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# Identifying barriers to routine soil testing within beef and sheep farming systems

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ABSTRACT

Soil testing in agriculture is associated with many economic and environmental benefits. However, previous studies have shown that a significant proportion of beef and sheep farmers in the UK do not carry out standard soil index testing (pH, available Mg, P and K); with much fewer again carrying out more extensive soil tests (e.g., organic matter, micronutrients). This study identifies barriers and motivations to soil testing amongst the beef and sheep sector, using a combination of farmer surveys, expert interviews, and a 5-year soil testing dataset from the largest commercial UK soil testing laboratory. Evidence for differences in the adoption of soil tests by beef and sheep farmers compared to the arable and dairy sectors is explained in relation to: (1) the extent of soil pH and nutrient imbalances, linking to the intensity of management in the different sectors; and (2) the extent to which farmers perceive links between their soils and their outputs (profits, yield, livestock health). We show a greater likelihood for farmers to engage with soil testing when the links to declining outputs are clearer. Our results showed that beef and sheep farmers who did engage with soil testing showed greater levels of innovation and were more likely to seek advisory support, most often associated with larger farm sizes. Our data also highlights the importance of an output-driven approach to initiate an interest in soil analyses amongst less engaged farmers. We argue that this avenue offers greater potential for enhancement of farmers' knowledge of the soil system than a primarily regulatory-driven approach, where soil testing becomes a compulsory action but does not lead to subsequent improvements in farm management.

## 1. Introduction

Globally, soil degradation in agroecosystems represents one of the greatest threats to achieving food and water security and continues to undermine our efforts to combat climate change (Montanarella et al., 2016; Wuepper et al., 2020). This decline in soil quality is typically characterised by high rates of soil erosion, a loss of organic matter and nutrient imbalances arising from land use change, agricultural intensification and climate change (Borrelli et al., 2020). However, recent years have seen a growing recognition of the importance of soils and the gradual adoption of more sustainable farming practices (Bouma et al., 2012; Keesstra et al., 2016). Despite these advances, there is still considerable scope to improve basic soil management, especially through greater adoption of routine soil testing for agronomic use (Carlisle, 2016; Li et al., 2020).

One common approach used to improve on-farm nutrient use efficiency is through nutrient management planning, which include a range of soil quality metrics, known as standard soil index testing (e.g., pH, P & K indices and Mg content; AHDB, 2020). Despite promotion of the potential benefits of soil index testing to farmers (through various channels), low rates of soil index testing still exist within some farming sectors, namely amongst beef and sheep producers (Carlisle, 2016). For example, in England, only 51% of beef and sheep farmers regularly carry out soil index tests compared to 89% of dairy farms and 97% of arable (DEFRA, 2013).

The lower rates of soil index testing adoption by the beef and sheep sector raises particular concerns. This is because soil testing provides opportunities for farmers to optimise productivity and reduce inefficient

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resource use (Goulding et al., 2008; Kettering et al., 2012), which can help ensure financial resilience at a time where state aid and farm subsidies are dramatically declining. Whilst many beef and sheep farms are less intensively managed than arable and dairy systems (with lower stocking and input levels), particularly those in upland areas and/or with areas of high environmental value, factors including topography, soil fragility and weather extremes mean these farms can be particularly sensitive to nutrient imbalances and losses (Caporn and Emmett, 2009; Orr et al., 2008). Given these concerns, and the distinctive characteristics of beef and sheep farms, tailored analysis to understand the behaviours and rationale of these farmers is needed to ensure widespread adoption of soil index testing in the future.

As our understanding of soil health improves, it has become apparent that a more holistic approach to soil testing that incorporates the physical, biological and chemical aspects of soils, rather than relying on a small suite of indicators through soil index testing (e.g., pH, P, K and Mg), can be more informative and beneficial for making farm management decisions. It has also been argued that the simplicity of current soil index testing impedes knowledge transfer between farm advisors and farmers (De Bruyn and Andrews, 2016). The use of additional soil tests beyond soil index testing (e.g., for micronutrients, organic matter content, soil texture and microbial biomass) are readily available from soil testing facilities across the UK but are not readily adopted. For example, in England only 35% of all farms (across all farming sectors) monitor soil organic matter (DEFRA, 2018, 2013). However, the reasons why and/or more advanced soil testing is not undertaken by farmers are unclear, preventing the design of effective campaigns to promote greater adoption to improve farm sustainability. For the purpose of this study, we define soil index tests used for agronomic purposes, that assess the lime and fertiliser/manure application needs to optimize crop production, as 'soil tests'; and those that help with other agronomic decisions and/or used to monitor soil health as 'advanced' soil tests.

Research into how farmers' perceptions of soil testing influences farm practice has been longstanding, but the lack of widespread adoption remains unresolved (Brandt, 2003; Daxini et al., 2018; Dessart et al., 2019; Hyland et al., 2018; Ingram et al., 2010; Osmond et al., 2015; Prager and Posthumus, 2011). Various socio-economic, cultural, institutional and environmental factors can influence a farmer's decision to engage with soil testing (Dessart et al., 2019; Hyland et al., 2018; Prager and Posthumus, 2011). However, the sectoral differences in soil testing adoption rates previously noted are largely unexplained; though larger, more intensive farms are more commonly seen to test (DEFRA, 2013). Daxini et al. (2018) emphasize the importance of psychological factors alongside socio-economic parameters, particularly attitudinal response and social norms, which reflect the benefits perceived from undertaking particular behaviours and whether wider peer and public pressure is felt. Better understanding of why and how positive attitudinal traits develop would advance these insights further. Regulatory pressure can also be a critical driver for soil testing, and has continued to increase in recent years (DEFRA and EA, 2018; Scottish Statutory, 2017; Welsh Government, 2020). However, regulation to enforce testing does not necessarily translate into changes in management (Daxini et al., 2018). The potential reasons for this include a lack of awareness or perceived benefit amongst farmers, reliance on customary practise, and associated costs and difficulties with implementation (Brandt, 2003; Hyland et al., 2018; Ingram, 2008; Ingram et al., 2010; Osmond et al., 2015). In these instances education therefore seems key, though despite marked educational efforts in recent years (Ingram, 2008; Krzywoszynska, 2019; Puig de la Bellacasa, 2015) some farmers do not appreciate the potential benefits of better management of their soils (Ingram, 2008; Krzywoszynska, 2019). In turn, this study aims to (i) understand why the beef and sheep sector has a much slower soil testing adoption rate in comparison to the arable and dairy sector, and (ii) ascertain what socio-economic and psychological factors are associated with soil testing and planned management behaviours.

## 2. Materials and methods

### 2.1. Grassland and arable soil indices status

To understand the influence of soil indices on farmers' likelihood to soil test, we investigated differences in soil pH, P & K indices and Mg content between grassland (this encompasses the dairy, beef and sheep, as the dataset did not allow for a split between these sectors) and arable soils. These indices were chosen as they are the recommended parameters to determine lime and fertiliser/manure requirements for optimal crop production, as outlined by the RB209 fertiliser manual guidelines (hereon noted as 'RB209′) (AHDB, 2020). This was done using the soil analysis data collected by a major UK soil testing lab. The database constituted the results of samples submitted by farmers and/or consultants over a 5-year period (2013–2017). For each soil variable, we calculated the proportion of samples from grassland or arable land that were lower, optimum and/or higher than the recommended values for the corresponding farming sector stated in RB209 (AHDB, 2020). In this way, differences in relative soil indices were compared between the sectors to determine whether this could be influencing the farmer's decision to soil test. To ensure that samples were from a 'continuous' land use (grass or arable), these comparisons were made on a subset of soil samples that classified both the previous and next crop as either arable or grassland, resulting in 92,001 and 73,454 samples from each sector, respectively.

### 2.2. Beef and sheep farmers survey

To attain broad-scale insight into the levels of engagement with soil testing amongst beef and sheep farmers, we surveyed 302 such farmers from across the UK. This was administered online using Kobo Toolbox and widely publicised in the farming press and on social media, and conducted face-to-face at key agricultural events between June and December 2019. The survey was designed to derive primarily quantitative information on the following points:

- Respondent demographics
- Farm business characteristics
- If/how they tested their soils
- Attitudes and rationale regarding soil testing
- Current and future management practices (responding to test results/not)
- The influence of regulatory pressures

The profile of survey participants can be found in Table 1. Some open-response questions were also included to provide additional qualitative detail to support analysis of the quantitative data. Questions were devised to capture both socio-economic and attitudinal factors, including perceptions of soil testing and links to outcomes, following recommendations from recent studies (see e.g. Daxini et al., 2018).

All statistical analysis of the survey data was carried out using the statistical programme R (R Core Team, 2019). We used linear discriminant analysis to calculate the average marginal effects of each factor that may contribute to a livestock farmer's decision to soil test. The response and explanatory variables included in the model are summarised in Table 1. An Innovation score and Positive soil testing perception score was calculated for each participant as the sum of answers to relevant questions associated with each, as detailed in Table 1.

We used the 'factoextra' R package (Kassambara and Mundt, 2019) to perform hierarchical clustering analysis on participants' Likert responses (0–1) to statements about how important they perceive soil testing can be in improving animal health, yield (of grass), profit, soil health and forage (grass or conserved grass) quality. We determined the optimal number of clusters through k-means partitioning methods to be $n = 3$. Respondents were grouped into their respective farmer group clusters and Kruskal-Wallis tests were performed for each Likert. This

**Table 1**
Summary description of response and explanatory variables with their associated levels used for binomial regression and the percentage of respondents within each level. We utilised soil testing as our response variable and all other variables as explanatory variables.

| Variables | Levels | Description for level | Percentage of total respondents (n = 302) |
|---|---|---|---|
| Soil testing | Yes | | 81 |
| | No | | 19 |
| Age | Younger than 54 | | 63 |
| | Older than 54 | | 37 |
| Education | Further education | Farmers with a level 4 qualification* (UK Gov Standard) or above were considered to have further education. | 63 |
| | Lower education | | 37 |
| Farm size | Small Farm (SLR $\leq$ 2) | Standard Labour Requirements (SLR) are a coefficient that represents the notional amount of labour required by a holding to carry out all of its agricultural activity and were calculated for each participating farm (Defra, 2014). | 68 |
| | Large Farm (SLR > 2) | | 32 |
| Tenancy | Yes | Participants with the whole or part of farm were considered as tenancy farmers. | 57 |
| | No | | 43 |
| Sector | Sheep | | 22 |
| | Beef | | 14 |
| | Both | | 63 |
| Farm turnover | Below Average Turnover | Participants who stated their turnover to be equal to or below £25,000 was considered to have a below average turnover for the grazing sector (DEFRA ONS, 2015). | 16 |
| | Above Average Turnover | | 84 |
| Agri-environment scheme | Within an Agri-environment scheme | | 50 |
| | Not within and Agri-environment scheme | | 50 |
| Diversification | Diversifying | | 76 |
| | Not Diversifying | | 24 |
| Engaging with independent advisors/consultants | Yes | | 32 |
| | No | | 68 |
| Innovation score | 0 – 1 (Low Innovation to Highly Innovative) | Participants were scored with an innovation score as the sum of the number of options chosen with regards to management practices made in the last 5 years to improve forage quality, animal genetics, soil pH, yields, prepare for flood and drought events and to incorporate new technologies onto the farm and divided by 6. | |
| Positive soil testing perception | 0–1 (Negative to positive perception) | Participants were scored with a positive perception score as the sum of five answers to 5-point Likert questions linking the importance for soil testing with positive on farm outcomes to animal health, profit, soil health, forage quality and yield and divided by 5. | |

* this is equivalent to a Higher national certificate (HNC), Certificate of higher education (CertHE), or Level 4 NVQ.

was followed by a Dunn multiple comparisons test (Dunn, 1964) to determine differences between farmer groups for each Likert question.

Binomial regressions were used to determine whether groupings differed characteristically (e.g. Age) and behaviourally (e.g. Innovation score) for attributes that were not included in the hierarchical cluster analysis.

### *2.3. Stakeholder interviews*

To provide further qualitative insight on farmers' behaviours, and the reasons underpinning these, interviews with eight expert stakeholders was undertaken in August-September 2019. This primarily involved farm advisory consultants who worked with farmers across the UK to offer support and advice on soils and associated farm management practices. Some of these advisors worked across all farm sectors (4 respondents), whilst others were selected specifically for their specialism in pasture-based livestock (3 respondents). Respondents from soil testing laboratories, who were also involved in extension activities, were also interviewed (1 respondent). Respondents each had over ten years' experience working in the sector and each work with a at least a hundred diverse farms on a regular basis, therefore providing insights from a wide cross-sector of the industry.

Interviews lasted between 30 and 60 min and were audio recorded to support transcription and subsequent thematic analysis. All respondents, for both interviews and the survey, were given a project information sheet and provided their informed consent prior to questioning. Saturation in themes was reached after eight interviews, meaning further data capture was not necessary.

## 3. Results and discussion

### *3.1. Understanding differences in motivations to soil test between sectors*

We found that 99.2% of arable soil samples sent for analysis and 98.6% from grasslands (dairy, beef and sheep) did not meet the optimum recommended UK guidelines for at least one of the four soil quality indicators (pH, P, K and Mg; Fig. 1). These results indicate that underperforming soils (i.e., soils that do not meet the soil indices criteria for optimal crop production) are an influential driver in a farmers' motivation to soil test.

Due to the more intensive nature of arable systems and their greater crop offtake rates (Chiari et al., 1989; Withers et al., 2006), these soils may more readily suffer nutrient or pH imbalances in comparison to grassland soils (Muhammed et al., 2018). This was reflected by the data that showed a lower proportion of soils from arable farms to have optimal pH compared to soils from grassland farms (15% and 37%

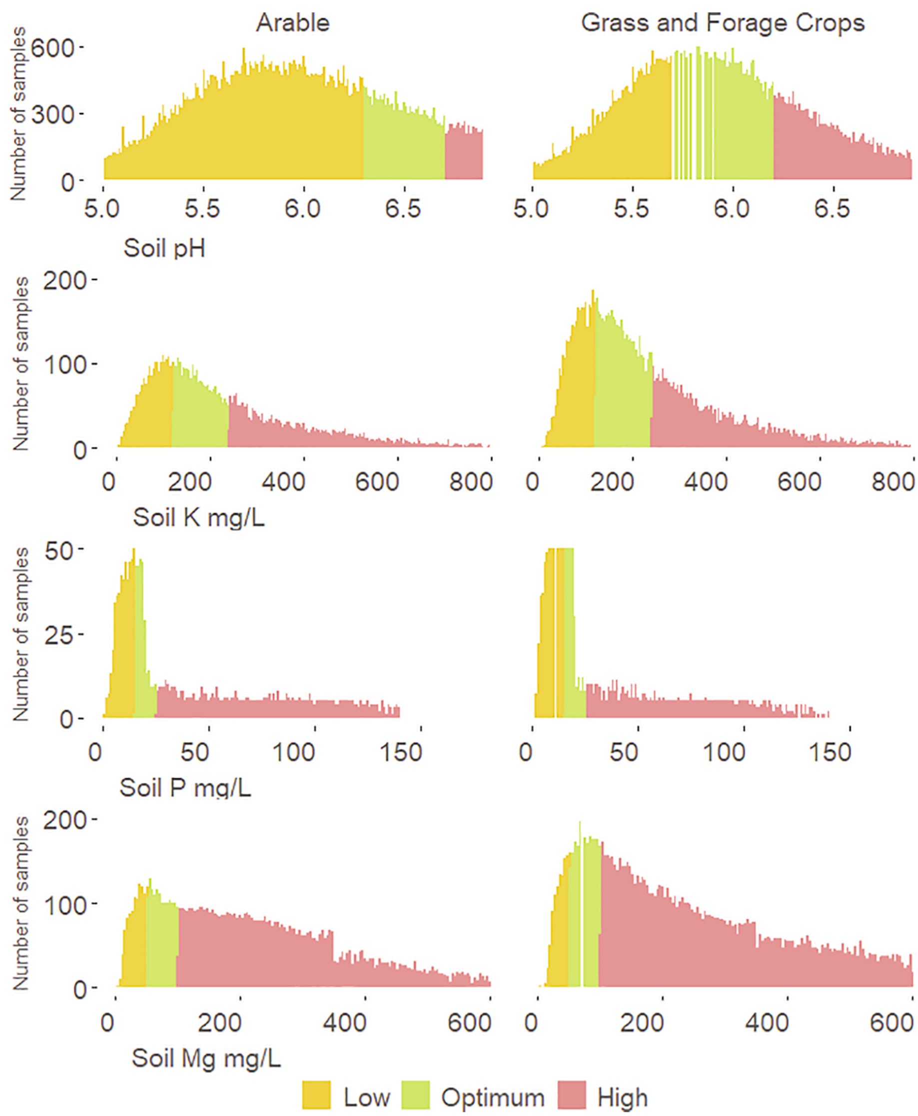


**Fig. 1.** Number of samples over 5 years sent into a major UK soil testing lab for analysis that are lower (yellow), optimum (green) and higher than the UK RB209 agronomic guidelines for soil a) pH b) K index c) P index and d) Mg index recommendations on arable and grass and forage crop field (arable $n = 92{,}001$ grassland and forage crops $n = 73{,}454$).

respectively, Fig. 1). On-farm productivity monitoring also varies between these sectors; arable farmers base this on crop yields, whilst grassland farmers traditionally focus on their livestock (e.g., growth, weight, health, milk yield, etc.). When productivity is compromised, the role of soil indices may therefore be more apparent for arable farmers due to the more direct soil–plant relationships compared to the indirect soil–plant-livestock relationships. The resulting realisation that their soil is underperforming thus explains the higher levels of soil testing adoption by arable farmers than grassland beef and sheep farmers across the UK (DEFRA, 2013). These differences in focus and awareness were outlined by interviewed experts:

> "The combine harvester tells [arable farmers] exactly what each field is doing [in terms of yields] but within the livestock sector very few [farmers] are measuring grass yield and quality (Expert 3)"
> "Arable farmers aim to produce the maximum yield possible […] grassland farmers aim to produce just enough grass for their livestock (Expert 1)"
> "[Beef and sheep farmers'] primary focus, in my experience, is always going to be their [livestock], not their soil. (Expert 7)"

Despite this, grassland farmers are increasingly being encouraged to assess visual soil parameters (e.g., compaction or earthworm counts Guimarães et al., 2011) and to monitor grass yield to better make the link between soil condition and farm productivity (AHDB, 2018a, 2018b). However, it appears that this has not been widely adopted by the beef and sheep sector (Forager, 2017) compared to the dairy sector, the latter generally being more engaged with such monitoring practices and thus more readily associate productivity with soil conditions and input management (Beegle et al., 2000). In turn, this helps explain their higher levels of soil testing compared to beef and sheep farmers (DEFRA, 2013). This notion was supported by Expert 4:

> "I think some of the dairy [farmers] are a little more in tune with soil testing, with them being more intensive systems. They also have more of a history of soil and tissue testing. (Expert 4)"

Furthermore, dairy farms produce more manure that is stored in fully liquid slurry storage systems compared to beef and sheep farms (DEFRA, 2013), which has also been shown to be positively associated with increased adoption of soil testing (Buckley et al., 2015).

We found that motivations to soil test are also linked to engagement with independent advisors (Fig. 2), which differs between farming sectors. Traditionally, a higher proportion of cereal and dairy farmers seek

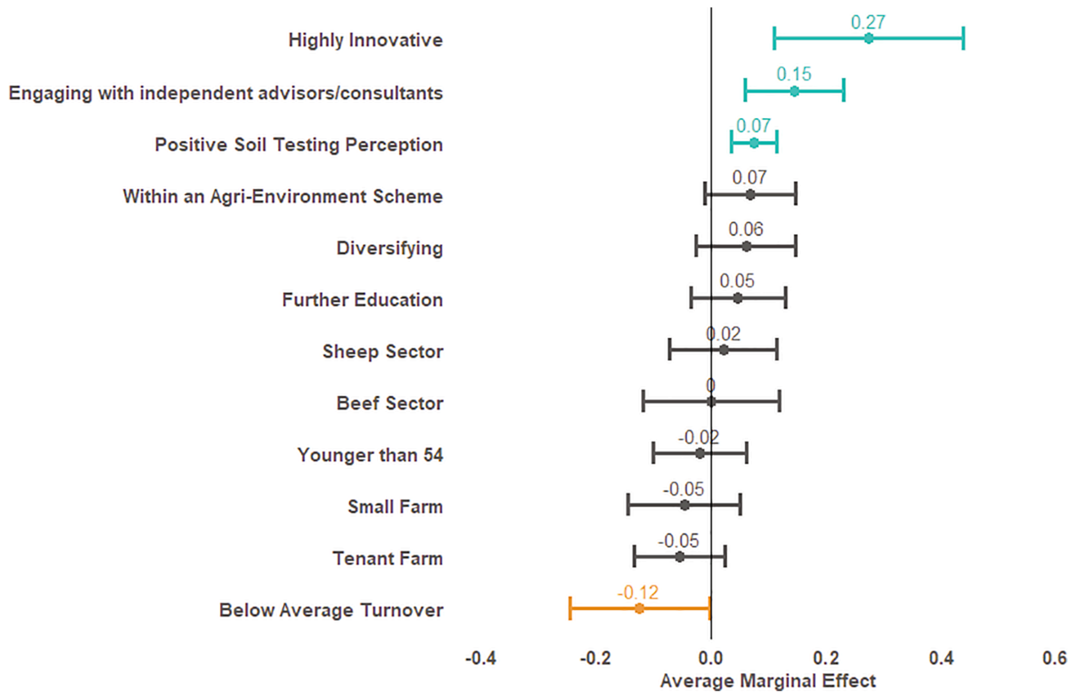


**Fig. 2.** Predictors for soil testing among grassland beef and sheep farmers. The estimated average marginal effects derived from a logit binomial model predicting whether survey participants soil test or not. Factors significantly influencing farmers to soil test are represented in blue and factors influencing farmers not to test are represented in orange. Horizontal lines from each data point 95% confidence intervals. See SI appendix for full regression output.

this type of advice for nutrient management planning compared to beef and sheep livestock farmers (85%, 78% and 59%, respectively DEFRA, 2019). We found that 55% of the beef and sheep farmers who soil test do so without help from an independent advisor. This highlights a clear lack of engagement with independent advisors amongst beef and sheep farmers which is also likely to be contributing towards adoption differences between sectors. As expressed by Expert 1:

> "Most arable farmers will have an agronomist… grassland farms, particularly smaller family-run farms will not have an agronomist or any other link to a company that provides this service. (Expert 1)"

As the above comment highlights, farm size may also be a corresponding factor determining farmer engagement with advisors. Hence, the distinction is not just one of farm type, but that farm type often correlates with size, with dairy and arable predominantly being larger farms (DEFRA, 2015).

### *3.2. Understanding beef and sheep farm(er) characteristics associated with (not) soil testing*

In descending order of average marginal effect, the significant factors that differentiated farmers who engaged in soil testing from farmers that did not included a higher farmer innovation score, engagement with independent advisors, higher farm turnovers and positive perception of soil testing (Table 1; Fig. 2). These findings are strongly aligned with similar factors identified in the wider literature (Daxini et al., 2018; Dessart et al., 2019; Hyland et al., 2018; Prager and Posthumus, 2011).

We saw that increased likelihood to soil test was correlated with reported adoption of other forms of innovation (High innovation score, Fig. 2) and hence these farmers seemed to be more actively adopting new practices to improve their farm systems rather than relying on customary practice. It was also notable that our farmer innovation score is co-correlated with the positive soil testing perception factor, which aligns with wider reporting that farmers adopt new technologies and/or farm practices when they perceive that an innovation will lead to positive impacts (see also Pannell et al., 2006).

We also found that engagement with an independent advisor increases the likelihood a farmer would soil test by 15% (Fig. 2). This demonstrates the crucial role advisors play initiating soil awareness, linking soil condition (e.g. soil indices) to farm productivity and supporting farmers to make appropriate management decisions based on test results (Daxini et al., 2018; Ingram, 2008). Farm turnover was also identified as an important factor (Fig. 2), where farmers with a below average turnover were 12% less likely to soil test (Fig. 2). This is likely to be linked to farms with higher financial turnovers generally being associated with more intensive systems, which typically have greater use of resources, and greater financial capacity to engage with advisors and implement the measures advised. Despite farm size not significantly contributing to soil testing adoption (Fig. 2), we saw a general trend where soil testing adoption is less frequent on smaller farms, similar to Ribaudo and Johansson (2007) and Daxini et al. (2018). This also aligns with a wider acknowledgement that small farmers have lower levels of turnover (DEFRA, 2015).

Finally, we found that farmers with a negative attitude towards soil testing were less likely to adopt soil testing than those who were more positive (Fig. 2), due to a general lack of awareness or perceived benefit. This was further confirmed by 49% of non-soil testers reporting that they "didn't see the point" of soil testing. This aligns with the findings of Daxini et al. (2018) on the psychological parameters underpinning decision making.

To further our understanding on how differences in soil testing perceptions influences the likelihood to soil test, we utilised hierarchical cluster analysis to identify distinct farmer groups based on how important they thought soil testing was for improving animal health, profit, soil health, forage quality and yield (these responses were averaged together to produce the perception parameter within our binomial regression). We identified three distinct groups (Fig. 3); 1) *The Engaged* farmers that expressed the highest level of positivity towards soil testing and had the highest engagement with soil testing, 2) *The Semi-engaged* farmers who expressed slightly more conservative views than *The Engaged* but still demonstrated high soil testing adoption, and 3) *The disengaged*, who expressed less confidence for soil testing improving

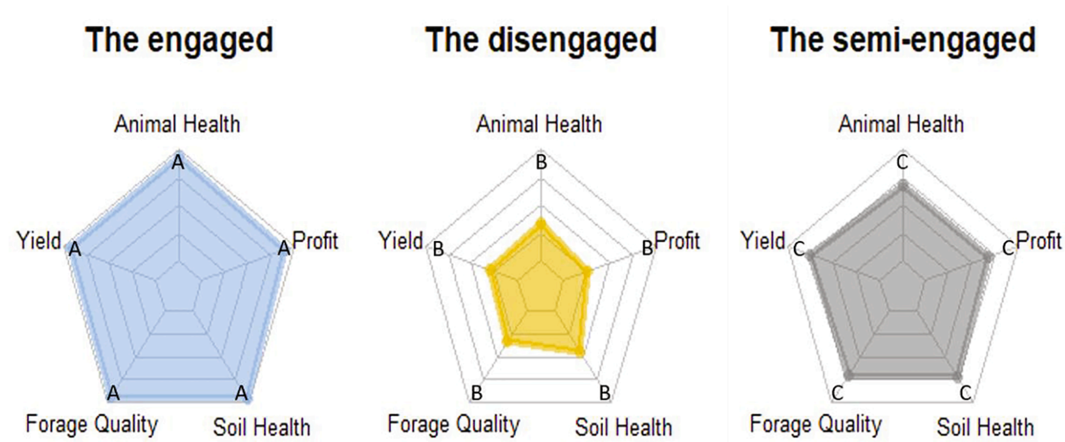


**Fig. 3.** Radar charts showing the average Likert responses (0–5: Not important - Very Important) to questions on how important farmers thought soil testing was for improving animal health, profit, soil health, forage quality and yields for each farmer group identified (Engaged, Semi-engaged, Disengaged). Letters denote significant differences between identified farmer groups for each question answered.

most aspects on the farm and a much lower proportion of which engaged with soil testing. This supports our findings from our binomial regression analysis by reinforcing the association between positive soil testing perceptions and soil testing adoption (Fig. 2, Fig. 3 and Fig. 4a).

The characteristics of our identified farmer groups found that *The Disengaged* had a much higher proportion of older farmers than *The Engaged* and *Semi-engaged* (Fig. 4c). Although our binomial analysis did not determine age as a contributing factor for poor soil testing adoption, when splitting the data into groups, it was clear that age influenced soil testing perceptions (Fig. 4c) and consequently adoption (Buckley et al.,

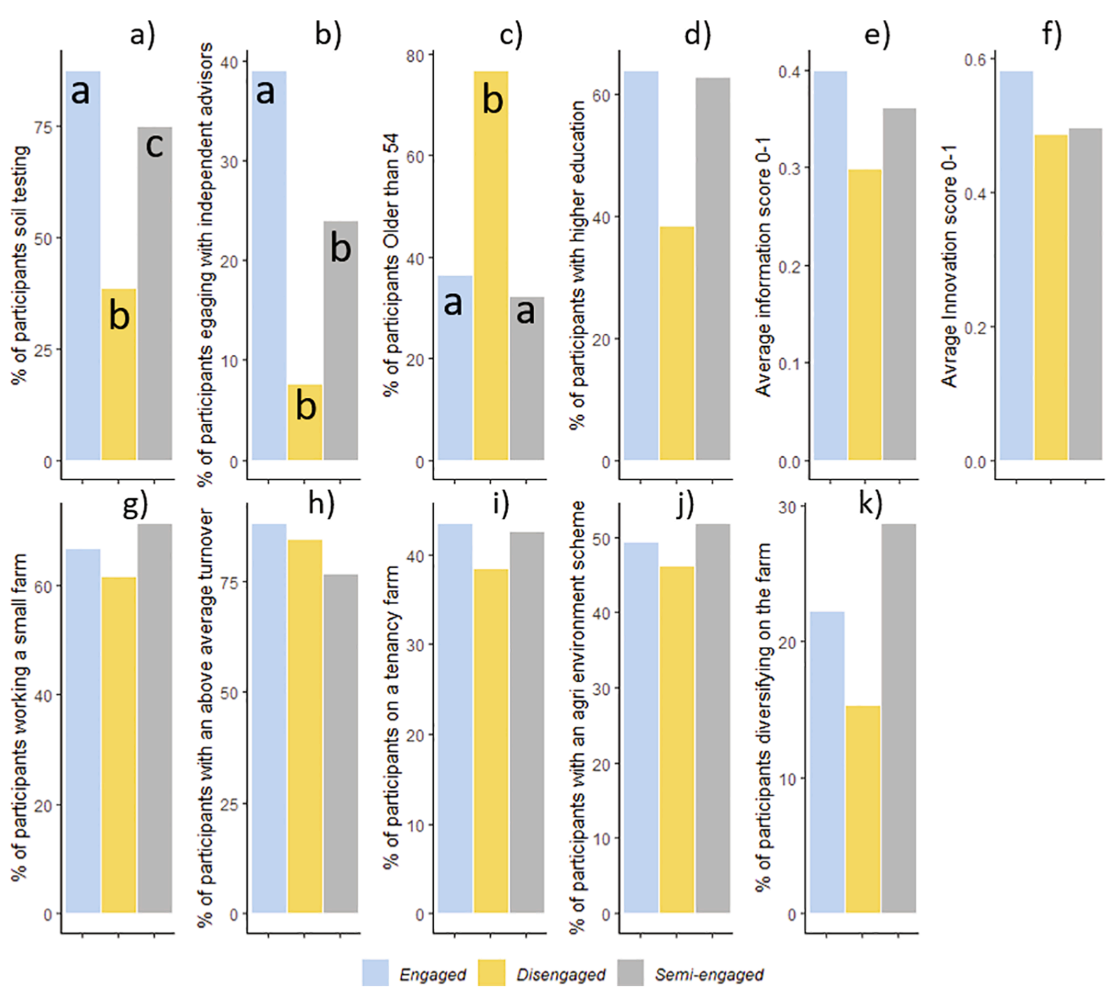


**Fig. 4.** The percentage of participant a) soil testing, b) engaging with independent advisors, c) older than 54, d) with higher education, e) information score, f) innovation score, g) on a small farm, h) with an above average turnover, i) on a tenancy farm, j) within an agri environment scheme and k) diversifying on the farm within each farmer group (Engaged, Semi-engaged, Disengaged). Different letters denote significant differences between farmer groups.

2015). Our identified farmer groups and their characteristics were also strongly supported by interviewed experts;

> "You get more progressive, interested farmers that are engaged and take advantage of soil workshops. They read the literature and they learn. And then you have other farmers who are less engaged and just doing things how they've always done. (Expert 1)"
> "There is a better understanding of the importance of soils with [younger farmers]. (Expert 3)"

*The Engaged* placed higher importance on the perceived benefits soil testing offers for improvements to each of these aspects on the farm, animal health, profit, soil health, forage quality and yield compared to *The Semi-engaged* and *Disengaged* (Fig. 3), as did *The Semi-engaged* when compared to *The Disengaged.* These findings highlight the need to reinforce how soil testing has the potential to benefit the farm, which corresponds to arguments made in section 3.1, regarding the importance of connecting soil to measurements of productivity/optimisation.

To fully appreciate the particularities of the beef and sheep sector, it is important to note that within our high soil testing adoption groups, *The Engaged* and *Semi-engaged*, we still found a small proportion of farmers who do not soil test (Fig. 4a), suggesting that in some instances farmers selectively choose not to soil test, even though they report a general awareness of the benefits soil testing can bring. This can be due to several factors that constrain production or ambition to maximise productivity, such as farmland that is part of an environmental scheme that prohibits application of high input levels (Welsh Government, 2019).

Of those livestock farmers that did not soil test, 22% stated that this was because they were satisfied with their productivity and did not intend to increase grass growth to meet their feed requirements. This is not unsurprising – typical nutrient application rates (as both fertiliser/manure) on extensive beef and sheep farms are often considerably lower than what is recommended to increase grass yields (AHDB, 2020; British Survey of Fertiliser Practise, 2019). Nutrient application recommendations based on soil index tests from such farms could therefore be notably higher than those rates currently applied. The environmental costs of such farmers acting on this advice, such as greater potential for eutrophication and greenhouse gas emissions from greater application of fertilisers/manures should be considered. From an economic perspective, there is a rationale for better optimisation of productivity, but it was notable that 24% of respondents did not test due to perceived 'high costs associated with acting on advice'. For example, liming to increase soil pH can cost more than the value of the extra return (Gibbons et al., 2014). Critical to this is whether recommendations following testing would reveal scope to optimise interventions within financially beneficial margins.

### 3.3. Soil testing adoption through policy

Finally, we consider the impact of policy. Here, we found that 65% of those farmers that were soil testing reported policy as a factor that influenced their decision to test (19%, important, 18%, fairly important and 28% very important). However, such regulation has only recently been implemented in England and whilst other countries in the UK are also likely to follow (DAERA, 2019; DEFRA and EA, 2018; Scottish Statutory, 2017; Welsh Government, 2020; DAERA, 2019; DEFRA and EA, 2018; Scottish Statutory, 2017; Welsh Government, 2020) this perceived pressure could therefore increase in the future. However, compulsory soil testing may not necessarily translate into good management behaviours (Daxini et al 2018). Instead, Daxini et al. (2018) and experts we interviewed felt that a notable proportion of farmers were just doing the minimum to meet regulatory requirements, and engagement with testing was not substantively improving their understanding of, or care for, their soil.

> "I want nutrient management plans to be used and not just stored in preparation for inspection … I worry the legislation is going to take us away from all the good work [advisors have] been doing to encourage good soil testing practice, and therefore it just becomes a compliance exercise… (Expert 3)"

Our survey results do not reflect these fears, showing that a high proportion of farmers were following the management advice for nutrient application rates (as both fertiliser/manure) and lime application rates based on their soil index tests (data not shown), with only a very small proportion ignoring the advice altogether (which was often explained in relation to environmental restrictions, connecting with points outlined above). However, the concerns raised by the interviewed advisers is clearly reflected in the wider literature. This is perhaps due to difference in context across different studies, with regulatory obligations more widespread in Ireland than in parts of the UK for example (Daxini et al., 2018).

### 3.4. Advanced soil testing

In line with DEFRA (2018, 2013), we found far fewer beef and sheep farmers to undertake advanced soil tests compared to conventional soil index testing (Fig. 5). Reasons for this are likely to be similar to those we identified with poor soil index testing adoption. Furthermore, poor adoption is also likely to be associated with the lack of standardised protocols, guidance as to which tests farmers should be engaging with and how to interpret the results (Briggs and Eclair-Heath, 2017).

## 4. Conclusions

Our analysis explores the influence of soil condition, socio-economic factors and psychological factors associated with lower levels of soil index testing amongst the UK beef and sheep sector, compared to their dairy and arable counterparts. We argue that it is accentuated by the characteristics of the beef and sheep sectors, where farms are generally smaller, have a lower turnover and engage less with advisory support compared to arable and dairy counterparts (Chiari et al., 1989; DEFRA ONS, 2015). Whilst this might appear to offer a poor prognosis for improved adoption in the future, our data also affirms the importance of an output driven approach to support farmer engagement with soil testing. We argue this approach offers greater potential to enhance farmers' knowledge of the soil system than a primarily regulatory driven approach, where soil testing becomes compulsory but does not necessarily lead to good management practice.

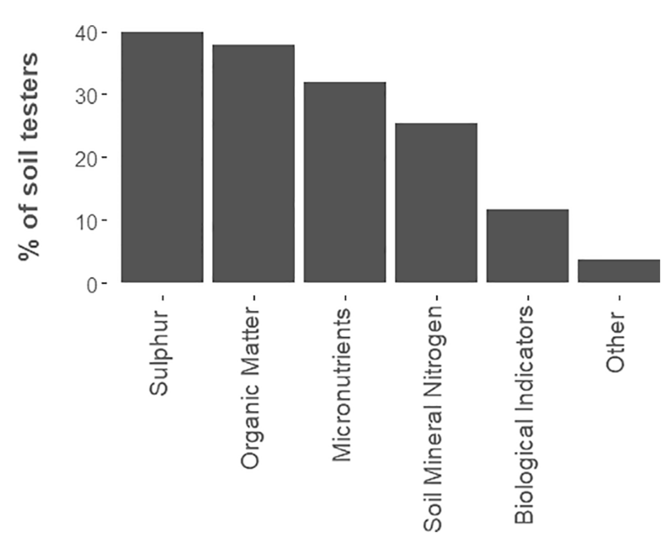


**Fig. 5.** Percentage of beef and sheep farmers who undertake advanced soil testing beyond the basic soil index testing.

Finally, our analysis raises some points of caution, firstly for extensive farms with high environmental importance, the imperative to soil test seems less obvious as farmers may be restricted (through environmental schemes) in their capacity to act on recommended inputs from soil test results. Secondly, if farmers are not aware of an apparent economic return from soil testing, farmers would be less inclined to do so. Nonetheless, these should be considered in future policy and market contexts where the need to optimise grass production and utilization will be fundamental to the survival, and ultimate success, of farmers in these sectors.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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