., 2023; Suprunenko et al., 2021). However, despite the availability of tools for assessing trees and ecosystem services (Ecosystems Knowledge Network, 2024; European Commission, 2023; Smith et al., 2021), there remains a significant gap in technologies specifically designed to evaluate the interactions between farmland trees and IPM. Developing effective decision support tools will require further research and validation, with sustained financial investment in both foundational research and practical applications.

Demonstration farms, established through academia–industry partnerships (e.g. LEAF, 2024), are considered important for showcasing sustainable agriculture practices and innovative farming techniques. These farms serve as real-world examples where growers and researchers can form collaborations to address practical and economic challenges that can hinder the adoption of IPM strategies (Walters et al., 2024). Furthermore, these interactions offer a platform to disseminate future research investigations to qualify and quantify the role of trees as integral elements of IPM systems. Promoting the economic and environmental benefits of IPM delivered by trees on arable farmland will lead to the development of farming systems that are more adaptable to climate variations and environmentally sustainable.

AUTHOR CONTRIBUTIONS

The project was led by researchers from the Royal Botanic Gardens Kew, Royal Agricultural University, Cranfield University and Imperial College London. All authors contributed to the development of the stakeholder's questionnaire, the analysis of the responses received and the dissemination of the initial responses to contributing participants. Authors contributed equally to reviewing the relevant literature and the editing of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no competing interests associated with the manuscript.

DATA AVAILABILITY STATEMENT

The initial report compiled to disseminate the stakeholder-elicitation results and comments to contributing participants is available in the supporting information (Data S1).

DISCLAIMER

The views expressed in the paper are those of the authors, and they do not necessarily reflect the views of the funding agency or the affiliated institutions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1. IPM & farmland trees: Survey analysis & dissemination.

Data S2. Table 1 showing high level summary of the potential interactions between pests and natural enemies (AHDB, 2024).

Data S3. Scoping literature (Section 4.2.1).

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