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RESEARCH ARTICLE OPEN ACCESS

Growers' Attitudes Towards and Experiences of the Soil Microbiome and Soil Inoculants in the UK: Key Insights for a Developing Research Field

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ABSTRACT

The soil microbiome provides many functions that play an important part in food production. Microbial inoculants are one method of directly boosting specific functions by introducing key microbes, for instance rhizobia—the nitrogen-fixing partners of legumes. However, the use of inoculants is quite variable amongst food growers. Previous research suggests this is largely due to inconsistent results of trials, but such studies typically only focus on growers' experiences at the 'end of the research and development pipeline', i.e., after the inoculants have been developed, packaged and sold on the market. In contrast, this paper investigates how growers' understandings and experiences can be used to shape microbial inoculant research and development. Incorporating insights about grower approaches to, and knowledge of soil microbes is vital for understanding attitudes to inoculation, and should ultimately inform future product development. In this qualitative study, we interviewed 28 UK legume growers (large-scale to medium-scale arable, organic, and dairy farmers, and urban growers i.e., small-scale home gardeners and allotment holders) to understand the different attitudes of participants towards the soil microbiome and soil inoculants. In addition, we also highlight the motivations, practices and assessment techniques that growers use in line with their attitudes as actions towards the soil and explicitly, the soil microbiome. We find that growers have a deep connection to their soil ecology and actively invest their efforts in supporting it through diverse, sometimes creative methods. Interest in inoculants is limited however, with participants overall favouring home-grown approaches to supporting their soil microbiome.

1 | Introduction

The soil microbiome is an integral part of the soil. It plays an important part in food production due to functions such as plant growth and development, nutrient recycling and disease resistance (Schlaeppli and Bulgarelli 2015; Shah et al. 2022). However, agricultural techniques such as excessive inorganic nitrogen fertiliser use have huge negative impacts on the soil microbiome (Beltran-Garcia et al. 2021; Hallin et al. 2009; Huang et al. 2019). These include changes in microbial community dynamics (Hallin et al. 2009) and reduced mutualist cooperation

between plants and microbes (Huang et al. 2019), leading to loss of diversity and associated functions in the long-term.

Microbial inoculants are microbial preparations that can be used as alternatives to chemical inputs to provide nutrients for plant growth and development, control pests and diseases, or as soil enhancers (Babalola and Glick 2012; O'Callaghan et al. 2022; Trabelsi and Mhamdi 2013; Verstraete et al. 2022). Rhizobia are one of the most commonly used bacterial inoculants. Rhizobia fix atmospheric nitrogen in partnership with legumes, which consequently reduces the need for nitrogen

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fertiliser. However, uptake by farmers and growers is variable, particularly where native or introduced rhizobial symbionts are also present (Bell et al. 2019; Denton et al. 2003). This has been explained as being inconsistent in their effectiveness (Bashan et al. 2014; Mukhongo et al. 2016; Omotayo and Chukwuka 2009). Consequently, efforts of both industry and research have focused on improving their efficacy. However, there remains a huge gap in research on understanding the perspectives of the end users on inoculant use and uptake (Catroux et al. 2001; Kaminsky et al. 2019).

To support soil inoculant research, we need more knowledge on growers' existing understandings and practices around the soil microbiome, as well as on their views of the use of microbial products. An understanding of end user perceptions has been shown to be an important pre-requisite for technology transfer as well as the implementation of practices and policies in sustainable agriculture (Liebig and Doran 1999; Petrescu-Mag et al. 2020). For instance, a study on the perceptions of farmers on soil quality found that farmer perceptions were important to design helpful and scientifically accurate on-farm indicators to assess soil quality (Liebig and Doran 1999).

For soil inoculants, previous work has explored farmers' decision-making around the use of inoculants. One study showed six main factors that affected usage; economic advantage, plant yields and health, testability i.e., whether the product had been trialled enough to show evidence of success, compatibility with their farms, uncertainty around using inoculants, and observability of the visible effects (Ploll et al. 2022). Moreover, the difference in communication channels about new innovations also mattered with farmer groups, extension services and traders being seen as the most relevant, and private network and contacts being the least trustworthy (Ploll et al. 2022). Similar attitudes have also been observed towards adoption of Smart Agriculture Technologies (Caffaro et al. 2020; Kernecker et al. 2020). These studies show that barriers to technology adoption by farmers in general include inconsistent results, higher financial and physical investment, and lack of access to trusted information about the products, especially from non-commercial players/stakeholders. Quantitative studies on microbial inoculants also show similar results. Tensi et al. (2022) through their study in the Netherlands and Germany found that trust in technology and positive results from field trials influenced farmers' motivation to use microbial inoculants (Ploll et al. 2022; Tensi et al. 2022). Similarly, capability to acquire knowledge about microbial inoculants can also drive farmers to use inoculants (Tensi et al. 2022). Here, capability was distinguished into psychological and physical capability, where psychological capability is the farmer's knowledge about microbial inoculants and physical capability is the available resources such as machines needed for the application (Tensi et al. 2022). However, lack of support and appropriate information were seen as a barrier to inoculant use (Tensi et al. 2022).

While these studies highlight important results, they are largely focused on what could be described as the end-point of the interaction between growers and inoculants i.e., the decision to use or not use already existing inoculant products. What is lacking is an understanding of the wider context, such as growers' perceptions of microbes and soil biology, and their existing practices of using microbes and soil biology in their farming.

Understanding this wider context is needed in order to design microbial inoculants and products which can support growers' existing development trajectories. Addressing this gap is the objective of this paper.

2 | Methodology

The aim of this study was to explore perceptions and practices around the soil microbiome to better understand the current trends of rhizobial and soil inoculant use amongst farmers and urban growers. To do this, we used a thematic analysis of semi-structured interviews with 28 UK growers about their understandings of, values around and practices associated with microbial inoculant use. The research took place from 2020 to 2023. We specifically targeted legume growers, with the assumption that they may have a richer experience of microbial relations due to the importance of nitrogen-fixing bacteria to legume production and the popularity of rhizobial inoculant products. A pilot test using five participants was initially conducted to fine-tune the research questions prior to the recruitment of participants. A survey was then distributed amongst farmers, urban growers, allotment associations, allotment unions (organisations that manage and promote allotments), and agricultural organisations as a first step to recruit participants. A total of 28 participants were recruited from England, Scotland, and Wales (Figure 1): 13 were urban growers (those who grow food on allotments or in private gardens for consumption and pleasure), 14 were farmers and 1 was a farmer advisor; 53% participants identified as male and 46% as female. The age range of participants was 39–74. Figure 2 shows the composition of the participants and Figure 3 shows the participant type according to farm size. University's Ethics Committee approval was obtained before commencing all recorded activities. The interviews were semi-structured, allowing flexibility to ask questions from pre-set topics but at the same time allowing new sub-themes to emerge.

The interview questions (Appendix S1) sought to understand, firstly, participant interactions with, understandings of, and attitudes towards the soil microbiome, and how these affect participant decisions to use soil inoculants. Secondly, the interviews explored inoculant use by the participants. The resulting interview data (recorded interviews) were transcribed, and the text analysed using thematic analysis (Barbour 2014; Castleberry and Nolen 2018) with the aid of NVivo coding software ((Lumivero 2025) NVivo (Version 13, 2020 R1), www.lumivero.com).

Themes were identified using thematic analysis and they were further investigated based on common sub-themes in interviews such as descriptions, uncertainty and scepticism, challenges and barriers, and knowledge needs.

3 | Results

3.1 | Soil Microbiome

The participants in this study showed a strong appreciation of soil microbes as the foundation of soil functions, providing many benefits to plant growth and overall sustainability. The exchange of nutrients between microbes such as rhizobia,

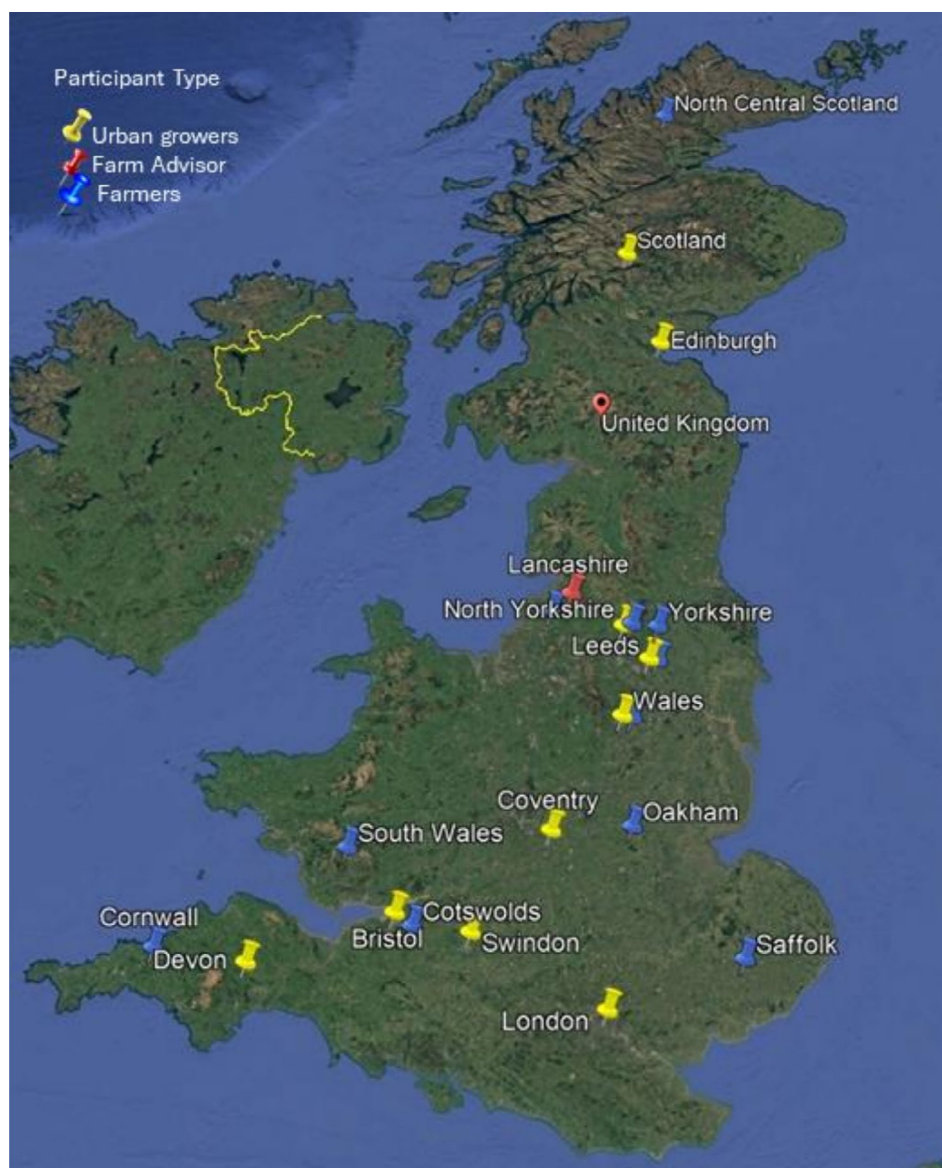


FIGURE 1 | Location of the interviewees across the UK. Yellow pins show the location of urban growers, blue pins show the location of farmers and red pin shows the location of the farm advisor.

mycorrhizae, and plants was frequently mentioned. These symbiotic interactions are also recognised as pivotal for soil health, soil fertility, and plant production by the scientific community (Denison and Kiers 2011; Wangiyana and Farida 2019). Some participants also mentioned other types of interactions such as competition and parasitism, recognising their role in the regulation of ecological processes. As participant 16 states, it 'keeps the soil in the right balance'.

If you can get your biological life right, then I know that will mean a healthy soil ... I guess it's important for helping us up resilience of the plants ... but things like mycorrhiza, how much they can extend the root system ... things like the rhizobium in legumes ... have the right balance ... [including] antagonistic organisms against some of the soil pathogens.

Participant 16 (Urban grower)

However, the use of the term 'soil microbiome' in this study was challenging, as many participants did not differentiate between the soil microbiome, soil health and soil quality. In spite of practical knowledge of soil health assessment, farmers may not feel comfortable discussing their knowledge of soil using concepts such as 'soil microbiome', which are seen to belong more to the world of scientific research.

Interviewer: How important is the soil microbiome to you personally in your farming?

Participant: I don't know? Not directly? Because at the moment, I think that the microbiomes, can we add to them? How do we add them? Is it something by rotation. Is it something by different crops? I don't know. I mean, I'm still [in] early days of learning. But obviously, you and scientists, anybody [need to] to look at the microbiomes and tell us what is right and what's wrong. Participant 3 (Farmer)

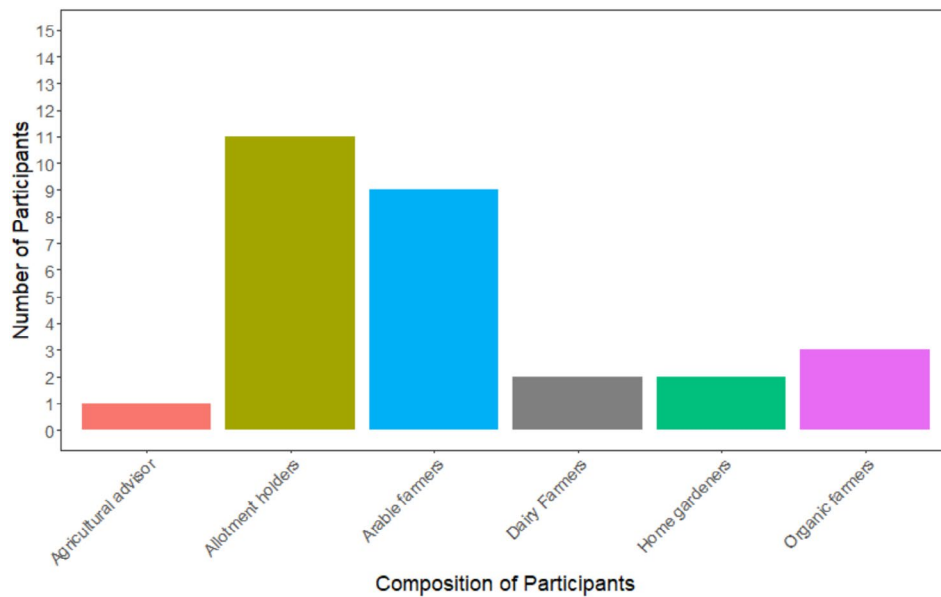


FIGURE 2 | Composition of the 28 participants according to farming type across the UK.

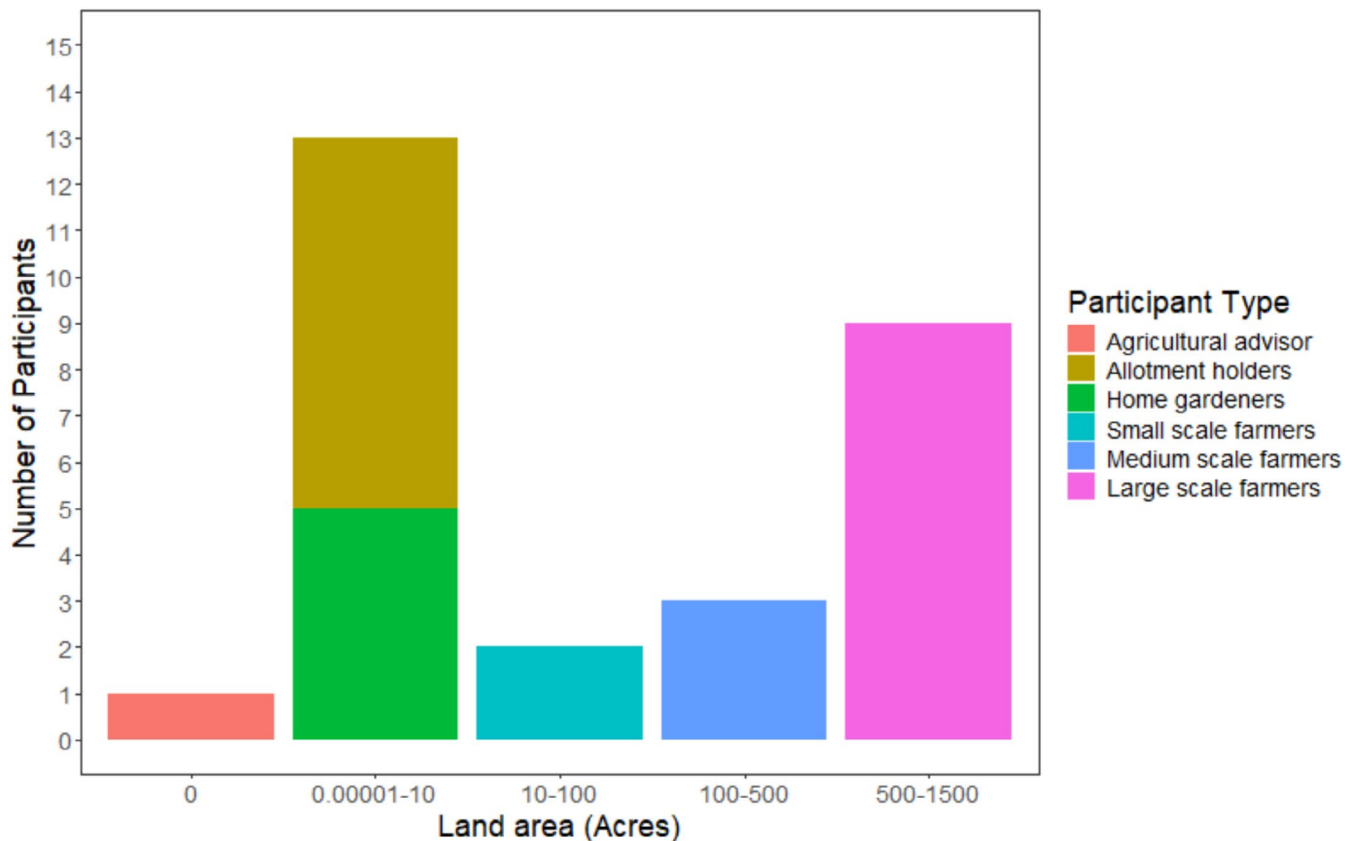


FIGURE 3 | Participant type according to the ownership and amount of land cultivated. The x axis shows the land area in acres divided into five categories. Each category corresponds to participants as follows: 0 to a farm advisor, 0.00001–10 to urban growers (home gardeners + allotment holders), 10–100 to small-scale farmers, 100–500 to medium-scale farmers, and 500–1500 to large-scale farmers. The y axis shows the number of participants in each of these categories.

Uncertainty around whether the soil microbiome was good or bad for the soil, whether it was a product that had to be applied to the soil or whether it could be cultivated using certain practices was quite common. The interpretation was different for

each participant. For instance, Participant 6 describes the soil microbiome as a fundamental unit of existence without which we will cease to exist by drawing out the difference between soil—which can sustain life—and sand—which cannot. She

describes soil as a living system which is capable of propagating itself, but expresses uncertainty around harnessing the soil microbiome for plant production.

There's a lot of bacteria and fungi, and ... things in the soil and ... they all help to create soil ... that's the difference between soil that you find in my field and sand that you find on the beach of the seaside. The sand on the beach is just nearly pure mineral, and nothing grows on that ... And it gets colonised a little by things, and then it gets roots grown in it ... it all self accelerates ... if we can harness the soil microbiome ... it would improve the effective root systems of the plant 100-fold. So, we have to keep trying to do that.

Participant 6 (Farmer)

The appreciation of the role of soil microbes also led some of the participants to critique current farming practices, which were seen to endanger the right balance in the soil ecosystem. For some there was a sense of urgency for this change—i.e., if we did not change our relationship with soils and the soil microbiome, it would be lost, which would negatively affect agriculture. There was a consensus that improving relations with soils by practices such as reducing fertiliser use as well as observing soils physically by touching or smelling them should be of utmost importance. This was seen as crucial for a personal connection or relationship with soils, which would steer off a more balanced soil ecosystem that supports better soil and plant health.

Soil care and soil stewardship were themes that emerged many times during the interviews. Soil care here refers to how humans provide for the soil community so that they repair and continue to maintain the many services it provides such as food production (Krzywoszynska 2016, 2019; Puig de la Bellacasa 2015). It entails personal values, responsibility, and personal ethics of the carer (Neaman et al. 2024; Peçanha Enqvist et al. 2018). The narratives on caring for the soil microbiome brought out that participants connect to the soil microbiome in their own ways. Some treat them as a living organism/pet residing in their home while others see them as positively beneficial for their soils and crops. For instance, Participant 20 describes how they actively cultivate their soil:

I think it's hugely important. And to that end, I even irrigate and water into spaces like polytunnels and greenhouses throughout the year. Because otherwise the soil will dry and various things will die. I use a lot of mulches. I use tree leaves and seaweed, things that I can get, I put on the soil. So, my soil is actually building.

Participant 20 (Urban grower)

Caring for the soil microbiome for personal as well as environmental reasons shows that stewardship was an important foundation for describing the soil microbiome. This narrative also points out that human-soil microbiome relationships can

be altruistic and caring for the soil does not necessarily entail benefit to humans (Puig de la Bellacasa 2015). Soil stewardship can be defined as a culmination of care, knowledge and agency (capacity to take actions) (Neaman et al. 2024; Peçanha Enqvist et al. 2018). Participant 2 explains this clearly, stating that he takes care of the soil microbiome because he wants to care for it altruistically:

I want to do things as well as I can. I want to improve the environment. I also want to make more money. It can be economic benefit for me. Also altruistically, I want to leave the farm in a better condition than how I've taken it over.

Participant 2 (Farmer)

The participants also felt that more knowledge and information would help them care for the soil microbiome better, which again brings out the aspect of stewardship. A lack of standard tests for measuring the soil microbiome as well as a lack of expert help to maintain a healthy microbiome was mentioned as a barrier to caring for the soil microbiome. Participants pointed out that apart from visual assessment of soil structure, they lacked tools to assess the health or even presence of soil microbiome's existence in the soil. They also expressed a desire for more assistance in maintaining the soil microbiome and soil health. There is thus, an appetite for products which actively sustain or support the soil microbiome and its functioning; and a standard tool or test which can also, measure this activity.

3.2 | Practices Around the Soil Microbiome

The interviewees evidenced a strong practical understanding of changing and improving the soil microbiome. Table 1 shows the list of practices that were used or are considered important by participants for the soil and soil microbiome. This includes established practices such as use of composts or manures, but also more experimental practices such as use of kombucha as a probiotic (please also see Figure S1 for information on how many participants used soil microbiome based practices). These findings are in line with a recent study in the UK, which showed that farmers are generally aware of soil sustainability and they use many sustainable practices to take care of their soils (Jaworski et al. 2023). Also, in line with previous studies, we found a difference in practices according to farming/growing principles, plot size, and primary motivation to grow plants (e.g., urban growers mostly grow plants for their own use while commercial farmers grow crops for income) (Carlisle 2016; Kirby et al. 2021). Organic farmers mostly used practices such as using manures and composts to ensure organic produce while traditional farmers used a mix of practices such as composts, minimum and no till, or using tramlines to disturb the soil as minimally as possible. This was also to help prevent soil erosion. Urban growers were less likely to use cover crops as compared to conventional farmers due to limited land as well as differences in produce use. Commercial farmers also tended to follow a strict 6 or 7 year rotation pattern, while urban growers did not. Minimal disturbance of soil was used by many participants, especially those who followed organic or regenerative practices such as minimum tilling and

TABLE 1 | Different practices used or considered important for the soil and/or the soil microbiome by the participants.

Category of practices	Practices
New and innovative practices	Hügelculture ^a , Johnson Su reactor ^b , Bokashi ^c , Moon-gardening ^d , Kombucha ^e
Alternatives to fertilisers and biocides	Dried blood, Fish, Bones, Seaweed/Kelp, Lime, Volcanic rock, Sheep wool mat, Inoculant use
Minimum disturbance to soil and life	No digging/tiling, Direct drilling, Minimum tilling, Keeping tram lines in the same place, Biochar, Physical barriers such as net for pest management
Composts and manures	Mixed composts, Farmyard manure, Dairy slurry, Green manures, Mulching, Poultry manure, Mushroom and fungi compost, Earthworm compost, Comfrey/nettle tea, Wood chip compost, Sugarbeet factory waste, Bio-solids from sewage works
Cropping practices	Companion gardening, Rotation of crops, Leaving root residue in the soil, Strip drill, Indigenous/heritage varieties of grass, Legumes as cover crops, Crop diversity, Crop under sowing
Minimising chemical use	Organic farming

^aHügelculture is the technique of raising soil bed, layering it with wood and then, covering it with soil and compost. Wood helps in water retention for longer time periods.
^bJohnson Su reactor is a type of compost tank.
^cBokashi involves covering farmyard manure with a plastic sheet which is left for fermenting. The sheet doesn't let the carbon dioxide escape which preserves the organic matter and maintains carbon and other nutrients.
^dMoon-gardening involves sowing seeds according to the moon cycle as it affects high and low tides and likely soil moisture.
^eKombucha—a fermented probiotic drink made by adding SCOBY, a cellulose cloth with symbiotic culture of bacteria and yeast to a mixture of tea with added sugar.

direct drilling. The main motivation mentioned was the preservation of soil life to maintain the fertility and infiltration capacity of soil. The second motivation for such practices was to increase carbon sequestration of the soil. These two motivations fall within the ecological sphere of traction to uptake sustainable practices as described by Gosnell et al. (2019). Participants also mentioned that such practices do not yield results in the short-term but instead, are part of a long-term process that results in better soil fertility and plant production (Beacham et al. 2023; Gosnell et al. 2019). Use of alternative/additional composts and manures was very common to increase soil fertility but several nutrient sources were also mentioned such as teas made from nettles and thistles, dry blood, seaweeds, nails and horns.

As participants were selected on the basis of being legume growers, legumes were unsurprisingly valued by the participants for their positive effects on soil health. They were commonly used by participants as rotational crops due to their ability to (1) fix nitrogen and (2) break the development of new diseases or the prevalence of existing diseases in the soil. Legume and brassica mixes were used as under-sown crops with cereals to prevent disease outbreaks in the main crop as well as provide nutrients to the soil. Native plant species were used by some participants as they are believed to be more productive and disease-resistant as compared to the modern varieties introduced after the Green Revolution (Shelef et al. 2017).

Many of the above mentioned practices were new to the participants. Participants had learnt about the new practices in farming magazines or heard about them in the farmer community and agricultural webinars. Some of these practices, such as using kombucha (a fermented probiotic drink) by Participant 4, were creatively modified for use on soils.

Kombucha is ... trendy as a drink I just thought I'll put kombucha on the garden. So, I've been making ... 20–30 litres of it. [I] pour it onto the soil and that's supposed to [act] as a probiotic for the soil.

Participant 4 (Urban grower)

Innovation and creativity clearly are part of the trial and error of grower experiences, which leads to the addition of new knowledge and unique practices to their list of agricultural practices to sustain the soil and the soil microbiome (Vogl et al. 2016). It is important to note that successful and beneficial practices diffuse in the farmer community and become part of local knowledge which is specific to farmer needs, socio-economic and cultural conditions (Vogl et al. 2016).

3.3 | Assessing the Soil Microbiome

While general soil health tests such as pH, organic matter and nutrient analysis were used by many participants, only one participant, a dairy farmer, specifically used soil microbiome testing. Factors such as cost, access and awareness about such tests influenced their low uptake. The participants note that the available tests were not attractive as they did not provide a holistic assessment of the state of their soils.

Moreover, participants were dubious about the usefulness of soil microbial testing in light of soil variability. These participants preferred qualitative techniques to observe the health of the soils, which linked to the importance of embodied expertise grounded in experience and observations. Some also mentioned the use of a microscope would help them to observe microscopic

things such as mycelia in the soil. But using these products and tests does not necessarily mean that they believe that any expert-led test was capable of giving a full comprehensive result. Participant 6 echoes the thoughts of many of these participants that measuring the changes in soil due to practices is not essential:

There's not a real point [of assessing], if you're trying to do everything you can ... to enhance it, you're not gonna say well, I've measured, it is enhanced. I've got to stop doing that now. You actually will want to carry on enhancing it, even if you've enhanced it on here.

Participant 6 (Farmer)

Assessment of the soil microbiome was typically undertaken as part of the more general soil health assessment. Almost all participants used tests, either quantitative or qualitative to check the state of their soils, especially before undertaking specific soil management practices and to observe the effectiveness of practices and progress of actions taken (please also see Figure S2 for information on how many participants assessed the soil microbiome). They used a range of physical (structure and texture), chemical (nutrient content) and biological soil health indicators (listed in Table 2). The indicators mentioned and used by the participants were site-specific and linked to the functions that the soil microbiome provides.

Visual or qualitative assessments of colour, texture and smell were commonly used by some participants to assess their soil health. Comparison to the soils of other growers in the community allowed participants to ascertain if their practices were successful. Participants also used assessment of biological health, presence of dung beetles or root nodules on leguminous plants as an indicator of a functional soil and more specifically, soil microbiome. Many participants felt that plant health was a critical indicator of healthy soil biology that often could be used to assess changes after practices.

Importantly, some participants stated that it was very difficult to find indicators that show changes in the soil accurately. They highlighted that changes can take years to be observable, particularly by quantitative methods. They also recognised that changes which are observed, e.g., in plant productivity, may not be due to soil-related practices but a mix of factors such as heat, rainfall. Even if the changes are due to the practices undertaken, it is not easy to distinguish which practice out of the many, led to the changes. Moreover, quantitative soil testing adds another task for the participants which needs time and, in case of commercial testing, money too.

While the participants interviewed had a rich experience of using soil health assessments, connecting these more specifically to the soil microbiome was seen as challenging. The participants shared their uncertainty about whether they were looking for the 'right' organisms or correct signs of soil microbiome presence in the soil. Participant 10, for example, stated that he knew what the signs of good/healthy soil are from experience but linking them to soil microbial presence was a challenge for him.

Earthworms are probably the easy example ... we know that they're good in terms of aerating and breaking up the soil, and incorporating organic matter. So that's always positive. When we apply organic manures, then, you know, it's great that you can see them there. [But] I don't think I would come with anything that allowed me to make any judgement around soil microbes.

Participant 10 (Urban grower)

3.4 | Soil Inoculants

All the participants in this study had heard about soil inoculants and had a general understanding of them (please also see

TABLE 2 | Different physical, chemical and biological indicators used by participants in quantitative and qualitative tests to assess changes due to various practices.

Indicator type	Quantitative indicators	Qualitative indicators
Physical	Soil temperature	Touch—soil texture, soil friability, soil moisture, soil biting, soil shaping Visual—smooth fields, infiltration rate, soil structure, water drainage, soil colour, soil fertility Smell—earthy smell of soil
Chemical	Nutrient testing—nitrogen, phosphorus and potassium, forage mineral analysis, organic matter tests, carbon level tests and CO ₂ burst, pH tests	Palatability of grass to sheep and cattle due to high potassium content
Biological	Total bacterial and fungal counts Plant yield	Microfauna—mycorrhizal fungi, grey network Macrofauna—earthworms, dung beetles, scarab beetles, moles, insect presence and activity, hedge line diversity, above ground wildlife Plant—plant quality, plant leaf colour, plant material decomposition, root nodules, soil mushrooms, disease resilience in plants

Figure S3 for information on familiarity of participants with soil inoculants), but were often not sure ‘what counts’ as a soil inoculant, and they often turned to the interviewer/researcher, who represents the research community to confirm whether their perception was right.

I'm not quite sure exactly what soil inoculants are. Is it right that the beans, they're inoculating the soil when you're growing [them] in the soil? Is that the case? Are they inoculating the soil because they have those little white things on their roots or is it about something else.

Participant 1 (Urban grower)

Some participants associated legumes with inoculants as through experience they know that legumes harbour rhizobia which fix nitrogen, which fits their definition of soil inoculants—a plant nutrient provider. Others drew parallels between microbial and macro-fauna-based biocontrol such as nematodes, which would not be counted as inoculants in the scientific community. Similarly, other participants associated the application of a soil product to soil inoculants, but some also included home-made products such as compost teas.

The uncertainty surrounding commercial inoculants, both in terms of their utility and the risks of their use, was a crucial theme in all interviews. Some participants didn't want to use commercial additives, as they did not trust the distributors and did not believe in the effectiveness of these products. These participants preferred to be creative and experimental with their home brewed inoculants. The idea that soils have a natural balance that could become upset through the use of commercial inoculants was very pronounced, being mentioned by 26/28 participants. Using non-native organisms was seen as potentially disturbing to the natural balance of their soils, and participants expressed that they did not require or want to use commercial inoculants as they were happy with the local soil microbiome. In the farmer group, out of 14 only one had used a rhizobial inoculant (please also see Figure S4). In the urban grower group, out of 14, three had used inoculants and one had used a bio-control agent: Two gardeners had used a mycorrhizal inoculant for nutrient provision while one had used a nematode inoculant for killing snails. The three participants who had experience with using soil inoculants considered them important but only in areas where the local beneficial microbes such as rhizobia and mycorrhiza are absent. The small number of microbes introduced in comparison to the overall microbiome also made it difficult for participants to be convinced of the effectiveness of inoculants.

Inconsistent results in terms of crop yields also contributed to the scepticism, as inoculants worked for the urban growers but not for the farmers who use them. Few research trials in fields and farms which show that soil inoculants are capable of omitting or reducing the use of fertilisers were a major reason cited. Participants wanted to see more evidence from the farm trials, especially with no legacy of fertiliser use. Naturally, cost and benefit were critical in decision-making. High cost of inoculants was commonly cited as a barrier. Participants were interested in spending money only if they could see consistent

benefits to crop yields at least at par with yields obtained after using fertilisers. Participants who had positive results also wanted to use soil inoculants that have a longer shelf/soil life so that the successive crops can also have the benefit (if any) of soil inoculant presence.

Finally, participants expressed that inoculants presented technical challenges. They stated that they found it very difficult to apply and visually confirm the application of soil inoculants and that the challenges of assessing the microbiome, as described above, made it hard to assess their usefulness.

However, soil inoculants were also seen in a positive light as a potential additive which can work well with other practices such as using compost and as a source of improving local soil biodiversity. Those who had positive experiences with their use were more likely to use and recommend their application.

It was quite good, actually... I [used them] ... for private clients and the roses [are] still growing quite well. ... So maybe there's something in it. Anyhow, it to me, seems more natural than perhaps adding a chemical-based fertiliser. But that's just my feeling as a hobby gardener.

Participant 1 (Urban grower)

4 | Discussion

This study seeks to strengthen the field of soil inoculant research by understanding the existing attitudes and practices around soil microbiome and soil inoculants amongst UK farmers and growers. End user experiences and perceptions are known to play an important role in technology transfer and adoption (Delgado and Stoorvogel 2022), yet it is rare in the soil research community to consider their importance. This study therefore offers important empirical insights and provides a model for future work.

Firstly, the results of this project highlight the importance of recognising a distinction between scientific and practice-oriented knowledge of the soil microbiome, and the consequences of this distinction for how research with end users should be conducted. With a rising interest in soil literacy as an important element in strengthening sustainable land use (Johnson et al. 2020; Katikas et al. 2024), a number of studies have sought to compare scientific and non-scientific understandings of soil functions in different parts of the world (Dawoe et al. 2012; Girard 2015; Mesfin et al. 2023). For understanding end user perspectives on soil functions, however, it is crucial to recognise that different concepts and languages may be used by scientific and non-scientific groups. It is therefore important to ensure that such an investigation is designed in a way that can uncover end users' practical experience with the subject matter (rather than testing the participants' understanding of scientific concepts).

In our study, we found alignments between participants' perceptions of the soil microbiome and scientific understandings. For example, symbiotic associations in the soil were seen as an

important component of appreciation of the soil microbiome by participants. Interactions such as symbiosis have in fact been recognised since the beginning of agriculture (Fierer 2017; Wang et al. 2019), for instance, it is mentioned in Chinese literature from at least 2000 years ago (206 BC to year 24 AD) (Wang et al. 2019; Zeng et al. 2016). On the other hand, participants also expressed doubts and uncertainty about the soil microbiome. This uncertainty stems from a mismatch between terms that researchers and participants use to describe the soil microbiome, which is a reflection of the different contexts that researchers and farmers hold, often related to differences in their aims (Ingram et al. 2010; Klebl et al. 2024). The disparities in perception and usage of different terms are common in the farmer and scientific community. An EU wide survey found different levels of disagreement in the terminologies being used in soil management within scientist as well as non-scientist groups (Ramler et al. 2024). In our study, scientific terms such as 'soil microbiome' made our participants less confident and more uncertain about their own perceptions and knowledge about the soil microbiome. The same was also true for soil inoculants. However, when explored in the context of soil health, something which the participants were quite familiar with, the participants were confident in describing a diversity of practices, drawing parallels between soil health and human health (via the gut microbiome). In addition, the participants provided detailed descriptions of the constituents and the functions that the soil microbiome performs in their soils and plant productivity. Previous studies on soil health have found similar results; even though farmers had differing definitions of soil health, which were shaped by individual management practices, they shared a good understanding of the soil microbiome and benefits of the soil microbiome to soil biology and crop production (Irvine et al. 2023; Wade et al. 2021).

Secondly, we find that the farmers and growers participating in this study are already actively involved in a range of experimental and innovative practices to improve the soil microbiome. Personal experiences, direct factors such as rising costs and indirect factors such as farmer identity and taking care of the environment have been shown to be major motivations to take on these sustainable practices (Gosnell et al. 2019). In addition, some of these practices such as nutrient alternatives i.e., blood and seaweed were used as they were local, cost-free, easily available but at the same time provided maximum nutrients (Durán-Lara et al. 2020). The alternatives such as sheep wool mats showed that participants used their creativity and knowledge to make the best use of the resources available to them. It was also noticeable from the interviews that urban growers were more likely to draw on non-traditional practices, indicating a tendency to be early adopters of new technology, in comparison with farmers. This aligns with Pfeiffer et al. (2015) and Sanyé-Mengual et al. (2019), who found limited and non-traditional land access to be a distinguishing feature of urban agriculture which led to development and adoption of newer practices. The use of new practices by urban grower participants is understandable, as urban growers work on small plots and are not economically reliant on outcomes, meaning they can afford to invest in new practices with uncertain outcomes. Farmers, in contrast, need to work at scale to produce high quality and productive crops increasingly under a constrained environment. Nonetheless, grower innovation leads to the generation of

diverse practices that underlie many innovations in agriculture (Sanyé-Mengual et al. 2019). The role of fostering innovation in agriculture is important and is becoming increasingly recognised for sustainability (MacMillan and Benton 2014; Moss et al. 2021; Tambo and Wünscher 2017).

We further found that observing and assessing change are important to participants' understanding, appreciation and shaping of their attitudes towards the soil microbiome and inoculants. Researchers and agronomists often use indicators to ascertain soil quality and to make decisions on the necessary efforts to conserve soil and agricultural productivity. Most of the indicators used by experts are quantitative. Quantitative indicators are derived from physical (such as soil texture), chemical (such as nitrogen or phosphorous content) or biological (microbial mass) properties of soil which can be compared to a reference value (Bünemann et al. 2018; Maurya et al. 2020). In addition, quantitative indicators are usually based on analytical laboratory approaches and require measuring data systematically with standardised processes or procedures (Bünemann et al. 2018). We found that participants used a mix of expert-led quantitative indicators such as pH and nutrient tests, and intuition-based qualitative indicators such as presence of insects and earthworms to measure soil health as a proxy for microbiome's functioning in the soil. Most participants had a clear preference for qualitative indicators as these indicators were embodied by being a part of their routine observations and contributing to participants' individual experiences. Qualitative indicators thus aligned better with participant practices. Preference for qualitative indicators is common in the farmer communities throughout the world. For instance, farmer communities in Philippines use traditional indicators, which rely on physical characteristics of soils such as texture and colour, to assess the soil fertility (Zapico et al. 2024). Similarly, Tanzanian farmers favoured the use of qualitative over quantitative methods to assess their soil's quality (Kelly and Anderson 2016). While quantitative indicators and assessments were also used and interested many of our participants, they reported quantitative indicators as being less accessible, an added cost and often hard to interpret, (O'Neill et al. 2021) making them less favoured over qualitative assessments. Furthermore, in our study, a need for comprehensive soil tests which included measuring the soil microbiome was also often mentioned because a thorough understanding of what is happening in soils is important to some participants (Maurya et al. 2020). There is thus a heightened interest in looking at the soil microbiome closely and using it to enhance soil fertility, soil functioning and thus, plant production. Overall, linking inoculants with appropriate indicators that are desirable by growers and farmers should be considered when planning for inoculant application. The need for indicators linked to inoculant use has previously been highlighted as important by UK and German farmers, regardless of prior experience of using bioinoculants or biostimulants (Plöhl et al. 2022).

The question of inoculant use must be understood in the context of pre-existing practices of soil health improvement, observation, and assessment. We found a difference in the perceptions of soil inoculants between the different participant groups in our study i.e., farmers and growers who followed different farming principles, such as organic or regenerative. Overall, our participants had little pre-existing knowledge of soil inoculants, and

especially of specific terms such as ‘soil or mycorrhizal or rhizobial inoculant’. In our study, urban growers and allotment holders, who mostly followed organic or regenerative farming practices perceived composts, manures and teas as home brewed soil inoculants, while most of the commercial farmer participants understood inoculants as commercial products which could be applied to the soil. These different understandings of microbe based products are quite common in the farmer communities (Plohl et al. 2022), as seen before with the understanding of soil microbiome.

Importantly, we also found strong scepticism towards the use of inoculants equally by the farmers and urban growers. It was quite clear that adequate knowledge transfer of soil inoculant research could reduce scepticism of inoculant use and thereby improve the adoption of soil inoculants (Cawley et al. 2023). In addition, assessment of soil inoculant desirability was linked to participants’ experiences of its use. This aligns with the findings of Plohl et al. (2022) where UK and German farmers who had a positive prior experience with microbial products perceived them positively. Three of the participants with positive views had seen positive results first hand while participants who had negative experiences or had never used soil inoculants were often sceptical. Practical barriers such as cost, application and difficulty in monitoring were often cited as poor evidence for their effectiveness. Scepticism to new technologies in agriculture is not new; for instance, in a study focussed on smart product adoption in German farmers reported that some farmers did not want to use smart products (such as ear tags which allow tracking of livestock) as they did not know of any benefits associated with using these products (Schukat and Heise 2021). Moreover, these farmers did not trust these smart products and using them was viewed as an added effort. In our study, participants also expressed more philosophical reasons for lack of uptake. Suspicion towards inoculant producers was mentioned and many participants stressed a holistic, local, and ecological approach to the soil microbiome. Participants were more interested in improving the soil microbiome through locally available means than through external additives, which, they were concerned, may upset the ecological balance in the soil. This was a sentiment especially pronounced amongst organic and regenerative growers. Similar sentiments around the benefits and disruption of soil microbiome due to added products has been observed in previous studies where certified organic farmers believed that the soil microbiome increases plant defences and supports pest suppression naturally (Bloom et al. 2024).

5 | Conclusions

The insights gathered in this study provide a window on the wider context for growers’ attitudes to the use of products such as soil inoculants. In the scientific literature, such products have been discussed as a potential tool for sustainable soil management (Díaz-Rodríguez et al. 2025; O’Callaghan et al. 2022). Our findings suggest that growers are likely to see commercial inoculants primarily as an input, and associate their use with the practices typical of input-dependent agriculture. In contrast, sustainable soil management, in which the soil microbiome plays an integral part through such practices as composting, was associated with more holistic approaches. Participants in

this study clearly saw soil stewardship as being of fundamental importance both to their own productivity but also as their responsibility for future generations. Participants considered that they were carefully managing and nurturing the soil microbial communities, often through locally produced supplements. The addition of products which lack convincing benefits was therefore seen as not necessary, or even potentially harmful to this holistic approach.

There are clearly some limitations to this study due to the geographical context, historical and contemporary use of inoculants in the UK, and the sample size. Nonetheless, this study suggests that qualitative research methods can be usefully employed in the design and development of agricultural technologies, such as microbial inoculants. Our findings reveal a clear interest in approaches which cultivate the existing microbiome, and a desire for more accessible monitoring tools. This study reinforces the message that (future) user participation in research and development is important, not just to ensure successful uptake of technologies, but also to develop new approaches and achieve successful knowledge transfer. We hope that such an approach is more embraced in microbial research in the future, and that it will help to address the communication and trust gaps between researchers, companies and the end users.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The additional [Supporting Information](#) that support the findings of this study are openly available on figshare at <https://doi.org/10.15131/shef.data.24569920>. However, the original data that support the findings of this study are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** Presents the list of questions used for the semi-structured interviews in the study. **Appendix S2:** Includes figures showing participant implementation of soil microbiome practices and assessment methods and; participant familiarity and usage of soil inoculants. **Figure S1:** Use of soil microbiome based practices by participants. The bar graph shows whether different participant groups used soil microbiome practices. **Figure S2:** Assessment of the soil microbiome by participants. The practices have been divided into Quantitative, Qualitative and Mixed. **Figure S3:** Familiarity with soil inoculants. The bar graph shows whether different participant groups knew about soil inoculants. **Figure S4:** Use of soil inoculants by participants. The bar graph shows whether different participant groups had use soil inoculants.