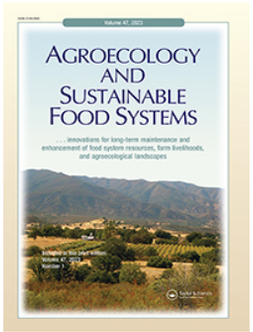

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Advantages, disadvantages, and reasons for non-adoption of rotational grazing, herbal leys, trees on farms and ley-arable rotations on English livestock farms

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ABSTRACT

Adoption of rotational grazing or multi-species herbal leys, planting trees and integrating livestock into arable rotations can increase agricultural productivity and carbon storage on temperate ruminant livestock farms. However, farmers frequently have rational reasons for not adopting seemingly beneficial management practices. Here, we conduct semi-structured interviews with sheep and beef cattle farmers and industry representatives in England, to determine the advantages, disadvantages, and reasons for non-adoption of these four management practices. We find key reasons that farmers rationally do not adopt these practices include capital outlay, incompatibility with farming objectives, and the risk that desired benefits are not delivered.

KEYWORDS

Regenerative agriculture; agroforestry; mixed farming; integrated crop-livestock; agroecology; farmer behavior

Introduction

The environmental sustainability of food production needs to increase to address the twin challenges of climate change and biodiversity loss. This issue is particularly acute for ruminant livestock farms, including sheep and beef cattle enterprises in the UK, which are associated with high greenhouse gas emissions from enteric fermentation along with other environmental impacts including reduced water quality and increased flood hazard (Bilotta, Brazier, And Haygarth 2007; Gerber Et Al. 2013; Marshall Et Al. 2014). Measures that improve the productivity of these farms can reduce the environmental impact per unit of food produced (Herrero Et Al. 2016; Hristov Et Al. 2013). In addition, the typically more marginal farmland that these enterprises are located on is increasingly attractive to policy makers for land-based carbon sequestration as part of national climate change mitigation strategies, such as the UK's target of net zero emissions by 2050 (Climate Change Committee 2020).

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Measures that improve sheep and cattle productivity and/or increase farm carbon stocks include rotational grazing practices, incorporation of perennial forbs into multi-species swards (also known as herbal leys), integrating trees onto farms, and including a grass-based ley phase in arable rotations (Table 1, and citations therein). These practices are currently supported to some extent under existing English farm support schemes (Table 1), and are likely to form key components of England's future Environmental Land Management schemes (DEFRA 2021b, 2021a). Combinations of these practices are simultaneously gaining interest from some land managers, policy makers and large corporations as part of a Regenerative Agriculture approach (Giller Et Al. 2021; Gosnell, Gill, and Voyer 2019), with private incentives and markets emerging to promote adoption of this e.g. (Elliott Et Al. 2022). However, although the theoretical productivity gains or carbon sequestration potential of these changes in land management practices have been estimated (Byrnes Et Al. 2018; Mayer Et Al. 2022; McCarthy Et Al. 2020; McDonald Et Al. 2019; Pent 2020; Torralba et al. 2016), this does not account for the appeal of these measures to land managers or the likelihood of adoption.

There is a substantial body of literature that seeks to understand and predict adoption of management practices by farmers. Many of these take a behavioral approach, focusing on "the motives, values and attitudes that determine the decision-making processes of individual farmers" (BURTON 2004a; Morris and Potter 1995), often developing or applying models of farmer behavior, see (Journeaux et al. 2018; ROSE, Keating, and Morris 2018a). However, studies of farmer adoption of agricultural innovations and new technologies often implicitly assume that adoption is beneficial, and these benefits will be equally realized by all farmers (Vanclay and Lawrence 1994), which may not account for the context-specific nature of farmer decision making (Journeaux et al. 2018). Moreover, where innovations are incompatible with existing, already successful, farmer workflows, this can lead to characterization of some farmers as problem 'non-adopters,' instead of recognizing the limitations of an innovation (Rose et al. 2018b; Vanclay and lawrence 1994). Cognitive and behavioral models also tend to center on the individual, which can miss "structural economic, environmental and social factors which affect an individual's ability to change behaviour" (Journeaux et al. 2018), unless these are explicitly accounted for as in the Theory of Planned Behavior. These, along with other factors, can result in farmers having a rational basis for non-adoption of management interventions, which have been categorized by Vanclay and lawrence (1994) as: complexity of intervention, inability to trial or partially adopt, incompatibility with farm and personal objectives, loss of flexibility, risk of failure, conflicting information regarding benefits, cost of implementation, infrastructure requirements, and limited economic benefit. The four interventions under consideration here (Table 1) are already adopted to some extent on English sheep and beef cattle farms. However, the prevalence

Table 1. Regenerative agriculture practices applicable to English sheep and beef livestock farms investigated here.

Interventions	Definition	Synonyms	Selected theoretical advantages	Current government support (England)
Rotational grazing	"Movement of livestock between two or more subunits of pasture such that alternating periods of grazing and no grazing (rest) occur within a single growing season" (Briske Et Al. 2011)	Mob grazing, cell grazing, paddock grazing, controlled grazing, holistic planned grazing, adaptive multi-paddock grazing, strip grazing, precision grazing	Enhanced grass growth leading to improved livestock growth rates and potential for higher pasture carrying capacity (Jordon et al. 2022, McDonald et al. 2019)	Farming Equipment and Technology Fund electric fencing package (Rural Payments Agency 2021)
Herbal leys	Intentional incorporation of perennial herbs and legumes into pasture swards, in addition to common grasses and clovers, either through sowing seeds or creating conditions for these to persist/ reestablish naturally (Jordon Et Al. 2022)	Multi-species leys, diverse swards	Enhanced sward diversity increases pasture productivity and resilience, inclusion of legumes build fertility through N fixation, deeper rooting species incur drought tolerance, plant trace mineral and secondary metabolite content improve livestock health (Jordon et al. 2022, McCarthy et al. 2020)	Countryside Stewardship option GS4 (RURAL Payments Agency & Natural England 2015a); Sustainable Farming Incentive grassland soils standard (DEFRA 2021b)
Trees on farms	"Incorporation of trees into farming systems" (Gordon et al. 2018)	Agroforestry, silvopasture, farm woodland, shelterbelts, hedgerows	Reduced livestock heat and cold stress from shelter and shade, increased combined production for given land area, increased farm carbon storage (Jordon et al. 2020, Torralba et al. 2016, PENT 2020, Mayer et al. 2022)	England Woodland Creation Offer (Forestry Commission 2021); Countryside Stewardship (Rural Payments Agency 2020)
Ley-arable	Temporary grass-based ley included for one or multiple consecutive years within arable rotation (Lemaire et al. 2015)	Integrated crop-livestock, mixed farming	Ley phase builds fertility for following arable cash crops, breaks arable weed lifecycles, and provides high-quality livestock forage (Elliot 1908, Turner 1951, Stapledon and Davies 1948, Martin et al. 2020). Arable phase can provide livestock feed and bedding.	Countryside Stewardship option SW7 (RURAL Payments Agency & Natural England 2015b)

and nature of such rational reasons for non-adoption needs to be understood, in order to determine the extent to which increased uptake for improved farm productivity or climate change mitigation is likely achievable in practice.

Here, we investigate the advantages and disadvantages of four Regenerative Agriculture practices applicable to sheep and beef cattle farms in England, UK. We conduct semi-structured interviews with national industry representatives, and farmers in two case study regions (Northumberland and Devon), to ascertain their views on rotational grazing, use of perennial forbs in multi-species swards (herbal leys), integrating trees onto farms, and incorporating livestock into arable rotations (ley-arable rotations) (Table 1). In addition to further understanding the benefits and downsides of these emerging management practices from farmers' perspectives, we aim to provide a preliminary indication of where rational reasons for non-adoption may exist and the aspects of the management practices or farmers' context that influences this. Although these practices have theoretical advantages including increasing carbon storage (i.e. sequestration) on livestock farms, our objective is to help inform the extent to which further adoption may be attainable in practice.

Methods

We used an inductive grounded-theory approach (Wengraf 2001). Interviewees were nonrandomly selected and initially contacted through the existing relationships and professional networks of the study authors. The lead author conducted semi-structured interviews with 12 respondents in total; four each of industry representatives and farmers from the two case study regions (see Tables S1-S4 for a summary of interviewee responses). We chose to include sheep and beef cattle farming industry representatives and farm advisors in our sampling as they can be well placed to provide a breadth of perspective across multiple contexts regarding the activities and views of the farmers they represent or work with (Mills et al. 2020). The farmer case study areas (mid Northumberland and west Devon) were not intended to be representative of the whole of the UK but were selected as illustrative of some beef cattle and sheep farming regions in England.

Interview questions were trialed on three social science researchers and non-participating farmers with oral feedback to ensure questions were clear, understandable, and likely to elicit informative responses that could be further probed. Respondents were provided with a Participant Information Sheet on first contact and informed consent was received through signing a written form before the interview commenced. Industry representative and farmer advisor interviews were conducted over Microsoft Teams video call in September 2021. They were asked to list all advantages and disadvantages of each practice based on conversations with or observations of their farming members/clients. They were

also asked for their own views on the barriers to wider adoption of these practices and possible interventions (e.g. dissemination of advice, financial incentives) that could help overcome these. Advantages and disadvantages of each intervention identified by these respondents were recorded so that farmers' extent of agreement with these could be explored in later interviews, which took place in late November (west Devon) and early December (mid Northumberland). Farmers were visited on farm and interviews conducted face-to-face in the farmhouse, with family members present in six out of eight cases. Where family members made contributions to the discussion of RA practices, these were included in the interview transcript, given the known importance of family influences on farm decision making (Wynne-Jones 2013). The interviewer (MWJ) explained his background in sheep and beef cattle farming and outlined his other research interests, in order to build rapport with the interviewee and put them at ease. Practices were discussed in turn, with farmers first asked whether they adopted these or not, with a different phrasing of questions used depending on response to this, to discuss their perceptions of the advantages and disadvantages to each practice, and ideal policies or incentives that would help mitigate any disadvantages. A series of close ended multiple-choice questions were also asked at the end of the interview to gather participant meta-data.

Interview data were collected via audio recordings. These were transcribed in NVivo Transcription with manual proof checking. Transcripts were analyzed in NVivo, with theme-based coding using well-established methods (Ryan and Bernard 2016) to identify advantages, disadvantages and reasons for non-adoption of each practice.

Three national industry representatives for paid membership organizations and one farm advisor were interviewed (referred to collectively as 'industry representatives' throughout). Of these, all bar one were also active farmers. There was a balanced mix of expertise in sheep and beef cattle enterprises and respondent ages (Fig S1), with all respondents having spent the majority of their working life in the agricultural sector. Of the farmers interviewed, all were the/one of the primary decision makers in a family business. Seven out of eight were owner-occupiers, although three of these also rented additional land on Farm Business Tenancies and/or Agriculture Holdings Act 'secure' tenancies. Land quality ranged from non-LFA (less favored areas) to Moorland Severely Disadvantaged. All bar one were in agri-environmental or stewardship schemes. All had beef enterprises, and six of the eight also farmed sheep (Fig S2). Farmers interviewed relied on a variety of sources for new information, with the agricultural press, farm vets, peer-to-peer networks (predominantly paid membership industry organizations) and social media all seen as important (Fig S3).

Results and discussion

Practice advantages and disadvantages

Rotational grazing

Rotational grazing (RG) was widely perceived to benefit forage production and livestock performance compared to continuous grazing (also known as set stocking). Improved grass productivity or growth rate was the most frequently cited advantage across respondents (Table S1), aligning with findings from a farmer survey in the USA (Wang et al. 2021) and mechanistic and empirical expectations that rest periods enable overall greater herbage dry matter production (Jordon et al. 2022; Voisin 1959).

> *"You undoubtedly grow more grass." Industry rep 1*

Industry representatives and adopting farmers also identified further aspects of improvement in forage production including enhanced quality, utilization and recovery rates post-grazing, in addition to creating a forage reserve which could act as a drought buffer (Table S1). Improved forage production was linked to better livestock performance, again only by industry reps and adopters of RG, implying that these benefits are potentially harder to recognize prior to adoption or receive less publicity. It was also found in the USA that benefits of RG are recognized to a greater extent by adopters than non-adopters (Wang et al. 2021). Although improvements in livestock performance in RG are primarily driven by improved forage production and quality (Jordon et al. 2022), one industry representative highlighted that mis-managed rotational grazing can result in compromised forage quality and therefore impair livestock performance, for example if livestock are not moved frequently enough so are grazing increasingly low-quality residuals.

The two key disadvantages of RG are infrastructure requirements (extra permanent or electric fencing to subdivide existing fields into smaller paddocks and supplying water to these) and labor (to erect fences and move stock), identified by industry representatives and adopting and non-adopting farmers (Table S1). This matches results of farmer surveys conducted in the USA (Wang et al. 2020), in particular the additive increase in labor requirements with RG intensity (Gillespie et al. 2008; Gurda, Renz, and Brink 2018; Winsten et al. 2010). A further limitation was the risk of poaching caused by high stocking densities on small paddocks in wet conditions, a factor not identified by industry representatives.

> *"When you see these strips [grazed] fields, and I've been past them after a wet day . . . and you see, it just looks like a quagmire. So I don't know if there's any benefit when I see that, do you know what I mean." – Northumberland farmer 2*

Some non-adopting farmers also indicated that they were not aware or unconvinced of the benefits of RG, as has been found in the USA (Wang et al. 2021).

> *"The grass will grow a certain amount a year." – Devon farmer 4*

> *"I don't know. Um, I'm not really sure, is it [RG] a benefit . . . ?" Northumberland farmer 2*

Herbal leys

Improved livestock performance was cited as an advantage by all farmers who use herbal leys (HL), and by two out of three non-adopters (Table S2). This corresponds with a previous study in southwest England which found that increased liveweight gain was a driver for adoption of white clover (McKemey and Yates 2003). Improved livestock growth or finishing rates were often linked by respondents to the higher protein content of forage due to the presence of legumes in the sward, as has recently been demonstrated by meta-analysis (Jordon et al. 2022). However, several farmers highlighted the potential for reduced palatability if the sward is allowed to become overgrown, particularly if chicory (*C. intybus*) is present and bolts, with one industry representative linking this risk of lost palatability and quality with potentially impaired livestock performance.

> *"You've got to make sure that you eat it. You can't let it get overgrown . . . Because actually, once it's reached a certain stage, you've got to leave it and cut it, because it becomes pretty unpalatable sometimes." Devon farmer 2*

In contrast to McKemey and Yates (2003), no respondents identified reduced concentrate use as an advantage of adopting HLs. Although there was recognition that including nitrogen-fixing legumes in the sward may benefit forage production and/or reduce fertilizer use, non-adopting farmers raised concerns that HL may not match the yields of ryegrass-dominated grass-clover leys (Table S2), with this uncertainty appearing to constrain uptake in some cases (see Section 3.2.1).

> *"Yield, fear of the unknown. I think a lot of that, a lot of people don't like change. The unknown." – Devon farmer 4*

Improved mineral or trace element content of forage plus drought resistance, conferred by increased diversity and depth of rooting structures in HLs, were identified by adopting farmers and industry representatives, in agreement with a survey of Danish organic dairy farmers regarding including herbs in pastures (Smidt and Brimer 2005). Although potential anthelmintic properties of HLs were identified by three out of four industry representatives, this was only mentioned by one farmer (non-adopter), suggesting that this well-publicized benefit of HLs may not be experienced in practice, in contrast to Smidt and Brimer (2005) who found this as a reason for including chicory in pastures.

> *"We know that it does have an impact, but it also means that if we have a faecal egg count burden in a lamb and we know from live weight gain it's not doing [growing well], we still need to worm it." Industry rep 3*

The most widely cited disadvantage of HLs is the difficulty of controlling broadleaved pasture weeds (Table S2), previously identified as a barrier to white clover adoption in southwest England (McKemey and Yates 2003). Available pasture herbicides are only safe to use on grasses, and are nonselective across both desirable broadleaf species (e.g. clovers, chicory, plantain) and weeds (e.g. docks, nettles, thistles). The cost of reseeding in general and HL seed mixes in particular was raised more by industry representatives than farmers, although all farmers that adopted HLs raised concerns about variable establishment and retention of all components sown in HL mixes, leading to one industry rep to question the cost-effectiveness of sowing expensive but poorly retained mixes.

> *"So that's reality is that people . . . a lot of money is being paid for mixtures, that you could have just put in a simpler one and it's still the same, having the same impact a year later." Industry rep 3*

Indeed, farmers frequently recognized that some species in HL mixes are unsuited to their land or climate, or that herbs in the mix may be unable to compete with the grasses, which could both explain poor retention. This contrasts with results from Denmark where establishment of herbs was found to be good on organic dairy farms (Smidt and Brimer 2005). Further, some respondents felt that HLs in general were unnecessary, due to the ability to achieve similar or greater benefits by focusing purely on grass-clover mixes (perennial ryegrass, timothy, cocksfoot, and white and red clover).

> *"I've tried to really put a lot of clover into the sward. I always ask for more clover. When we're sowing the ordinary medium to long term leys, always have a higher clover content. And then we'll oversow with clover or stitch it in sometimes as well, as an alternative to herbal grazing, the herbal mixtures. And so, because I think that the clover is, for me is probably more important than herbal." Northumberland farmer 4*

Trees on farms

All farmers interviewed identified increased shelter and shade for livestock as a benefit of integrating trees onto their farms (Table S3), in agreement with previous UK studies (Lawrence and Dandy 2014) and found by a recent systematic map to be a clear benefit to farmers in temperate regions (Jordon et al. 2020). Although this had been a reason for many farmers (seven out of the eight interviewed) to increase tree and/or hedge cover on their farms, the reluctance of the non-adopting farmer to plant trees and some adopters to plant more was due to the feeling that the farm already had sufficient shelter, so no further trees were required, or that all land deemed 'suitable' for trees

(i.e. areas that are unproductive, marginal or difficult to farm) had already been planted.

> *"I'm not sure if, you know, when we've got sort of ten percent of the farm under trees anyway, that's, I think in an awful lot of cases, most of the land that I would feel should be under trees is under trees. To plant any more would be taking away what I would call decent, the better productive land. And then you take the balance out of the farming business. So it's a bit of a mixed bag. Yes, I'd like to plant where appropriate, but not just for the sake of it." – Devon farmer 2*

Nevertheless, where marginal or unproductive land was available, planting trees represented a good use of this to some farmers. This was identified by an industry representative as potentially representing an attitude shift, although the non-adopting farmer noted that even marginal or less productive areas were still grazeable and saw a clear opportunity cost in terms of reduced stock carrying capacity if they were to plant these parts of their farm with trees.

> *"Where you've got a bad bit of a field, people are now happy to plant trees in it, whereas 10 or 15 years ago they were just trying to make it better." – Interview rep 4*

Although previous reviews have found little interest from UK land owners in creating new woodlands (Lawrence and Dandy 2014), more recent surveys indicate that attitudes could be changing (Hemery et al. 2020; Royal Forestry Society 2020) and our study identifies significant *interest* in planting trees but over a small *extent* of a holding. Equally, it could be that the farm types interviewed here are particularly open to planting trees due to the relative compatibility with their existing farming system (i.e. grazed livestock) (Wynne-jones 2013).

Some farmers also referenced the cultural value of restoring tree cover and hedgerows, particularly in Devon where hedged field boundaries are an iconic part of the landscape. This has similarities to the findings of Lawrence and Dandy (2014) that maintaining landscape features is often given as a reason for woodland management, and accords with the results of Rois-Díaz et al. (2017) that a key driver for adopting agroforestry in Europe was tradition linked to culture. Lawrence and Dandy (2014) identify benefits to wildlife or biodiversity as the most common or primary objective of woodland creation and management in the UK, and while this wasn't the case here (shelter and shade were identified by all respondents), biodiversity was mentioned as an advantage by five out of seven adopting farmers. Planting trees and hedges on farms was also seen to improve sporting value through providing cover for gamebirds, stabilize soil at risk of erosion, and provide an opportunity to achieve other objectives as co-benefits of planting grants such as sub-dividing fields for rotational grazing, improving farm biosecurity at boundaries with neighbors, and fencing off water courses.

We identified nuanced responses regarding the impact of tree planting on farm economics. Three farmers felt that trees could in the future provide a diversified source of income to the farm business, both through the potential to harvest food from fruit and nut trees, and through enabling access to future farming support schemes. This contrasts with agroforestry across Europe, where diversification of products was found to be a key driver for adoption (Rois-Díaz et al. 2017), whereas in our study it was only mentioned once, potentially because such systems are relatively novel in the UK compared to other parts of Europe.

> *"If we're going down in agroforestry route where you would do it in field, I would be keen to look for something that was potentially another source of income, whether that's an orchard or whether something, you know, I haven't quite worked out what it is, whether it's hazelnuts, walnuts, orchard or something like that, it'd be interesting to see what, you know, rather than just planting trees for the sake of it." – Devon farmer 1*

> *"I think if we want to earn any money, take any money out, we're going to have to do these sorts of things. That's the motivation, earning an income from the farm. And if it pays to . . . I don't think I'd take out any, I'm not one for taking out good land to put into trees." – Northumberland farmer 4*

However, there was also a perception that food production was more profitable than planting trees (Hardaker 2018; Lawrence and Dandy 2014), particularly on more productive areas of the farm (see above). Respondents expressed frustration that grant support is i) insufficient to incentivize further uptake, ii) too restrictive in species required to be planted, and iii) not available for the small-scale planting that most farmers are interested in doing,

> *"Its all money. That's all it is. I'm sure lots of farmers would have corners to plant they'd plant up, if they were paid the right amount to do it. There's got to be an awful, awful lot more flexibility from government really." – Northumberland farmer 4*

Although this accords with existing evidence that woodland creation grants are inadequate and overly bureaucratic, complex and changeable (Hardaker 2018; Jordon and Wentworth 2021; Lawrence and Dandy 2014) and we did find some suggestion that increased payment rates could potentially motivate further uptake ("*Well, if there'd been more money we might have planted a bit more*" – *Northumberland farmer 1*), it is also well established the UK land managers are not primarily motivated by making money when planting trees (Lawrence and Dandy 2014). Production or value of timber was not mentioned by any respondents, according with the findings of Lawrence and Dandy (2014) that timber production is "consistently rated low" as an objective for woodland management, in contrast to biodiversity conservation, shelter, shooting and other amenities or leisure activities identified as more important by woodland owners.

A repeated theme, as seen in the quotes above, was a reluctance to plant trees "for the sake of it" or to plant on a farm's more productive land. This aligns with widespread evidence of a cultural perception among UK farmers that agricultural land is 'too good' for trees (Hardaker 2018; Lawrence and Dandy 2014) and that land that can be farmed should (BURTON 2004b), plus evidence from Europe that where land is highly valuable and productive, farmers prefer to focus on agriculture and see agroforestry as having an opportunity cost (Rois-Díaz et al. 2017). This linked to a broader sentiment expressed by some farmers that an over-emphasis on tree planting would negatively impact national food security and their livelihood as farmers, particularly emotive given many farmers' strong identity as food producers (BURTON 2004b; Jordon and Wentworth 2021; Wynne-Jones 2013).

> *"If they plant trees all round here there's going to be no need for us to exist anymore. So I don't know what's going to happen to me. What am I going to do? Is the government going to supply me with a job? I don't know what will happen. But. I think that I just think it's a bit short-sighted." – Northumberland farmer 2*

> *"What they [policymakers] want is everything bar food. Isn't it? They just want [expletive]. Planting trees." – Northumberland farmer 1*

Relatedly, although carbon sequestration was mentioned as a benefit of increasing farm tree cover by two farmers, one farmer identified the growing carbon offset market as their biggest concern around the current political focus on tree planting in the UK.

> *"And one of our biggest fears is businesses coming in and buying up land and using us as carbon offsets. And that can't then . . . No farmer in the future, a genuine farmer, will be able to get back into it and buy it back. And once that sort of land is gone . . . And then we will not have any food security. I think, I think other businesses . . . I think you have to think, if there was an ideal rule it would be that to purchase land you have to be a genuine farmer, not a businessman." – Devon farmer 4*

If trees are planted within fields rather than at field edges, disadvantages include the inconvenience to farm operations, also found to be a barrier for adopting agroforestry in Europe (Rois-Díaz et al. 2017), risk of blocking field drains, loss of production directly under trees due to shading, competition for nutrients in the surrounding soil, and the perception that farming is more profitable (Table S3). Although the permanence of land use change following tree planting was raised as an issue (Lawrence and Dandy 2014), one farmer noted that this didn't matter as the land they had planted was so marginal they wouldn't be able to farm it anyway. The potential loss of the Agricultural Property Relief inheritance tax break from planting trees on farmland was also raised, which has previously been highlighted for review by the UK Climate Change Committee to ensure no tax disadvantage from woodland creation (Climate Change Committee 2020).

Ley-arable

There are two possible aspects of engagement by English livestock farmers with ley-arable rotations and integrating livestock into arable systems; they can either grow arable crops on their own farm in rotation with temporary grass leys (mixed farming) or send livestock to temporary grazing on arable farms either on short term leys or overwinter fodder or cover crops (sending stock to arable). Five of the eight farmers interviewed currently practice or had practiced mixed farming, but none sent stock to arable.

The most cited benefits of mixed farming were improved soil health, fertility and crop yield compared to continuous arable cropping, identified by industry representatives and both adopting and non-adopting farmers (Table S4) and matching previous studies and reviews (Bell, Moore, And Kirkegaard 2014; Cullen and Hill 2006; kragt, Dumbrell, And Blackmore 2017; Schut et al. 2021; Smith et al. 2007). Improved soil health was linked to increased soil organic matter by industry representatives but not by farmers, suggesting a potential disconnect between broader industry and policy interest in restoring soil organic matter for carbon sequestration (Smith et al. 2007) versus the more practical and immediate concerns of farmers.

The role of temporary grass leys in helping to manage arable weeds, particularly for which herbicide resistance is increasing such as blackgrass (*A. myosuroides*), was also widely recognized by respondents (Table S4) and is a well-established benefit of integrating livestock into arable (Bell and Moore 2012; Bell, Moore, and Kirkegaard 2014; Cullen and Hill 2006; Schut et al. 2021). Indeed, weed management benefits of mixed farming is thought to be one reason why this practice has persisted in Australia rather than simplifying to continuous cropping systems which are more profitable in the short term (Kirkegaard et al. 2014). Interestingly, there was also a perception that ley-arable rotations provided opportunities for *grassland* weed control and may improve some aspects of grassland soil health, i.e. some benefits apply both to the arable and grassland phases of the rotation. Furthermore, one mixed farming adopter grazed their autumn-sown cereal crops during the winter with sheep, finding that this helped reduce weeds and built fertility.

> *"It tillers a lot better. Like I say, we'll save a herbicide and they're putting manure back on it. So I, at a guess, I would say 10 units of nitrogen, it would save us. But like I say, the agronomist hates it. We just don't take any notice of him." – Devon farmer 4*

Although currently not widely adopted in the UK, over-winter grazing of cereals is increasingly popular on mixed farms in Australia, where benefits include increased productivity through the ability to rest pastures overwinter (Bell, Moore, and Kirkegaard 2014).

Farmers widely recognized the benefit of producing their own cereal for livestock feed and straw for bedding, i.e. providing production complementarity (Bell and Moore 2012) or economies of scope (schut et al. 2021).

Respondents perceived this as a way of reducing costs and dependence on bought-in inputs, potentially improving business resilience to the upcoming removal of the Basic Payment Scheme in England. Mixed farming in Australia has been demonstrated to mitigate financial risk from fluctuations in livestock vs arable income sources (Bell and Moore 2012), although this could be less applicable here where most adopting farmers used a significant portion of homegrown cereal for their own livestock feed.

Conversely, mixed farming can struggle to be cost effective, particularly when done at a small scale and in years when cereal grains are cheap to buy due to low commodity prices (although not currently the case). This was cited as a key disadvantage and reason some farmers interviewed had stopped mixed farming in favor of grass-only. Higher costs and being uneconomical without subsidies have similarly been identified as barriers to the inclusion of legumes in arable rotations in Europe (Mills et al. 2020), although this is a different practice to ley-arable. Further, arable machinery and implements are increasingly expensive and therefore unviable to purchase for small cropping areas. Cost of adoption, inefficient resource allocation and inability to access economies of scale are widely identified as key barriers to uptake of mixed farming and other climate mitigation practices (Bell and Moore 2012; Kragt, Dumbrell, and Blackmore 2017; Schut et al. 2021; Smith and Olesen 2010; Wreford, Ignaciuk, and Gruère 2017). This can result in reliance on contractors to complete work which is also costly and can be difficult to arrange for when conditions are suitable and the crop is ready, especially as contractors may not prioritize small jobs and their machinery can be too big for small fields and gateways.

> *"Price of gear . . . We'd have to get contractors to do everything, and then you're at their beck and call . . . I can see that, you know, there's some benefits to putting, you know, having a field of corn in, but I think it's cheaper not to." – Northumberland farmer 2*

Economic trade-offs were also highlighted, with some farmers recognizing the need to reduce the livestock kept on the farm if they used some fields to grow arable crops, and conversely an industry representative noted the reduction in total crop yields for arable farms that incorporated grass leys into their rotations (Table S4).

> *"I felt we were a bit overstocked last summer, I think, last year, when we had that dry period . . . I just felt that I wish I'd got a bit more grass. Probably haven't got the balance right still. I mean, you could argue, you know, reduce the stock numbers and keep the barley. But then I was able to buy barley last year for £145 a tonne at harvest . . . I just thought I could buy barley cheap. I wouldn't be able to say the same thing today barley's £200[1] a tonne." – Northumberland farmer 4*

Regarding sending stock away to temporary grassland or overwinter forage or cover crops, although no farmers interviewed did this, perceived benefits included: i) the ability to outwinter stock at low cost while resting their own

fields, ii) reduced dependence on bought-in inputs for overwinter feed, iii) a potentially reduced winter workload, and iv) for some, a low-cost way to enter the industry or increase their stock. In terms of disadvantages, both industry representatives and farmers identified lack of infrastructure to fence, water and handle stock on arable farms, particularly cattle, and labor to look after stock (either unavailability of skilled labor on or near arable farms with stock, or labor burden of livestock farmer having to travel to arable farm to look stock) (Table S4). These disadvantages are well-characterized as barriers to integrating livestock into arable and similar climate friendly or carbon farming practices (Bell and Moore 2012; Schut et al. 2021; Wreford, Ignaciuk, and Gruère 2017). This is accentuated by the difficulty for arable and livestock farmers to identify respectively interested parties to form partnerships, and the spatial separation of arable and livestock farming areas in the UK making transport and husbandry of livestock challenging and expensive (Table S4).

Factors influencing adoption

Rational reasons for non-adoption

Vanclay and Lawrence (1994) identified eleven categories of rational reasons that farmers may have for not adopting seemingly beneficial management practices: complexity of intervention, inability to trial or partially adopt, incompatibility with farm and personal objectives, loss of flexibility, risk of failure, conflicting information regarding benefits, cost of implementation, infrastructure requirements, and limited economic benefit. We consider each of these in turn and discuss the extent to which these may apply to the management practices studied here.

Capital outlay required for adoption was seen as an issue for rotational grazing in terms of fencing and water infrastructure required, herbal leys regarding the cost of reseeding, and ley-arable (mixed farming) in terms of the ability of livestock farms to afford arable equipment. However, the extent to which this constrained adoption depended on other aspects of the farms' circumstance. For example, farmers that had an existing small field structure (particularly relevant in Devon where maintaining or restoring hedges which created small fields had high cultural value) found it easier to adopt rotational grazing compared to farms with on average larger fields that would require substantial up-front investment to divide and provide water to. Furthermore, industry representatives noted that where farmers rented land on short-term leases this limited the viability of investing in infrastructure. Although electric fencing can provide a cheaper entry point for rotational grazing, this was not widely used by the adopting respondents here. Additionally, farmers that had diversified into contracting did not regard cost of equipment for mixed farming or reseeding as an issue due to already

the necessary machinery availability. The economics of adoption was mainly raised in relation to tree planting, due to perceptions that farming was a more profitable land use and the fact that planting trees overall cost farmers money even with grant support. Industry representatives also highlighted the long time before a return from timber harvesting, and uncertainty about future government support payments or carbon markets, as factors that negatively influenced the economics of tree planting. Mixed farming (ley-arable) also has economic constraints in market conditions where cereal animal feeds are cheaper for farmers to buy in than grow on farm.

Regarding congruence or compatibility with farm objectives, this was most clearly expressed for trees on farms by farmers who identified strongly as food producers or were reluctant to plant trees 'for the sake of it,' particularly where farms already had substantial tree and hedge cover. Conversely, where farmers felt their land lacked shelter or they had an interest in game shooting, the presence of trees or hedges on their farms helped them meet their objectives and was viewed positively. Rotational grazing and herbal leys were most likely to be incompatible with farm objectives where farmers had specialized systems. For example, one farmer provided supplementary cereal feed to finishing cattle during the grazing season so felt that moving feeders would be challenging in a rotational grazing system and did not prioritize grass productivity as highly because livestock performance was underpinned by the supplementary feed. Another bred pedigree cattle which required splitting the herd into small groups of varying sizes to run with different bulls for mating, which again made implementing a rotation system more challenging. Other farmers relied on high-performance perennial ryegrasses (*L. perenne*) for forage productivity and felt that including herb species that had received less plant breeding attention may struggle to compete in these swards. One industry representative identified that where farmers have exclusively permanent pasture, they are not conducting any reseeding so are unlikely to consider a herbal ley. Furthermore, industry representatives identified that some farmers are not adopting RG or HL as they are coming toward the end of their careers and so are scaling back their farming activities and reducing their workload. This is often correlated with a shift to relying on environmental schemes for income rather than farm productivity, so such farmers are not interested in management practices that increase workload for productivity gains that they don't want or need. This position may become less financially sustainable as the Basic Payment Scheme is withdrawn in England and replaced with Environmental Land Management schemes with anticipated lower net payments to be received by farms. Regarding adopting mixed farming (ley-arable) , non-adopting farmers highlighted a trade-off with stock carrying capacity if they used some land to grow crops, implying this was counter to their objectives.

The risk or uncertainty that a practice would deliver desired outcomes was seen as a particular issue for herbal leys. Some farmers cited concerns that the yield or productivity was unknown for them or could be less than conventional leys, and some herb species were seen to be unsuitable to a given farmer's climate or soil type. Relatedly, industry representatives noted that herbal leys can be difficult to establish, and more broadly that reseeding pasture comes with a risk of failure particularly if there is a high weed burden or drought conditions impair germination. This relates to conflicting information about the applicability or effectiveness of a practice; some farmers and industry representatives felt that any benefits of herbal leys could be equally achieved through well-managed grass and clover leys, and questioned whether herbal leys do in fact have anthelmintic properties. Regarding rotational grazing, there was also uncertainty about whether this would in fact improve forage or livestock growth, with one industry representative noting the potential for reduced livestock performance if rotational grazing wasn't managed correctly, and indeed acknowledgment in the literature that the perceived benefits of rotational grazing are not realized universally (Briske et al. 2011; Gillespie et al. 2008).

Loss of flexibility was perceived as a particular issue for herbal leys and trees on farms. Herbal leys need to be grazed rotationally and the stock removed in the winter to ensure persistence of more sensitive herb species, and there are ongoing concerns about ewe fertility on swards with a high red clover content. Regarding trees on farms, some farmers highlighted the inconvenience of in-field trees to their farming operations, and the loss of flexibility due to the permanence of land use change following tree planting via compulsory re-stocking requirements following felling. On the other hand, trees on farms are highly 'divisible' or trial-able (i.e. able to be partially adopted). This may partially account for the high level of uptake of this practice among respondents, as farmers have a high degree of control over the manner and scale of integrating trees onto their farms. In contrast, mixed farming (ley-arable) has low divisibility due to the economics of scale required to justify capital outlay in equipment.

Industry representatives identified farmer confidence as a factor limiting adoption of rotational grazing and herbal leys, corresponding with intellectual outlay (the requirement to learn new ways of doing things). Some farmers similarly identified they would need to seek advice from professionals or existing adopters before implementing these practices, and one farmer citing a lack of time and energy as part of the reason they had not tried growing herbal leys. However, the related issue of complexity was not raised for any of the management practices investigated here by farmers or industry representatives, i.e. although non-adopting farmers may need additional knowledge to implement these successfully, any potential increase in complexity is not deterring them. Physical and social infrastructure only appeared to be an

issue for ley-arable systems, in particular relating to sending stock to arable, due to i) the lack of infrastructure for livestock on arable farms (fencing, water, handling), ii) the widespread spatial separation of livestock and arable farming areas in England resulting in limited livestock availability close to arable farms, and iii) the difficulty of livestock and arable farmers identifying interested parties to form a partnership.

Although not included by Vanclay and Lawrence (1994) in their framework, farm geography (particularly climate and soil type) may be a further rational basis for why farmers do or don't adopt certain management practices. For example, one farmer viewed rotational grazing as unworkable on their farm due to concerns about soil damage from poaching in wet weather, exacerbated by that farm's poorly draining soils and high spring and autumn rainfall. Similarly, farmers in Devon (typically high rainfall including during the growing season) did not value the deep-rooted properties of herbal leys in delivering drought tolerance, whereas another respondent on shallow and free draining soils viewed deep rooting herbal leys as essential in ensuring sustained forage productivity on their farm. These inherent sources of variability between farms are potentially important in understanding differences in attitudes to adoption of certain management practices

Types of farmer

In our analysis of farmer interviews, four groups of farmers became apparent, based on their revealed priorities and reasons for adopting practices considered here or not. Firstly, some farmers appeared to be aware of and in agreement with the principles of Regenerative Agriculture (Moyer et al. 2020; Newton et al. 2020; Schreefel et al. 2020), and framed their farming decisions in this holistic context. These farmers had an ideological motive that adopting regenerative practices (RG, HL and trees on farms) is how farming should be done and the way livestock should be kept. This grouping would fall within the 'enthusiast/hobbyist' segment identified by Rehman et al. (2008) or Group B of DEFRA (2011), particularly in that farming was not the main source of income.

A second group could be described as Regenerative Agriculture practice pragmatists, in that they readily engaged with practices such as RG and HL without buying into the more holistic regenerative principles underlying these and would not see themselves as 'regenerative' farmers (Gosnell, Gill, and Voyer 2019). Instead, practices were adopted because they were perceived as the latest innovations to increase productivity, and as a means to future-proof the business to future subsidy changes. This could relate to the 'family orientation' segment identified by REHMAN et al. (2008) and Groups A or C of DEFRA (2011). This group also matches the perceptions of industry representatives that adopters of RG and HL tend to be younger and focused on

maximizing productivity, and potentially more progressive, open-minded, willing to try new things or 'forward thinking' in their outlook.

A third group were more explicitly business-focused, in that their priority in considering adopting practices was how much it could increase farm income, particularly relating to eligibility for farm support payments, and were reasonably clear-eyed in recognizing that land management decisions needed to be profitable and deliver an income from the farm. This corresponds with the 'business/entrepreneur' segment of Rehman et al. (2008) and Group C of DEFRA (2011). This was notably relevant to reasons for tree planting and accords with perceptions of industry representatives that owner occupiers are particularly likely to consider tree planting as a form of income diversification.

Finally, some farmers strongly identified as food producers. These farmers operated relatively intensive (use of inorganic fertilizers and cereal-based animal feeds) and largely conventional systems (e.g. didn't adopt RG or HL), and were wary of changes in management practice that would shift their enterprise focus from food production. These farmers expressed a strong desire to earn a livelihood from producing food without having to rely on government support payments. This could relate to the 'independent/small farmer' segment of Rehman et al. (2008) (although the farmers in question here were not small-scale producers) or Group D of DEFRA (2011). Industry representatives described non-adopters of RG and HL as typically more traditional or resistant to change, which may be correct in some instances but farmers in this group ran modern, productive systems and had rational reasons for not adopting these practices (Section 3.2.1).

Implications for policy

Knowledge exchange was seen as particularly important in facilitating adoption of rotational grazing and herbal leys by industry representative and farmers who had adopted each practice, and this could help address the constraints of risk or uncertainty, conflicting information and intellectual outlay (Section 3.2.1). Industry representatives referred to the benefits of case study farms and field trials, suggesting that demonstrating how to implement these in practice and the potential for productivity gains in particular could help convince non-adopting farmers. Farmers interviewed had a slightly different emphasis, highlighting the importance of talking to an existing adopter they know or trusted source of advice for pointers, advice and to learn from their mistakes. Regarding productivity, one farmer suggested they would appreciate the means to see the productivity benefits on their own farm (e.g. infrastructure to monitor livestock growth rates) rather than having to rely on industry-wide examples or case studies from 'model' farms. Another farmer wanted to gain experience from existing adopters but expressed frustration that they rarely have time to attend formal knowledge exchange events

such as monitor farm open days. This suggests potential limitations of the 'top-down' knowledge exchange model in reaching non-adopting farmers, corresponding with the findings of ROSE, Keating, and Morris (2018a) that farmers' informal networks and existing trusted sources of advice are currently under-utilized opportunities for knowledge exchange.

Perceptions of the role of government financial support differed between interventions. For rotational grazing, herbal leys and sending stock to arable farms, industry representatives and farmers widely suggested that capital grants to help with infrastructure costs (rotational grazing and ley-arable) or reseeding equipment (e.g. direct drills for herbal leys) would further increase uptake, rather than payments for adoption per se. This accords with the increasingly widespread acknowledgment that farmers are not simply motivated by profit maximization (Journeaux Et Al. 2018), but rather this form of incentive helps overcome the capital outlay constraint discussed in Section 3.2.1. Regarding sending stock to arable farms (ley-arable), respondents noted the risk of disparity if support payments are directed at arable farmers to encourage improved soil health without necessarily rewarding the livestock farmer who has provided the stock, which could be mitigated through careful scheme design. Farmers widely reported a net financial cost from planting trees even with government support payments, and it was suggested by both industry representatives and farmers that were this economic constraint (Section 3.2.1) overcome by increasing payment rates, in addition to sufficiently long-term maintenance payments, then farmers would readily plant more trees. Indeed, it is difficult to see how the UK government's tree planting targets will be met in England based on current levels of grant uptake (Jordon and Wentworth 2021). Again, crucially, this is not to assert that farmers are exclusively motivated by money, but rather to acknowledge that farmers cannot be expected to perform actions that deliver mostly public benefits at a net private cost to themselves (Vanclay and Lawrence 1994).

Conclusion

We provide an initial indication of the advantages and disadvantages of four management practices (rotational grazing, herbal leys, trees on farms and ley-arable rotations) from the perspective of selected English sheep and beef cattle livestock farmers. These have previously been demonstrated to increase farm productivity and/or carbon stocks and are already incentivized through various mechanisms by Defra in England (Table 1). However, we identify disadvantages to adopting these practices, which in turn contribute to rational reasons for farmers not to adopt. In addition, some farmers are more receptive than others to such practices based on their outlook and values. Given further adoption of these practices is likely required to meet the UK's climate change mitigation targets, we suggest how support available to farmers (knowledge exchange and

incentives) could be modified to promote uptake. Our findings also provide the basis for future work with a more rigorous theoretical underpinning, e.g. using the Theory of Planned Behavior, to understand the likely extent of further adoption of these practices.

It is key to recognize that complete uptake of some practices may not be i) desirable, as they are not universally beneficial, or ii) achievable, as some reasons for non-adoption such as farm geography or farmer objectives are not necessarily addressable through extension activities or incentives. Policymakers need to further recognize the rational reasons farmers have for not adopting seemingly beneficial interventions, in order to establish whether targets for increased uptake of certain management practices (e.g. tree planting) are achievable with the current incentive structures. This will be key in designing land management scenarios that not only address major challenges like climate change mitigation in theory (Climate Change Committee 2020) but are also achievable in practice.

Note

1. Correct at time of interview in December 2021

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