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Field testing the user-friendliness of a rapid, low-cost in-field available soil phosphate test kit

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1. Abstract

Background

Phosphorus (P) fertilisers are vital to current agricultural production and recommending optimal quantities to be applied to soils is a major challenge. Currently this is done by taking a bulked soil sample from fields and sending them to specialist laboratories where they are analysed, and results are returned after several days with recommendations for application rates. This delay and expense can be off-putting to many farmers. Additionally, in many countries this service is either not available or beyond the economic means of many farmers. Rothamsted Research has developed a prototype P field test kit that is robust, rapid and low-cost. This may enable widespread, independent, rapid and accurate soil testing linked to existing P fertiliser recommendations. Ultimately, this will enable farmers and land managers to make their own measurements and recommendations for P fertiliser applications.

Aims

The primary aim of this project was to carry out user-friendliness tests of our prototype kit to:

- Enable modifications and improvement of the procedure, kit design and user instructions
- Provide evidence of the interest and usability of the field kit prior to subsequent activities to make the kit available to end-users

Key findings and conclusions

The main findings from this project are:

- Several improvements can be made to the user-friendliness of the kit including:
  - Modifications to user guide
  - Inclusion of additional equipment
  - Modification of the filtering system
- Some soil types are difficult to filter using our process
- Most users would consider using the kit again

Practical outputs and outcomes

The main outputs and outcomes are that we will now be able to improve several aspects of the kit and provide feedback to potential commercialisation partners on the preliminary results of our field trial.

Beneficiaries

Following modification of the kit we hope to move towards commercialisation to make the soil test kit widely available to end-users (primarily, agronomists, farmers and environmental researchers).

2. Introduction

Phosphorus (P) fertilisers are vital to current agricultural production and recommending optimal quantities to be applied to soils is a major challenge. Currently this is done by taking a bulked soil sample from fields and sending them to specialist laboratories where they are analysed, and results are returned after several days with recommendations for application rates. This delay and expense can be off-putting to many farmers, and in many countries, this service is either not available or beyond the economic means of regular farmers. Rothamsted Research have developed an in-field, low-cost available soil P test kit with funding from an EU ERDF Cornwall Agritech Project. The kit will enable farmers and agronomists to carry out independent soil testing as frequently as they wish and at spatial resolutions appropriate to their land, thereby helping to encourage the use of precision farming and management. This means fertiliser use can be optimised, and consequently so can crop production, improving the efficiency and resilience of agricultural businesses. Materials to produce ten prototype kits were acquired, and the main aims of this project were:

1) To assemble 10 complete kits for distribution to users (Figure 1).
2) To distribute the kits to 20 potential users for field testing (in two batches of 10).
3) To obtain user feedback on i) the clarity of the instructions ii) the user-friendliness of the kit.
4) To compare results obtained with the test kit by users in the field and laboratory results, using the same samples, to test the accuracy and repeatability of the soil test in the hands of end-users.

Figure 1. Assembling the Phosfield kits.

Figure 2. The assembled Phosfield kit

3. Materials and methods

3.1. Kit preparation

Preparation of the kits for distribution involved labelling components, mixing chemicals, printing instructions and packaging all equipment in robust carrycases (see Figures 1 and 2).

3.2. Identifying and contacting testers and distributing kits

A list of 20 potential testers was drawn up using our existing contacts and networks of farmers, agronomists and researchers established through our Institute Strategic Programmes (e.g. Achieving Sustainable Agriculture - ASSIST) and also through our ERDF Cornwall Agritech Project. During these projects the potential to test our field kit was discussed and many expressed interest in participating. These included 2 agronomists, 3 research organisations, and 15 farmers. These, along with others, were contacted by email and their willingness to participate confirmed.

Kits were distributed to testers in two batches. This involved delivery in-person and a brief familiarisation session of the kit with the testers. The kit was left with the users for two weeks during which they were requested to carry out a minimum of 10 soil tests. At the end of the testing period, the kits were collected in person, and a brief questionnaire completed with the user to gather feedback on their experience and future interest, along with the results of their soil tests. After collection, consumables were replenished, and the kits were distributed to the second group of users as above and the process repeated.

3.3. Laboratory testing

Users were asked to collect sub-samples of the soils that they tested and store them appropriately (e.g. in a fridge) so that we could carry out our own tests using both the kits and standard laboratory analyses (Olsen P measurements as per Olsen et al. (1954)) to compare with the results obtained by the users. This has provided useful information on the range of error likely due to differences in the way the kits are used by different people and supports our existing database of laboratory versus field test kit analyses (see section 4 – Results).

3.4. Data gathering and questionnaire

Data was gathered upon collection of the test kits via a questionnaire and the collection of recording sheets upon which the users recorded the results of their analyses. The questionnaire was compiled in consultation with Rothamsted's Knowledge Exchange Manager. As part of the knowledge exchange component of this project, individual users have been sent the results from their own samples/tests and an anonymised report providing summary statistics of all the tests carried out, the feedback received, and the accuracy of the tests compared to laboratory equivalents to inform them of the outcomes of the field trials.

4. Results

A total of twenty-two people in various organisations around the UK were approached to take part in the project to test the user friendliness of the Phosfield soil test kit - of which seventeen agreed to take part. Due to various reasons some had to drop out of the project, and thus a total of twelve people had the soil test kit demonstrated to them between January and March 2022. Unfortunately, four of these were subsequently unable to carry out the testing of their own soil samples within the two weeks that the soil test kits were available for them to use. Two of these four were however able to supply the ten soil samples asked for within the project agreement, and these soils were tested using the Phosfield kit by staff at Rothamsted Research North Wyke.

The users of the test kits ranged from farmers with large cereal enterprises to agricultural consultants advising dairy and cereal farming enterprises as well as staff from water companies to academic researchers interested in testing of P within soils. Soil samples were collected from a variety of different agricultural practices ranging from stubble fields or cover crops following the growth of winter wheat, to forage maize and pasture, which also included some samples from bird seed and pollen mixes. The locations of the users were spread out across the UK ranging from Devon in the south-west to Essex in the south-east, to Lincolnshire in the north-east to Lancashire in the north-west. Table 1 illustrates the agricultural sector and location of the tester, and participation within the project.

Table 1. Summary of participants within the project and their level of participation within the project.

County	Enterprise	Agreed to participate	Kit demon-strated	Soil tested	Soil provided	No. of samples	Feedback given	Comments
Devon	Researcher - pasture	✓	✓	✓	✓	10	✓	Full test
Norfolk	Cereals	✓	✓	✓	✓	10	✓	Full test
Shropshire	Researcher - crops	✓	✓	✓	✓	9	✓	Full test
Cheshire	Researcher - pasture	✓	✓	✓	✓	10	✓	Full test
Anglesey	Researcher - crops	✓	✓	✓	✓	10	✓	Full test
Devon	Cereals and pasture	✓	✓	✓	✓	6	✓	Trouble filtering all soils - partially tested
Northamptonshire	Agricultural advisor	✓	✓	✓	✓	4	✓	Trouble filtering all soils - partially tested
Avon	Agricultural advisor	✓	✓	✓	✓	3	✓	Trouble filtering all soils - partially tested
Lincolnshire	Agricultural advisor	✓	✓	x	✓	10	x	Legal issues with agreement
Suffolk	Researcher - crops	✓	✓	x	✓	10	x	Subsequently unable to test soils
Hertfordshire	Researcher - crops	✓	✓	x	x	0	x	Subsequently unable to test soils
Essex	Agricultural advisor	✓	✓	x	x	0	x	Subsequently unable to test soils
Suffolk	Cereals	✓	x	x	x	0	x	Failed to reply in time
Devon	Agricultural advisor	✓	x	x	x	0	x	Covid delay then unable to test soils
Cornwall	Researcher - pasture	✓	x	x	x	0	x	Legal issues with agreement
Cheshire	Agricultural advisor	✓	x					Subsequently unable to test soils
Cumbria	Agricultural advisor	✓	x	x	x	0	x	Never replied after initial contact

County	Enterprise	Agreed to participate	Kit demon-strated	Soil tested	Soil provided	No. of samples	Feedback given	Comments
Devon	Agricultural advisor	x						Never replied
Devon	Agricultural advisor	x						Never replied
Lancashire	College farm manager	x						Never replied
Norfolk	Agricultural advisor	x						Never replied
Suffolk	Agricultural advisor	x						Never replied

A total of 82 soil samples were made available for laboratory testing using the Olsen P extraction procedure. This is lower than was expected due to some participants not completing analysis of their own soils, and thus not having a Phosfield extraction value for that individual soil sample. All of the soil samples received from the participants were air dried and sieved to pass a 2mm screen prior to being processed with the Olsen extractant chemical (sodium bicarbonate at 20°C) as per Olsen et al. (1954). The data generated by the participants in the study was compared to the laboratory derived Olsen P data for the same soil sample (Figure 3).

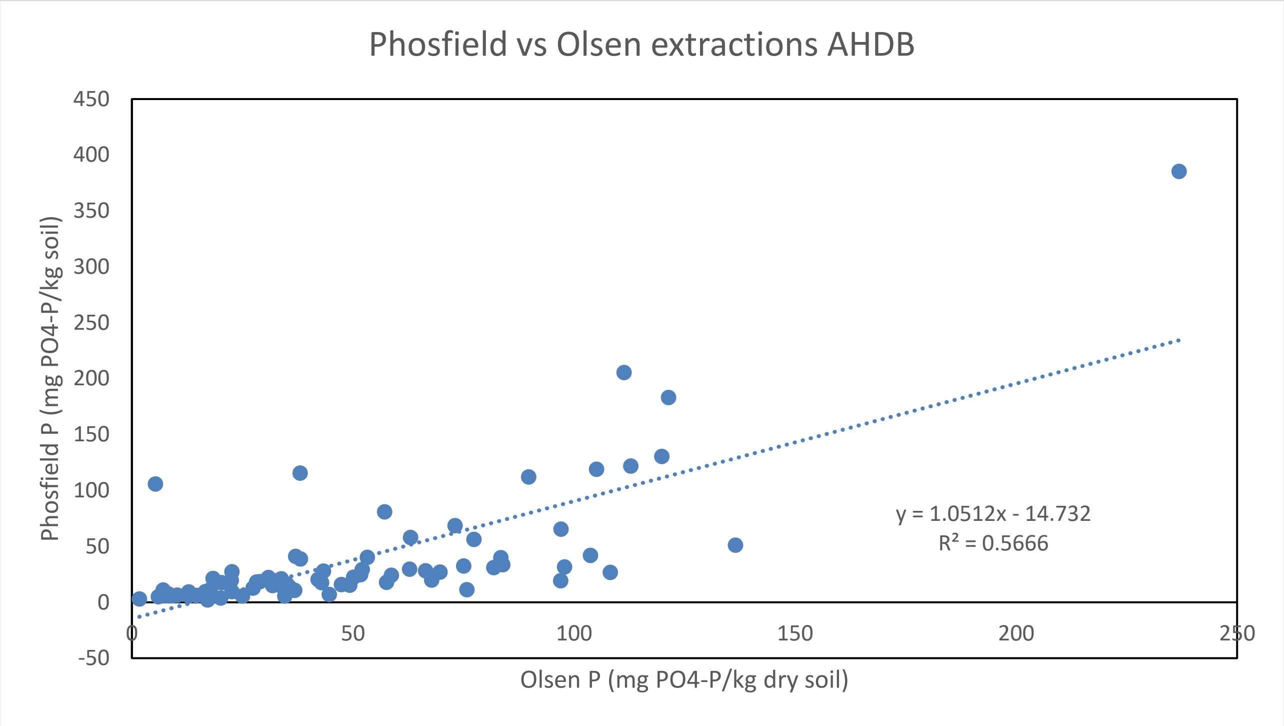

Figure 3. Relationship between Phosfield and Olsen extracted P

The different chemicals used in the extraction procedure, differing states in which the soil is tested (partially dried soil used with the field based Phosfield test kit as opposed to air dried and sieved soil in the laboratory-based Olsen test), various temperatures at which the Phosfield extractions would have been undertaken versus the stable laboratory temperature used for the Olsen extractions will all play a role in altering the final measured amount of P being measured. The relationship between the Phosfield and Olsen extracted P is therefore unsurprisingly not a perfect 1:1 value. However, we recorded an r^2 value of 0.57 for the variation between all soil samples extracted by the two different methods. The pH of all soils included in the analysis were measured and values ranged from pH 4.81 to pH 8.36, highlighting the wide range of soil types included in the project. These values were used to separate the soils into 3 groups; acidic soils (pH <6.5), circumneutral soils (pH 6.5 – 7.5) and basic soils (pH >7.5). The relationships between Phosfield and Olsen extracted P for these three groups are shown in Figures 4-6. Relatively strong relationships occurred in acidic soils (r^2=0.77, n=42) and circumneutral soils (r^2=0.72, n=17), with the basic soils having a relatively weaker relationship (r^2=039, n=22). This indicates that the Phosfield test is more accurate in acid and circumneutral soils and perhaps less reliable in basic soils.

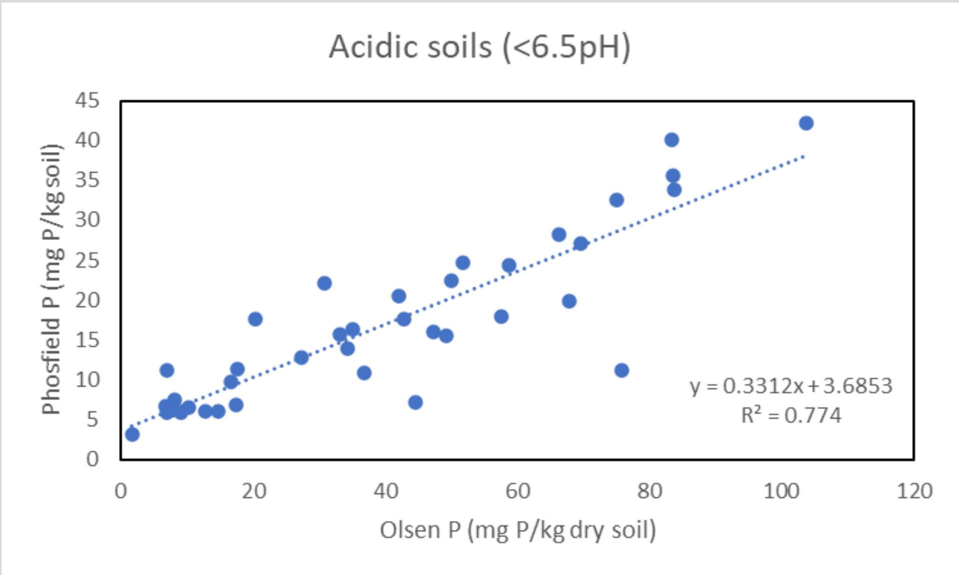

Figure 4 Relationship between Phosfield and Olsen extracted P in acidic soils

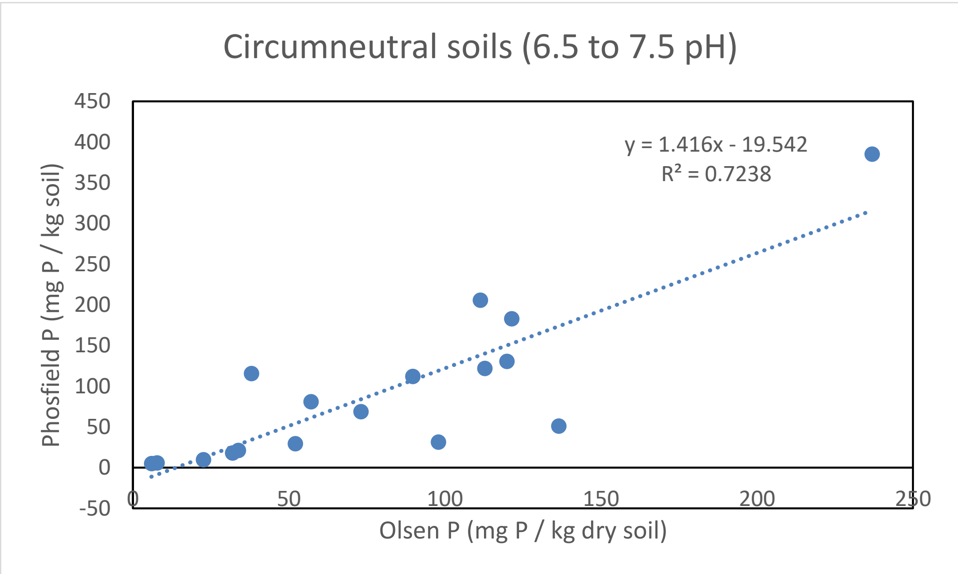

Figure 5 Relationship between Phosfield and Olsen extracted P in circumneutral soils

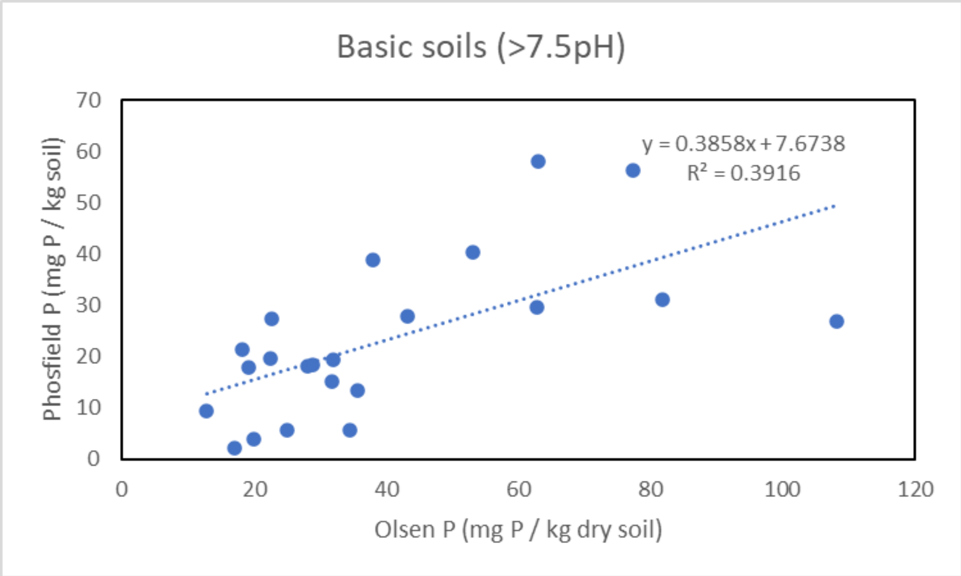

Figure 6 Relationship between Phosfield and Olsen extracted P in basic soils

A questionnaire was used to assess the various aspects of the Phosfield kit to determine which, if any, were most problematic. The steps involved are basically covered by i) sample preparation, ii) extraction of phosphates from soil sample, iii) filtration, iv) reaction and v) measurement. The step that caused most participants in the study the greatest amount of difficulty was the filtering of the soil/extractant solution (see Figure 7). The filtering procedure prevented three participants from completing their analyses. Almost all the responders used the comment section to mention the difficulty they had experienced in using the filtering system or the time taken to gain sufficient filtrate for the next stage of the measurement process.

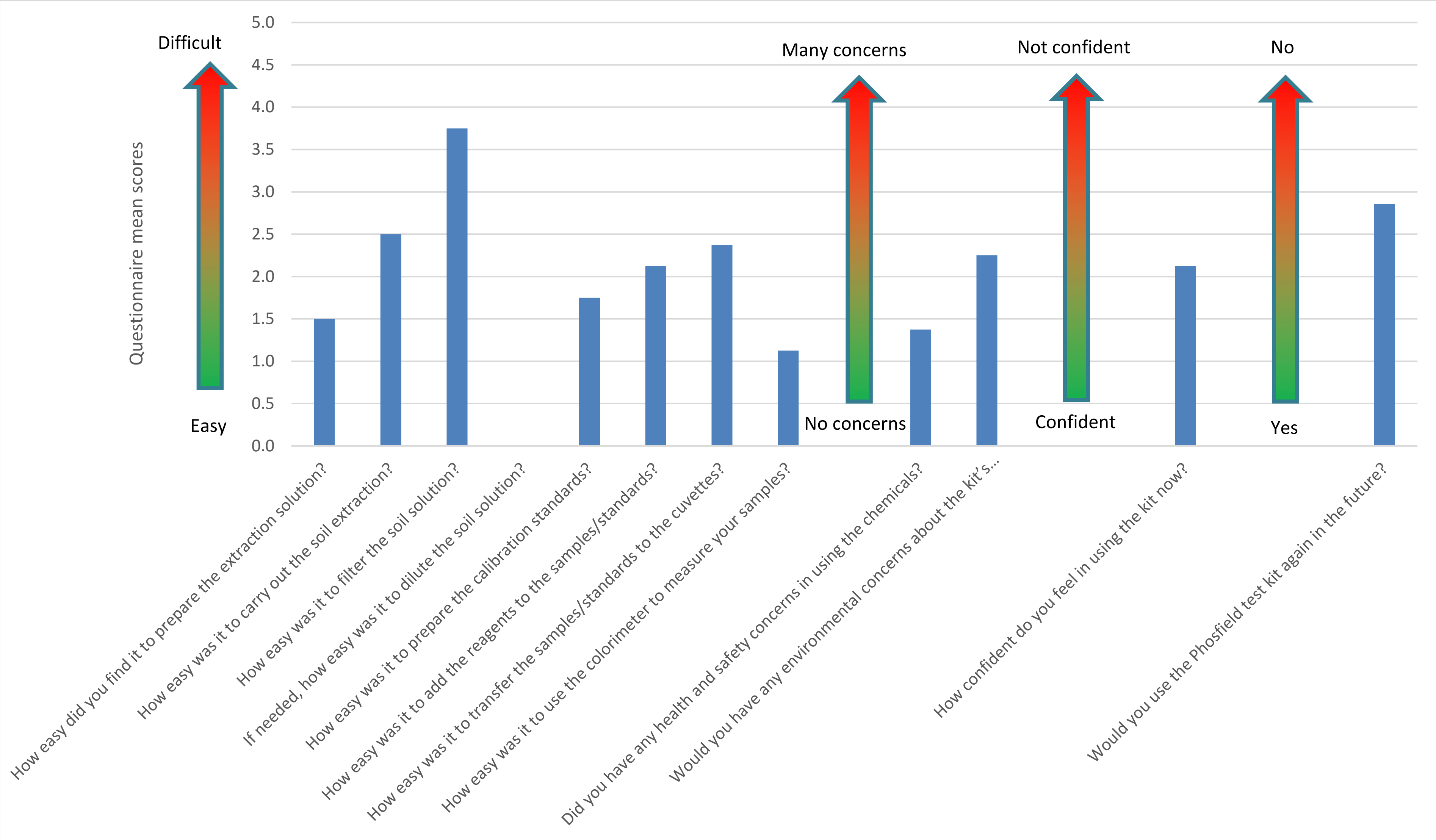

Figure 7. Results of the user feedback questionnaire (answering options ranged on a five-point scale).

5. Discussion

A soil P test kit that is reliable, quick to use, relatively cheap and, very importantly, able to be used in a variety of situations on a variety of soils would be of benefit to both farmers, agricultural advisors and environmental scientists. Farmers would benefit because a reliable measurement of their soil P contents would provide them with sufficient information upon which to base fertiliser applications. Agricultural advisors would benefit because it would be a rapidly available vital piece of information upon which farming decisions could be based. Environmental consultants would benefit by reducing the over application of P-based fertilisers and thereby reduce the potential for P passing from farmland areas into those more sensitive to overloading with P such as freshwater rivers and lakes. The Phosfield test kit has been developed to meet all four of these requirements, and the current project aimed to assess the user friendliness of the kit by a variety of users. Due to a variety of reasons not all of the participants approached to take part in the study were able to complete the testing of their soil samples and thus provide feedback on the test kit. Most of those that did provide feedback expressed an opinion that the filtering stage was the most problematic, sometimes to the point that no filtrate could be obtained and tested. During the course of the project it has become clear that steps can be taken to alleviate some of the problems associated with the filtering process, and the instruction manual will be altered to reflect this.

Most users of the kit had already sent soil samples to be analysed for P in the past, and so were aware of where high P soils were located on their farms. In situations where high soil P results were obtained from the Phosfield test kit, these tallied with the expectations of the testers. Three of the four soil samples with an Olsen P value >100 mg PO_4-P/kg soil also had high Phosfield P results (these coming from situations where previous soil sampling had indicated high soil P contents due to a muck heap being stored in the location previously, and where the ashes from the burning of turkey waste (including bones) had been spread on to one field).

The values obtained from soil testing using the Olsen extraction system forms the basis of the fertiliser application recommendations for England and Wales (RB209, 2017). No additional P fertiliser is recommended for soils greater than Index 2 for pastures being grazed, and no additional P fertiliser for soils greater than Index 3 when used for making silage. No cereal crops have P applications recommended where the soil is greater than Index 2. A total of 35 of the 82 soil samples tested were of an Olsen P Index of 4 or above (i.e. 43% of the samples tested), and 56 of 82 (i.e. 68%) were of Index 3 or above (Table 2). Clearly, in these situations it can be said that there has been an over application of P-based fertilisers in the past, which may have potentially led to incidents of environmental pollution downstream of the fields in which the fertiliser was applied. Having a soil P test kit that can reliably inform the decision-making process as to whether P based fertilisers should or should not be applied would prevent such overapplications and the environmental issues these can form.

Table 2. Olsen P values from the 82 soils available for testing.

Index	Olsen P (mgP/kg soil)	Number of samples
0	0-9	10
1	10-15	4
2	16-25	12
3	26-45	21
4	46-70	14
5	71-100	12
6	101-140	8
7	141-200	0
8	201-280	1
9	Over 280	0

Key feedback:

- Clearer instructions required to describe the filter system use,
- Guidance notes on the expected timeframe for filtering soil samples,
- Provision of extra pipettes to allow more precise transferring of fluids from one stage of the process to the next (in particular when transferring the extraction liquid to the 15ml standard and sample tubes,
- Provide an extra three filter holders and filter stands to match the six soil sample bottles and filter attachments within the kit,
- Provide clearer advice on the suitable moisture content of the soils prior to being added to the soil extraction bottles (when the soil in too wet it sticks to the scoop very easily and thereby making it difficult to reliably obtain 5mL of soil,
- Extra guidance on the option of using the 5ml or 10ml scoop depending on soil organic matter content,
- Highlighting of when soil samples need to be diluted due to the high levels of P within the samples.

The results and feedback from this project will be used to improve the user-friendliness of the kit and to understand its limitations. Olsen P, even when carried out in a laboratory, is notorious for being difficult to measure accurately, but the relationship we obtained with our Phosfield in-field measurements and the laboratory-based measurements are relatively good, especially when being used to classify the soil P status into a relatively broad P-index for the purpose of making fertiliser application rate recommendations. Further work, building on the results of this research, should focus on understanding the accuracy of the test kit in different soil types across different P indices, and developing methods for analysis of other soil properties of interest, e.g. potassium (K) and carbon (C).

6. References

Olsen, S. R., Cole, C. V., Watanabe, F., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (p. 19). Washington, D.C.: U.S.D.A. Circular No. 939.

Nutrient Management Guide (RB209) (2017) AHDB.