

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

Rhymes, Jennifer; Wynne-Jones, Sophie; Williams, Prysor; Harris, Ian; Rose, Duncan ; Chadwick, Dave; Jones, Davey L.

Geoderma

DOI:

[10.1016/j.geoderma.2021.115298](https://doi.org/10.1016/j.geoderma.2021.115298)

Published: 15/12/2021

[Cyswllt i'r cyhoeddiad / Link to publication](#)

Dyfyniad o'r fersiwn a gyhoeddwyd / Citation for published version (APA):

Rhymes, J., Wynne-Jones, S., Williams, P., Harris, I., Rose, D., Chadwick, D., & Jones, D. L. (2021). Identifying barriers to routine soil testing within beef and sheep farming systems. *Geoderma*, 404, Article 115298. <https://doi.org/10.1016/j.geoderma.2021.115298>

Hawliau Cyffredinol / General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

1 **Identifying barriers to routine soil testing**
2 **within beef and sheep farming systems**

3 Jennifer M Rhymes^{1*}, Sophie Wynne-Jones¹, A Prysor
4 Williams¹, Ian M Harris¹, Duncan Rose², David R
5 Chadwick^{1,3}, David L Jones^{1,4}

6 ¹School of Natural Sciences, Bangor University, Deiniol Road,
7 Bangor, Gwynedd, LL57 2UW, UK

8 ²NRM Laboratories, Bracknell, Berkshire, UK

9 ³Interdisciplinary Research Centre for Agriculture Green
10 Development in Yangtze River Basin, Southwest University,
11 Chongqing, China

12 ⁴UWA School of Agriculture and Environment, The
13 University of Western Australia, Perth, WA 6009, Australia

14

15 **Highlights**

- 16 • Fewer UK beef & sheep farmers adopt soil index tests
17 than farmers from other sectors.
- 18 • We explored factors influencing soil testing adoption
19 in the beef & sheep sector.
- 20 • Differences in pressures and practice explain sectoral
21 differences in soil testing.
- 22 • Beef & sheep farmer engagement with advisors results
23 in higher use of soil test data.
- 24 • Linking soil condition to farm outputs is more likely to
25 prompt greater engagement.

26

27 **Abstract**

28 Soil testing in agriculture is associated with many
29 economic and environmental benefits. However, previous
30 studies have shown that a significant proportion of beef and
31 sheep farmers in the UK do not carry out standard soil index
32 testing (pH, available Mg, P and K); with much fewer again
33 carrying out more extensive soil tests (e.g., organic matter,
34 micronutrients). This study identifies barriers and motivations
35 to soil testing amongst the beef and sheep sector, using a
36 combination of farmer surveys, expert interviews, and a 5-year
37 soil testing dataset from the largest commercial UK soil testing

38 laboratory. Evidence for differences in the adoption of soil
39 tests by beef and sheep farmers compared to the arable and
40 dairy sectors is explained in relation to: (1) the extent of soil
41 pH and nutrient imbalances, linking to the intensity of
42 management in the different sectors; and (2) the extent to
43 which farmers perceive links between their soils and their
44 outputs (profits, yield, livestock health). We show a greater
45 likelihood for farmers to engage with soil testing when the
46 links to declining outputs are clearer. Our results showed that
47 beef and sheep farmers who did engage with soil testing
48 showed greater levels of innovation and were more likely to
49 seek advisory support, most often associated with larger farm
50 sizes. Our data also highlights the importance of an output-
51 driven approach to initiate an interest in soil analyses amongst
52 less engaged farmers. We argue that this avenue offers greater
53 potential for enhancement of farmers' knowledge of the soil
54 system than a primarily regulatory-driven approach, where soil
55 testing becomes a compulsory action but does not lead to
56 subsequent improvements in farm management.

57

58 **1. Introduction**

59 Globally, soil degradation in agroecosystems
60 represents one of the greatest threats to achieving food and
61 water security and continues to undermine our efforts to
62 combat climate change (Montanarella et al., 2016; Wuepper et

63 al., 2020). This decline in soil quality is typically characterised
64 by high rates of soil erosion, a loss of organic matter and
65 nutrient imbalances arising from land use change, agricultural
66 intensification and climate change (Borrelli et al., 2020).
67 However, recent years have seen a growing recognition of the
68 importance of soils and the gradual adoption of more
69 sustainable farming practices (Bouma et al., 2012; Keesstra et
70 al., 2016). Despite these advances, there is still considerable
71 scope to improve basic soil management, especially through
72 greater adoption of routine soil testing for agronomic use
73 (Carlisle, 2016; Li et al., 2020).

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

85 The lower rates of soil index testing adoption by the
86 beef and sheep sector raises particular concerns. This is
87 because soil testing provides opportunities for farmers to

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

103 As our understanding of soil health improves, it has
104 become apparent that a more holistic approach to soil testing
105 that incorporates the physical, biological and chemical aspects
106 of soils, rather than relying on a small suite of indicators
107 through soil index testing (e.g., pH, P, K and Mg), can be more
108 informative and beneficial for making farm management
109 decisions. It has also been argued that the simplicity of current
110 soil index testing impedes knowledge transfer between farm
111 advisors and farmers (De Bruyn and Andrews, 2016). The use
112 of additional soil tests beyond soil index testing (e.g., for

113 micronutrients, organic matter content, soil texture and
114 microbial biomass) are readily available from soil testing
115 facilities across the UK but are not readily adopted. For
116 example, in England only 35% of all farms (across all farming
117 sectors) monitor soil organic matter (DEFRA, 2018, 2013).
118 However, the reasons why and/or more advanced soil testing
119 is not undertaken by farmers are unclear, preventing the design
120 of effective campaigns to promote greater adoption to improve
121 farm sustainability. For the purpose of this study, we define
122 soil index tests used for agronomic purposes, that assess the
123 lime and fertiliser/manure application needs to optimize crop
124 production, as ‘soil tests’; and those that help with other
125 agronomic decisions and/or used to monitor soil health as
126 ‘advanced’ soil tests.

127 Research into how farmers’ perceptions of soil testing
128 influences farm practice has been longstanding, but the lack of
129 widespread adoption remains unresolved (Brandt, 2003;
130 Daxini et al., 2018; Dessart et al., 2019; Hyland et al., 2018;
131 Ingram et al., 2010; Osmond et al., 2015; Prager and
132 Posthumus, 2011). Various socio-economic, cultural,
133 institutional and environmental factors can influence a
134 farmer’s decision to engage with soil testing (Dessart et al.,
135 2019; Hyland et al., 2018; Prager and Posthumus, 2011).
136 However, the sectoral differences in soil testing adoption rates
137 previously noted are largely unexplained; though larger, more

138 intensive farms are more commonly seen to test (DEFRA,
139 2013). Daxini et al. (2018) emphasize the importance of
140 psychological factors alongside socio-economic parameters,
141 particularly attitudinal response and social norms, which
142 reflect the benefits perceived from undertaking particular
143 behaviours and whether wider peer and public pressure is felt.
144 Better understanding of why and how positive attitudinal traits
145 develop would advance these insights further. Regulatory
146 pressure can also be a critical driver for soil testing, and has
147 continued to increase in recent years (DEFRA and EA, 2018;
148 Scottish Statutory, 2017; Welsh Government, 2020). However,
149 regulation to enforce testing does not necessarily translate into
150 changes in management (Daxini et al., 2018). The potential
151 reasons for this include a lack of awareness or perceived
152 benefit amongst farmers, reliance on customary practise, and
153 associated costs and difficulties with implementation (Brandt,
154 2003; Hyland et al., 2018; Ingram, 2008; Ingram et al., 2010;
155 Osmond et al., 2015). In these instances education therefore
156 seems key, though despite marked educational efforts in recent
157 years (Ingram, 2008; Krzywoszynska, 2019; Puig de la
158 Bellacasa, 2015) some farmers do not appreciate the potential
159 benefits of better management of their soils (Ingram, 2008;
160 Krzywoszynska, 2019). In turn, this study aims to (i)
161 understand why the beef and sheep sector has a much slower
162 soil testing adoption rate in comparison to the arable and dairy

163 sector, and (ii) ascertain what socio-economic and
164 psychological factors are associated with soil testing and
165 planned management behaviours.

166 **2. Materials and methods**

167 **2.1. Grassland and arable soil indices status**

168 To understand the influence of soil indices on farmers’
169 likelihood to soil test, we investigated differences in soil pH, P
170 & K indices and Mg content between grassland (this
171 encompasses the dairy, beef and sheep, as the dataset did not
172 allow for a split between these sectors) and arable soils. These
173 indices were chosen as they are the recommended parameters
174 to determine lime and fertiliser/manure requirements for
175 optimal crop production, as outlined by the RB209 fertiliser
176 manual guidelines (hereon noted as ‘RB209’) (AHDB, 2020).
177 This was done using the soil analysis data collected by a major
178 UK soil testing lab. The database constituted the results of
179 samples submitted by farmers and/or consultants over a 5-year
180 period (2013-2017). For each soil variable, we calculated the
181 proportion of samples from grassland or arable land that were
182 lower, optimum and/or higher than the recommended values
183 for the corresponding farming sector stated in RB209 (AHDB,
184 2020). In this way, differences in relative soil indices were
185 compared between the sectors to determine whether this could
186 be influencing the farmer’s decision to soil test. To ensure that
187 samples were from a ‘continuous’ land use (grass or arable),

188 these comparisons were made on a subset of soil samples that
189 classified both the previous and next crop as either arable or
190 grassland, resulting in 92,001 and 73,454 samples from each
191 sector, respectively.

192 **2.2. Beef and sheep farmers survey**

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

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

208 The profile of survey participants can be found in Table 1.

209 Some open-response questions were also included to provide
210 additional qualitative detail to support analysis
211 of the quantitative data. Questions were devised to capture
212 both socio-economic and attitudinal factors, including

213 perceptions of soil testing and links to outcomes, following
214 recommendations from recent studies (see e.g. Daxini et al.,
215 2018).

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

226 We used the 'factoextra' R package (Kassambara and
227 Mundt, 2019) to perform hierarchical clustering analysis on
228 participants' Likert responses (0-1) to statements about how
229 important they perceive soil testing can be in improving animal
230 health, yield (of grass), profit, soil health and forage (grass or
231 conserved grass) quality. We determined the optimal number
232 of clusters through k-means partitioning methods to be $n = 3$.
233 Respondents were grouped into their respective farmer group
234 clusters and Kruskal-Wallis tests were performed for each
235 Likert. This was followed by a Dunn multiple comparisons test
236 (Dunn, 1964) to determine differences between farmer groups
237 for each Likert question.

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

242 **2.3. Stakeholder interviews**

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

258 Interviews lasted between 30–60 minutes and
259 were audio recorded to support transcription and subsequent
260 thematic analysis. All respondents, for both interviews and the
261 survey, were given a project information sheet and provided
262 their informed consent prior to questioning. Saturation in

263 themes was reached after eight interviews, meaning further
264 data capture was not necessary.

265 **3. Results and Discussion**

266 **3.1. Understanding differences in motivations to soil** 267 **test between sectors**

268 We found that 99.2% of arable soil samples sent for analysis and
269 98.6% from grasslands (dairy, beef and sheep) did not meet the
270 optimum recommended UK guidelines for at least one of the four
271 soil quality indicators (pH, P, K and Mg; Figure 1). These results
272 indicate that underperforming soils (i.e., soils that do not meet
273 the soil indices criteria for optimal crop production) are an
274 influential driver in a farmers' motivation to soil test.

275 Due to the more intensive nature of arable systems and
276 their greater crop offtake rates (Chiari et al., 1989; Withers et
277 al., 2006), these soils may more readily suffer nutrient or pH
278 imbalances in comparison to grassland soils (Muhammed et
279 al., 2018). This was reflected by the data that showed a lower
280 proportion of soils from arable farms to have optimal pH
281 compared to soils from grassland farms (15% and 37%
282 respectively, Figure 1). On-farm productivity monitoring also
283 varies between these sectors; arable farmers base this on crop
284 yields, whilst grassland farmers traditionally focus on their
285 livestock (e.g., growth, weight, health, milk yield, etc.). When
286 productivity is compromised, the role of soil indices may
287 therefore be more apparent for arable farmers due to the more

288 direct soil-plant relationships compared to the indirect soil-
289 plant-livestock relationships. The resulting realisation that
290 their soil is underperforming thus explains the higher levels of
291 soil testing adoption by arable farmers than grassland beef and
292 sheep farmers across the UK (DEFRA, 2013). These
293 differences in focus and awareness were outlined by
294 interviewed experts:

295 “The combine harvester tells [arable farmers] exactly
296 what each field is doing [in terms of yields] but within the
297 livestock sector very few [farmers] are measuring grass yield
298 and quality (Expert 3)”

299 “Arable farmers aim to produce the maximum yield
300 possible [...] grassland farmers aim to produce just enough
301 grass for their livestock (Expert 1)”

302 “[Beef and sheep farmers’] primary focus, in my
303 experience, is always going to be their [livestock], not their
304 soil. (Expert 7)”

305 Despite this, grassland farmers are increasingly being
306 encouraged to assess visual soil parameters (e.g., compaction
307 or earthworm counts (Guimarães et al., 2011)) and to monitor
308 grass yield to better make the link between soil condition and
309 farm productivity (AHDB, 2018a, 2018b). However, it appears
310 that this has not been widely adopted by the beef and sheep
311 sector (Forager, 2017) compared to the dairy sector, the latter
312 generally being more engaged with such monitoring practices

313 and thus more readily associate productivity with soil
314 conditions and input management (Beegle et al., 2000). In turn,
315 this helps explain their higher levels of soil testing compared
316 to beef and sheep farmers (DEFRA, 2013). This notion was
317 supported by Expert 4:

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

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

327 We found that motivations to soil test are also linked to
328 engagement with independent advisors (Figure 2), which
329 differs between farming sectors. Traditionally, a higher
330 proportion of cereal and dairy farmers seek this type of advice
331 for nutrient management planning compared to beef and sheep
332 livestock farmers (85%, 78% and 59%, respectively(DEFRA,
333 2019)). We found that 55% of the beef and sheep farmers who
334 soil test do so without help from an independent advisor (data
335 not shown). This highlights a clear lack of engagement with
336 independent advisors amongst beef and sheep farmers which is

337 also likely to be contributing towards adoption differences
338 between sectors. As expressed by Expert 1:

339 “Most arable farmers will have an agronomist...
340 grassland farms, particularly smaller family-run farms
341 will not have an agronomist or any other link to a
342 company that provides this service. (Expert 1)”

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

348

349 **3.2. Understanding beef and sheep farm(er)** 350 **characteristics associated with (not) soil testing**

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

359 We saw that increased likelihood to soil test was
360 correlated with reported adoption of other forms of innovation
361 (High innovation score, Figure 2) and hence these farmers

362 seemed to be more actively adopting new practices to improve
363 their farm systems rather than relying on customary practice.
364 It was also notable that our farmer innovation score is co-
365 correlated with the positive soil testing perception factor,
366 which aligns with wider reporting that farmers adopt new
367 technologies and/or farm practices when they perceive that an
368 innovation will lead to positive impacts (see also Pannell et al.,
369 2006).

370 We also found that engagement with an independent
371 advisor increases the likelihood a farmer would soil test by
372 15% (Figure 2). This demonstrates the crucial role advisors
373 play initiating soil awareness, linking soil condition (e.g. soil
374 indices) to farm productivity and supporting farmers to make
375 appropriate management decisions based on test results
376 (Daxini et al., 2018; Ingram, 2008). Farm turnover was also
377 identified as an important factor (Figure 2), where farmers with
378 a below average turnover were 12% less likely to soil test
379 (Figure 2). This is likely to be linked to farms with higher
380 financial turnovers generally being associated with more
381 intensive systems, which typically have greater use of
382 resources, and greater financial capacity to engage with
383 advisors and implement the measures advised. Despite farm
384 size not significantly contributing to soil testing adoption
385 (Figure 2), we saw a general trend where soil testing adoption
386 is less frequent on smaller farms, similar to Ribaudo and

387 Johansson (2007) and Daxini et al. (2018). This also aligns
388 with a wider acknowledgement that small farmers have lower
389 levels of turnover (DEFRA, 2015).

390 Finally, we found that farmers with a negative attitude
391 towards soil testing were less likely to adopt soil testing than
392 those who were more positive (Figure 2), due to a general lack
393 of awareness or perceived benefit. This was further confirmed
394 by 49% of non-soil testers reporting that they “didn’t see the
395 point” of soil testing (data not shown). This aligns with the
396 findings of Daxini et al. (2018) on the psychological
397 parameters underpinning decision making.

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

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

417 The characteristics of our identified farmer groups
418 found that *The Disengaged* had a much higher proportion of
419 older farmers than *The Engaged* and *Semi-engaged* (Figure
420 4c). Although our binomial analysis did not determine age as a
421 contributing factor for poor soil testing adoption, when
422 splitting the data into groups, it was clear that age influenced
423 soil testing perceptions (Figure 4c) and consequently adoption
424 (Buckley et al., 2015). Our identified farmer groups and their
425 characteristics were also strongly supported by interviewed
426 experts;

427 “You get more progressive, interested farmers
428 that are engaged and take advantage of soil workshops.
429 They read the literature and they learn. And then you
430 have other farmers who are less engaged and just doing
431 things how they've always done. (Expert 1)”

432 “There is a better understanding of the
433 importance of soils with [younger farmers]. (Expert 3)”

434 *The Engaged* placed higher importance on the
435 perceived benefits soil testing offers for improvements to each
436 of these aspects on the farm, animal health, profit, soil health,

437 forage quality and yield compared to *The Semi-engaged* and
438 *Disengaged* (Figure 3), as did *The Semi-engaged* when
439 compared to *The Disengaged*. These findings highlight the
440 need to reinforce how soil testing has the potential to benefit
441 the farm, which corresponds to arguments made in section 3.1,
442 regarding the importance of connecting soil to measurements
443 of productivity/optimisation.

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

455 Of those livestock farmers that did not soil test, 22%
456 stated that this was because they were satisfied with their
457 productivity and did not intend to increase grass growth to
458 meet their feed requirements (data not shown). This is not
459 unsurprising – typical nutrient application rates (as both
460 fertiliser/manure) on extensive beef and sheep farms are often
461 considerably lower than what is recommended to increase

462 grass yields (AHDB, 2020; British Survey of Fertiliser
463 Practise, 2019). Nutrient application recommendations based
464 on soil index tests from such farms could therefore be notably
465 higher than those rates currently applied. The environmental
466 costs of such farmers acting on this advice, such as greater
467 potential for eutrophication and greenhouse gas emissions
468 from greater application of fertilisers/manures should be
469 considered. From an economic perspective, there is a rationale
470 for better optimisation of productivity, but it was notable that
471 24% of respondents did not test due to perceived ‘high costs
472 associated with acting on advice’ (data not shown). For
473 example, liming to increase soil pH can cost more than the
474 value of the extra return (Gibbons et al., 2014). Critical to this
475 is whether recommendations following testing would reveal
476 scope to optimise interventions within financially beneficial
477 margins.

478 **3.3. Soil testing adoption through policy**

479 Finally, we consider the impact of policy. Here, we
480 found that 65% of those farmers that were soil testing reported
481 policy as a factor that influenced their decision to test (19%,
482 important, 18%, fairly important and 28% very important, data
483 not shown). However, such regulation has only recently been
484 implemented in England and whilst other countries in the UK
485 are also likely to follow (DAERA, 2019; DEFRA and EA,
486 2018; Scottish Statutory, 2017; Welsh Government,

487 2020)(DAERA, 2019; DEFRA and EA, 2018; Scottish
488 Statutory, 2017; Welsh Government, 2020) this perceived
489 pressure could therefore increase in the future. However,
490 compulsory soil testing may not necessarily translate into good
491 management behaviours (Daxini et al 2018). Instead, Daxini et
492 al. (2018) and experts we interviewed felt that a notable
493 proportion of farmers were just doing the minimum to meet
494 regulatory requirements, and engagement with testing was not
495 substantively improving their understanding of, or care for,
496 their soil.

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

503 Our survey results do not reflect these fears, showing
504 that a high proportion of farmers were following the
505 management advice for nutrient application rates (as both
506 fertiliser/manure) and lime application rates based on their soil
507 index tests (data not shown), with only a very small proportion
508 ignoring the advice altogether (which was often explained in
509 relation to environmental restrictions, connecting with points
510 outlined above). However, the concerns raised by the
511 interviewed advisers is clearly reflected in the wider literature.

512 This is perhaps due to difference in context across different
513 studies, with regulatory obligations more widespread in Ireland
514 than in parts of the UK for example (Daxini et al., 2018).

515 **3.4. Advanced soil testing**

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

525 **4. Conclusions**

526 Our analysis explores the influence of soil condition, socio-
527 economic factors and psychological factors associated with
528 lower levels of soil index testing amongst the UK beef and sheep
529 sector, compared to their dairy and arable counterparts. We
530 argue that it is accentuated by the characteristics of the beef and
531 sheep sectors, where farms are generally smaller, have a lower
532 turnover and engage less with advisory support compared to
533 arable and dairy counterparts (Chiari et al., 1989; DEFRA ONS,
534 2015). Whilst this might appear to offer a poor prognosis for
535 improved adoption in the future, our data also affirms the
536 importance of an output driven approach to support farmer

537 engagement with soil testing. We argue this approach offers
538 greater potential to enhance farmers' knowledge of the soil
539 system than a primarily regulatory driven approach, where soil
540 testing becomes compulsory but does not necessarily lead to
541 good management practice.

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

553 **5. Acknowledgements**

554 The authors would like to thank Lara Pritchard, the
555 British Grassland Society and the Farming Community
556 Network for their contributions towards survey data collection.

557 This work was supported by The Sustainable Agriculture
558 Research and Innovation Club, a joint BBSRC and NERC
559 initiative [grant number NE/R017425/1].

560 **6. References**

- 561 AHDB, 2020. Nutrient management guide (RB209), Agriculture
562 and Horticulture Development Board, Kenilworth, UK.
- 563 AHDB, 2018a. Planning grazing strategies for Better Returns,
564 Agriculture and Horticulture Development Board,
565 Kenilworth, UK.
- 566 AHDB, 2018b. Improving soils for Better Returns, Agriculture
567 and Horticulture Development Board, Kenilworth, UK.
- 568 Beegle, D.B., Carton, O.T., Bailey, J.S., 2000. Nutrient
569 management planning: justification, theory, practice. *J.*
570 *Environ. Qual.* 29, 72–79.
571 <https://doi.org/10.2134/jeq2000.00472425002900010009x>
- 572 Borrelli, P., Robinson, D.A., Panagos, P., Lugato, E., Yang, J.E.,
573 Alewell, C., Wuepper, D., Montanarella, L., Ballabio, C.,
574 2020. Land use and climate change impacts on global soil
575 erosion by water (2015-2070). *Proc. Natl. Acad. Sci. U. S.*
576 *A.* 117, 21994–22001.
577 <https://doi.org/10.1073/pnas.2001403117>
- 578 Bouma, J., Broll, G., Crane, T.A., Dewitte, O., Gardi, C.,
579 Schulte, R.P.O., Towers, W., 2012. Soil information in
580 support of policy making and awareness raising. *Curr.*
581 *Opin. Environ. Sustain.* 4, 552–558.
582 <https://doi.org/10.1016/j.cosust.2012.07.001>
- 583 Brandt, G., 2003. Barriers and strategies influencing the
584 adoption of nutrient management practices, TR13.1. Tech.

585 Rep. 13.1 1–20.

586 Briggs, S., Eclair-Heath, G., 2017. Helping UK farmers to
587 choose, use, and interpret soil test results to inform soil
588 management decisions for soil health. *Asp. Appl. Biol.*
589 *Crop Prod. South. Britain* 134, 161–168.

590 British Survey of Fertiliser Practise, 2019. British Survey of
591 Fertiliser Practice, 2019.

592 Buckley, C., Howley, P., Jordan, P., 2015. The role of differing
593 farming motivations on the adoption of nutrient
594 management practices. *role differing farming Motiv.*
595 *Adopt. Nutr. Manag. Pract.* 4, 152–162.
596 <https://doi.org/10.5836/ijam/2015-04-152>

597 Caporn, S.J.M., Emmett, B.A., 2009. Threats from air pollution
598 and climate change to upland systems: past, present and
599 future, in: *Drivers of Environmental Change in Uplands.*
600 Routledge, pp. 62–86.

601 Carlisle, L., 2016. Factors influencing farmer adoption of soil
602 health practices in the United States: a narrative review.
603 *Agroecol. Sustain. Food Syst.* 40, 583–613.
604 <https://doi.org/10.1080/21683565.2016.1156596>

605 Chiari, M., Casale, E., Santaniello, E., Righetti, P.G., 1989.
606 Synthesis of buffers for generating immobilized pH
607 gradients. II: Basic acrylamido buffers. *Appl. Theor.*
608 *Electrophor.* 1, 103–107.

609 DAERA, 2019. Nutrients Action Programme (NAP) 2019-2022.

610 Daxini, A., O'Donoghue, C., Ryan, M., Buckley, C., Barnes,
611 A.P., Daly, K., 2018. Which factors influence farmers'
612 intentions to adopt nutrient management planning? J.
613 Environ. Manage. 224, 350–360.
614 <https://doi.org/https://doi.org/10.1016/j.jenvman.2018.07.0>
615 59

616 De Bruyn, L.L., Andrews, S., 2016. Are Australian and United
617 States farmers using soil information for soil health
618 management? Sustain. 8, 304.
619 <https://doi.org/10.3390/su8040304>

620 DEFRA, 2019. Farm practices survey February 2019 -
621 greenhouse gas mitigation practices, National Statistics
622 England.

623 DEFRA, 2018. Farm practices survey February 2018 -
624 greenhouse gas mitigation practices, National Statistics
625 England.

626 DEFRA, 2015. Farm Business Income by type of farm in
627 England, 2014/15. Natl. Stat. Engl.

628 DEFRA, 2013. Farm practices survey February 2013 -
629 greenhouse gas mitigation practices. National Statistics
630 England.

631 DEFRA, EA, 2018. Farming rules for water Questions and
632 Answers. Accessed 25/03/2021
633 [https://www.farmingadvice.service.org.uk/sites/default/file](https://www.farmingadvice.service.org.uk/sites/default/files/docs/2020-09/Farming-rules-for-water-QA-FINAL-vsn-)
634 [s/docs/2020-09/Farming-rules-for-water-QA-FINAL-vsn-](https://www.farmingadvice.service.org.uk/sites/default/files/docs/2020-09/Farming-rules-for-water-QA-FINAL-vsn-)

635 1.pdf.

636 Dessart, F.J., Barreiro-Hurlé, J., Van Bavel, R., 2019.

637 Behavioural factors affecting the adoption of sustainable

638 farming practices: A policy-oriented review. *Eur. Rev.*

639 *Agric. Econ.* 46, 417–471.

640 <https://doi.org/10.1093/erae/jbz019>

641 Dunn, O.J., 1964. Multiple comparisons using rank sums.

642 *Technometrics* 6, 241–252.

643 Forager, 2017. Aly Balsom (Ed.), *Homegrown Feed for*

644 *Sustainable Farming*.

645 Gibbons, J.M., Williamson, J.C., Williams, A.P., Withers,

646 P.J.A., Hockley, N., Harris, I.M., Hughes, J.W., Taylor,

647 R.L., Jones, D.L., Healey, J.R., 2014. Sustainable nutrient

648 management at field, farm and regional level: Soil testing,

649 nutrient budgets and the trade-off between lime application

650 and greenhouse gas emissions. *Agric. Ecosyst. Environ.*

651 188, 48–56. <https://doi.org/10.1016/j.agee.2014.02.016>

652 Goulding, K., Jarvis, S., Whitmore, A., 2008. Optimizing

653 nutrient management for farm systems. *Philos. Trans. R.*

654 *Soc. B Biol. Sci.* 363, 667–680.

655 <https://doi.org/10.1098/rstb.2007.2177>

656 Guimarães, R.M.L., Ball, B.C., Tormena, C.A., 2011.

657 Improvements in the visual evaluation of soil structure. *Soil*

658 *Use Manag.* 27, 395–403. [https://doi.org/10.1111/j.1475-](https://doi.org/10.1111/j.1475-2743.2011.00354.x)

659 [2743.2011.00354.x](https://doi.org/10.1111/j.1475-2743.2011.00354.x)

660 Hyland, J.J., Heanue, K., McKillop, J., Micha, E., 2018. Factors
661 influencing dairy farmers' adoption of best management
662 grazing practices. *Land use policy* 78, 562–571.
663 <https://doi.org/10.1016/j.landusepol.2018.07.006>

664 Ingram, J., 2008. Are farmers in England equipped to meet the
665 knowledge challenge of sustainable soil management? An
666 analysis of farmer and advisor views. *J. Environ. Manage.*
667 86, 214–228.
668 <https://doi.org/10.1016/j.jenvman.2006.12.036>

669 Ingram, J., Fry, P., Mathieu, A., 2010. Revealing different
670 understandings of soil held by scientists and farmers in the
671 context of soil protection and management. *Land use policy*
672 27, 51–60.
673 <https://doi.org/10.1016/j.landusepol.2008.07.005>

674 Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P.,
675 Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y.,
676 Van Der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol,
677 G., Jansen, B., Fresco, L.O., 2016. The significance of soils
678 and soil science towards realization of the United Nations
679 sustainable development goals. *Soil* 2, 111–128.
680 <https://doi.org/10.5194/soil-2-111-2016>

681 Kettering, J., Park, J.H., Lindner, S., Lee, B., Tenhunen, J.,
682 Kuzyakov, Y., 2012. N fluxes in an agricultural catchment
683 under monsoon climate: A budget approach at different
684 scales. *Agric. Ecosyst. Environ.* 161, 101–111.

685 <https://doi.org/10.1016/j.agee.2012.07.027>

686 Krzywoszynska, A., 2019. Making knowledge and meaning in
687 communities of practice: What role may science play? The
688 case of sustainable soil management in England. *Soil Use*
689 *Manag.* 35, 160–168. <https://doi.org/10.1111/sum.12487>

690 Li, J., Feng, S., Luo, T., Guan, Z., 2020. What drives the
691 adoption of sustainable production technology? Evidence
692 from the large scale farming sector in East China. *J. Clean.*
693 *Prod.* 257, 120611.
694 <https://doi.org/10.1016/j.jclepro.2020.120611>

695 Montanarella, L., Pennock, D.J., McKenzie, N., Badraoui, M.,
696 Chude, V., Baptista, I., Mamo, T., Yemefack, M., Aulakh,
697 M.S., Yagi, K., Hong, S.Y., Vijarnsorn, P., Zhang, G.L.,
698 Arrouays, D., Black, H., Krasilnikov, P., Sobocká, J.,
699 Alegre, J., Henriquez, C.R., Mendonça-Santos, M. de L.,
700 Taboada, M., Espinosa-Victoria, D., AlShankiti, A.,
701 AlaviPanah, S.K., Mustafa Elsheikh, E.A. El, Hempel, J.,
702 Arbestain, M.C., Nachtergaele, F., Vargas, R., 2016.
703 World's soils are under threat. *Soil* 2, 79–82.
704 <https://doi.org/10.5194/soil-2-79-2016>

705 Muhammed, S.E., Coleman, K., Wu, L., Bell, V.A., Davies,
706 J.A.C., Quinton, J.N., Carnell, E.J., Tomlinson, S.J., Dore,
707 A.J., Dragosits, U., Naden, P.S., Glendining, M.J., Tipping,
708 E., Whitmore, A.P., 2018. Impact of two centuries of
709 intensive agriculture on soil carbon, nitrogen and

710 phosphorus cycling in the UK. *Sci. Total Environ.* 634,
711 1486–1504.
712 <https://doi.org/10.1016/j.scitotenv.2018.03.378>

713 Orr, H.G., Wilby, R.L., Hedger, M.M., Brown, I., 2008. Climate
714 change in the uplands: a UK perspective on safeguarding
715 regulatory ecosystem services. *Clim. Res.* 37, 77–98.

716 Osmond, D.L., Hoag, D.L.K., Luloff, A.E., Meals, D.W., Neas,
717 K., 2015. Farmers’ Use of Nutrient Management: Lessons
718 from Watershed Case Studies. *J. Environ. Qual.* 44, 382–
719 390. <https://doi.org/10.2134/jeq2014.02.0091>

720 Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F.,
721 Wilkinson, R., 2006. Understanding and promoting
722 adoption of conservation practices by rural landholders.
723 *Aust. J. Exp. Agric.* 46, 1407–1424.
724 <https://doi.org/10.1071/EA05037>

725 Prager, K., Posthumus, H., 2011. Socio-economic factors
726 influencing farmers’ adoption of soil conservation practices
727 in Europe, in: *Human Dimensions of Soil and Water
728 Conservation: A Global Perspective*. Nova Science
729 Publishers, Inc., pp. 203–223.

730 Puig de la Bellacasa, M., 2015. Making time for soil:
731 Technoscientific futurity and the pace of care. *Soc. Stud.*
732 *Sci.* 45, 691–716.
733 <https://doi.org/10.1177/0306312715599851>

734 Scottish Statutory, 2017. *Water Environment (Miscellaneous)*

735 (Scotland) Regulations 2017 and come into force on 1st
736 January 2018.

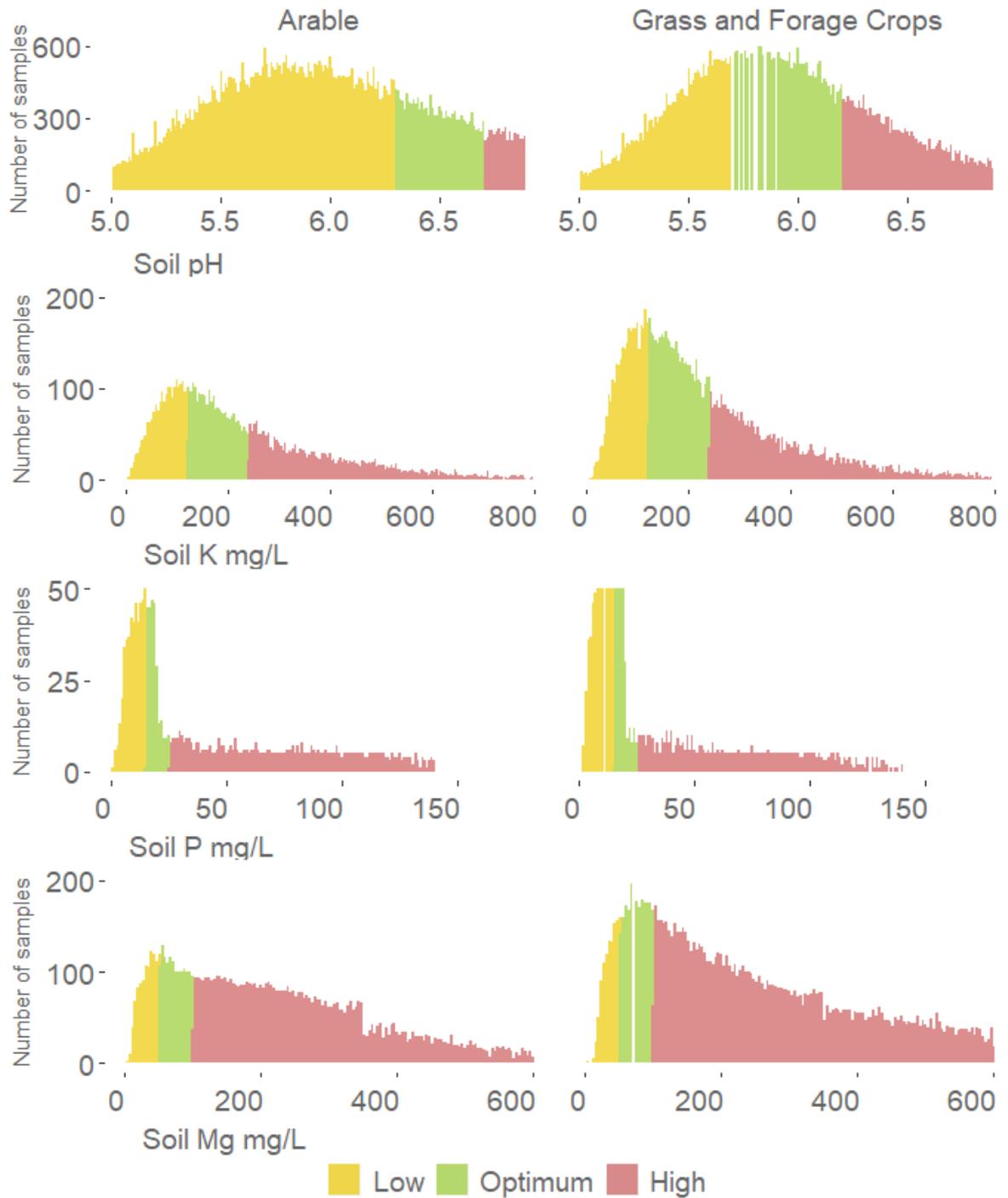
737 Welsh Government, 2020. Information on the draft Water
738 Resources (Control of Agricultural Pollution) (Wales)
739 Regulations 2020.

740 Welsh Government, 2019. Glastir Advanced 2019: rules
741 booklets.

742 Withers, P.J.A., Edwards, A.C., Foy, R.H., 2006. Phosphorus
743 cycling in UK agriculture and implications for phosphorus
744 loss from soil. *Soil Use Manag.* 17, 139–149.
745 <https://doi.org/10.1111/j.1475-2743.2001.tb00020.x>

746 Wuepper, D., Borrelli, P., Finger, R., 2020. Countries and the
747 global rate of soil erosion. *Nat. Sustain.* 3, 51–55.
748 <https://doi.org/10.1038/s41893-019-0438-4>

749



750

751

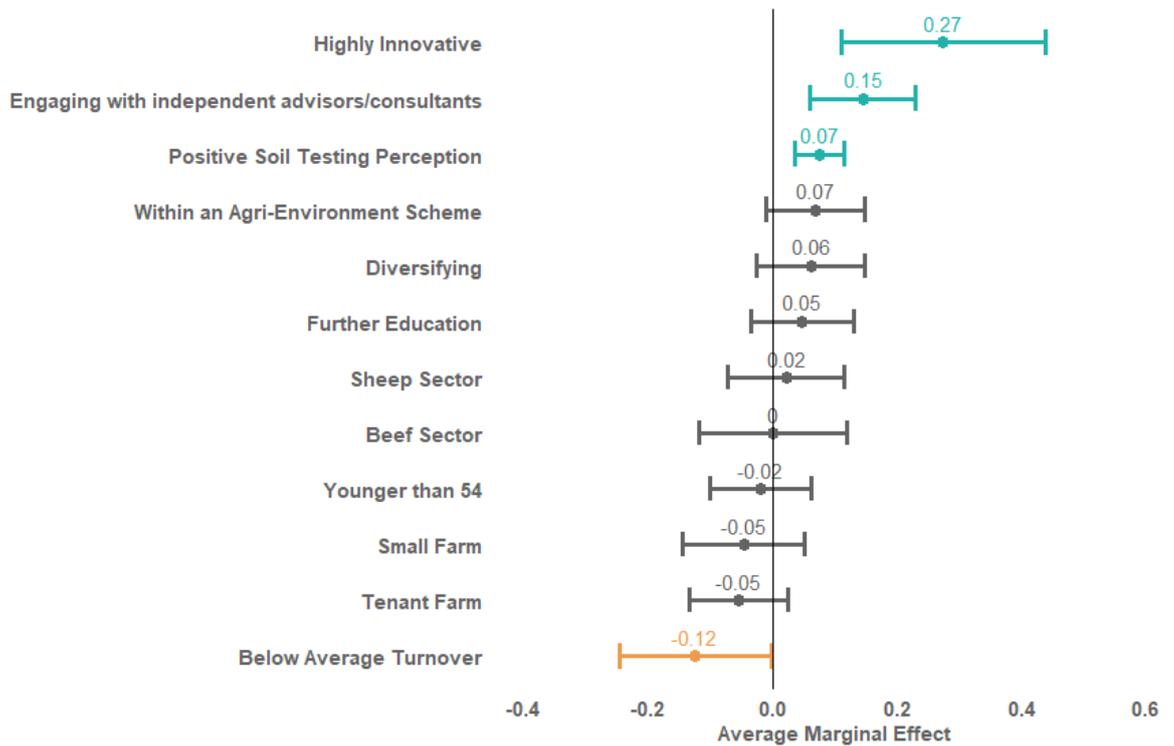
752

753

754

755

Figure 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 $n = 73,454$).



756

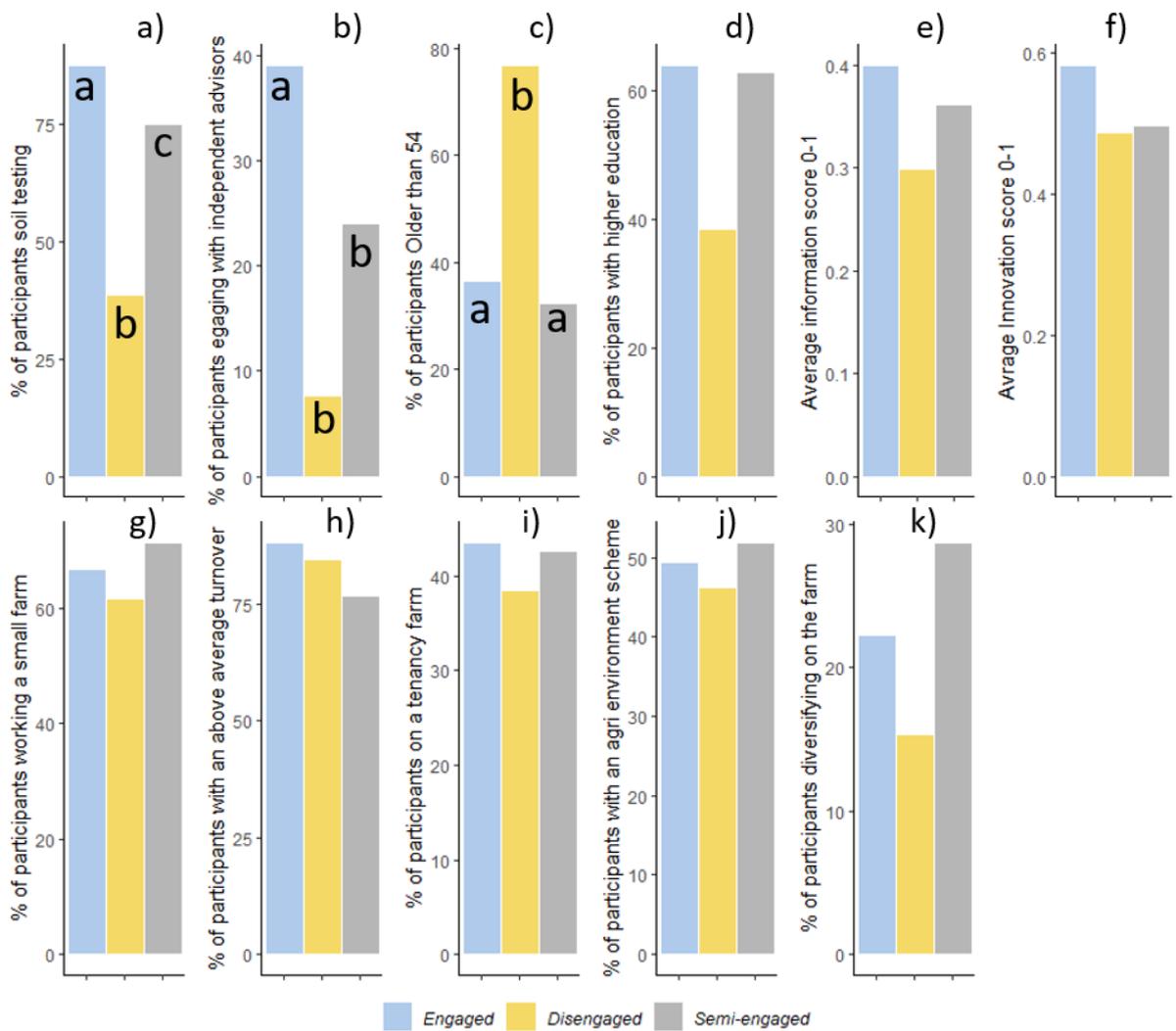
757

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



763

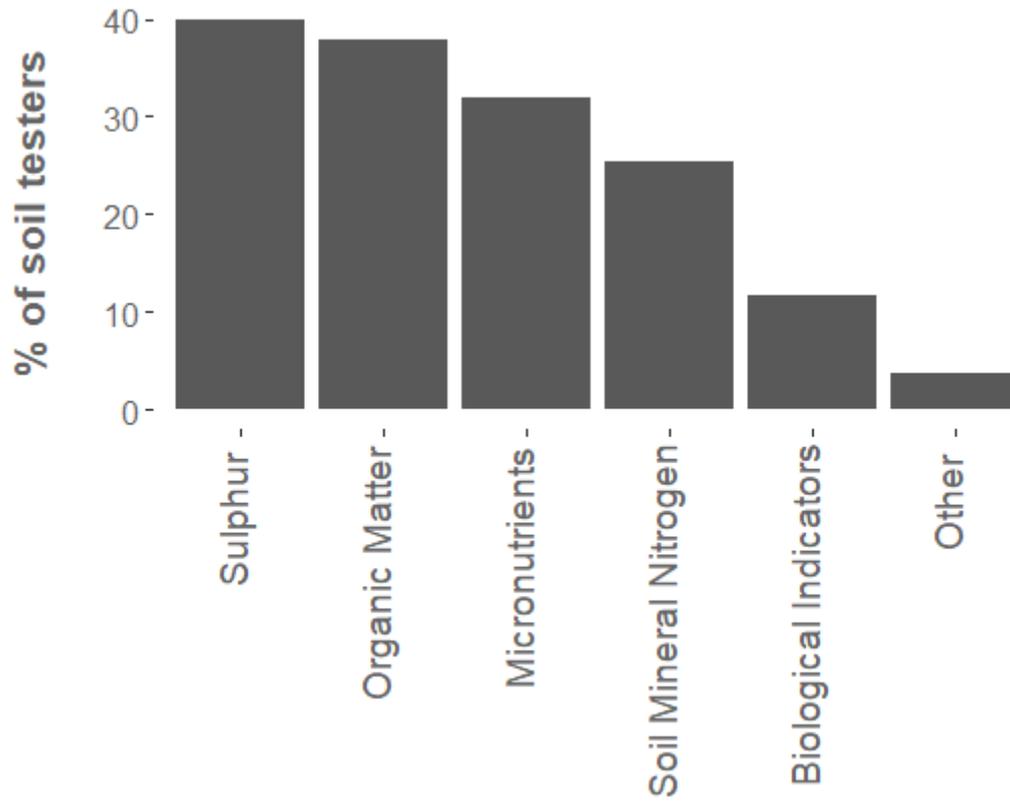
764 Figure 3 Radar charts showing the average Likert responses (0-5: Not important - Very
 765 Important) to questions on how important farmers thought soil testing was for improving animal
 766 health, profit, soil health, forage quality and yields for each farmer group identified (Engaged, Semi-
 767 engaged, Disengaged). Letters denote significant differences between identified farmer groups for
 768 each question answered.
 769



770
 771 Figure 4 The percentage of participant a) soil testing, b) engaging with independent advisors,
 772 c) older than 54, d) with higher education, e) information score, f) innovation score, g) on a small
 773 farm, h) with an above average turnover, i) on a tenancy farm, j) within an agri environment scheme

774 and k) diversifying on the farm within each farmer group (Engaged, Semi-engaged, Disengaged).

775 Different letters denote significant differences between farmer groups.



776

777 Figure 5 Percentage of beef and sheep farmers who undertake advanced soil testing beyond
778 the basic soil index testing.

779

780 Table 1 Summary description of response and explanatory variables with their associated levels used
 781 for binomial regression and the percentage of respondents within each level. We utilised soil testing
 782 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 ≤ 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		57

	No	Participants with the whole or part of farm were considered as tenancy farmers.	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 an Agri-environment scheme		50
Diversification	Diversifying		76
	Not Diversifying		24
	Yes		32

Engaging with independent advisors/consultants	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.	

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