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The role of experiential learning in the adoption of best land management practices

ABSTRACT

Agriculture is both the cornerstone of global food security and one of the main drivers of environmental degradation. To address existing and potential environmental impacts of agriculture, policymakers are increasingly focussing on influencing farmers' behaviour to adopt best management practices (BMPs). One of the strategies adopted is the provision of advice aimed at raising awareness of environmental pollution and mitigation measures. By improving farmers' awareness, it is expected that changes in behaviour would be reflected in the adoption of BMPs. This expectation is based on the assumption of a direct link between awareness and uptake of BMPs. So far, however, the limited empirical research has shown that, while there is a link between awareness and adoption, this link is indirect and is mediated and moderated by other factors. One of the potential intervening factors that remains poorly understood is the enabling capacity that experiential learning brings. Through a mixed-methods approach, we explored farmers' awareness and the role of experiential learning in the adoption of BMPs. The study focusses on the experiential learning process associated with the use of nutrient management plans to reduce diffuse water pollution from agriculture in the context of a soil sampling scheme in Northern Ireland (UK). Overall, we found that while advice seems to have contributed to increased uptake of BMPs, likelihood of adoption increased if the farmers had prepared the nutrient management plans themselves. This shows the critical role that experiential learning plays in deepening farmers' understanding and increasing the likelihood of their adopting BMPs. This provides support for the conceptual premise that while information provision is important, farmers need to actively engage in and be able to reflect on the practice for it to lead to behavioural changes. The role of experiential learning also suggests the need to move from the predominant model of a unidirectional relationship (the notion that the relationship always starts from awareness to behaviour), to a bidirectional one (i.e. from behaviour to awareness) and such interactions need to be understood through analysing the feedback loops over time. More research on this could offer insights into effective ways to help farmers adopt BMPs and ultimately contribute to reducing the environmental impacts of agricultural land management.

KEYWORDS: Awareness; Behaviour change; Farm advice; Nutrient Management; Soil Testing; Northern Ireland

1. INTRODUCTION

Agriculture is both the cornerstone of global food security and one of the main drivers of environmental degradation (Hosonuma et al., 2012, United Nations, 2016, United Nations Environment Programme, 2017). Conventional agricultural systems which currently dominate global food production contribute to biodiversity loss, soil degradation, water pollution and climate change (Hutchins, 2012, OECD, 2012, United Nations World Water Assessment Programme, 2015, Novotny, 2013, UNCCD, 2015). Sustainable (global) food production can only be achieved by safeguarding environmental systems and natural resources such as soil health, biodiversity and water quality, which underpin agricultural production (United Nations, 2015). Therefore, the integration of agricultural and environmental policies is recognised as a priority for sustainability transitions (UNCCD, 2015, United Nations, 2015, Environment Agency, 2014). Farmers are key decision makers in addressing environmental problems (Stringer et al., 2020, Macgregor and Warren, 2006a, Blackstock et al., 2010). In their search for new measures to tackle environmental degradation, researchers and policymakers are thus increasingly focussed on finding effective ways to help farmers adopt best management practices (BMPs) (Evans et al., 2019).

One such BMP challenge is farm-sourced diffuse pollution (e.g. phosphate, nitrogen, pesticides, herbicides, desiccants, etc.) in waterbodies. The increasing consideration of behavioural change as a means to address this problem is evident in the emergence of many behaviour focussed policies such as the Water Quality Scheme and the Environmental Quality Incentive Programme in the United States of America (Dwyer et al., 2007), the Catchment Sensitive Farming Delivery Initiative started in England (Environment Agency, 2011, Environment Agency, 2014) and the Diffuse Pollution Management Strategy established in Scotland (DPMAG, 2015, SEPA, 2015). One of the strategies adopted by policymakers has been to provide advice in order to raise awareness of environmental pollution and BMPs amongst farmers (Merrilees and Duncan, 2005, Blackstock et al., 2010), under the expectation that this will lead to increased adoption of BMPs (Okumah et al., 2019). This is based on the assumption of a direct link between awareness and behavioural changes.

To date, however, the limited empirical research examining behavioural aspects of awareness-focussed strategies suggests that the link between awareness and adoption of BMPs is not a direct one (Okumah et al., 2019). A number of factors influence the awareness-behaviour link. For instance, Inman et al. (2018) have demonstrated that while awareness might be useful in fostering behavioural changes, sources of advice and social norms also play key roles in whether farmers adopt BMPs (see also, Vrain and Lovett, 2016). Other studies have indicated that beyond awareness, farmers' decision to take up BMPs depends very much on the context; for example, the flexibility of arrangements (e.g. agri-environmental schemes (AES)) in the framework in which they are delivered (Barnes et al., 2009, Macgregor and Warren, 2006b) or the receptiveness of farmers (Houser et al., 2020). Some important issues regarding the flexibility of AES include terms of ease of application, choice of options, or how easy it is to leave or change those options (Barnes et al., 2009).

Some of these (indirect) influencing factors have to do with the enabling capacity that experiential learning brings. For instance, Okumah et al. (2018) found that although farmers' awareness influenced compliance with Diffuse Pollution General Binding Rules (GBRs)[1] in Scotland (UK) (DPMAG, 2015), this link was found to be mediated by farmers participation in AES. The study revealed that awareness

[1] General Binding Rules represent a set of mandatory rules which cover specific low risk activities.

of diffuse pollution was not sufficient to yield farmers' compliance with GBRs and that significantly more farmers complied if they also participated in (voluntary) AES. The study suggests that awareness could lead to farmers' involvement in some practices, which in turn, deepens their understanding of their environmental impacts and mitigation strategies, leading to a wider uptake of BMPs. As put forward in Kolb's experiential learning theory, individuals' reflections on new experiences provide the impetus for learning which leads to further active engagement or experimentation (Kolb, 1984). Based on this, hands-on strategies that allow farmers to engage in such experiential learning appear to be essential in maximising the value of awareness strategies. Indeed the role of experiential learning has been recognised in studies focussing on farmers' establishment of wildlife friendly habitats (Science for Environment Policy, 2017) and identification of pollution sources (Okumah and Yeboah, 2019, Okumah et al., 2019b, Boiral, 2002). Moreover, the experience of engaging in conservation practices also helps to shape individuals' understanding of the complex socio-ecological systems in which they operate (Whiteman et al., 2004) and this understanding has implications on their decisions and behaviours (Woodwell, 1989, Adams and Sandbrook, 2013, Sutherland et al., 2004).

Despite its potentially critical importance in the success awareness-based land management policies (Fazey et al., 2006, Pahl-Wostl and Hare, 2004, Whiteman et al., 2004, Suškevičs et al., 2019), the role of experiential learning still remains under studied with existing studies focussing on Latin America (D'Angelo and Brunstein, 2014, Kumler and Lemos, 2008). The current research aims to fill this knowledge gap by exploring, through a mixed methods approach, farmers' awareness and the role of experiential learning in the adoption of BMPs. The study focusses on the experiential learning process associated with the use of nutrient management plans to reduce diffuse water pollution from agriculture. It is set in the context of the European Union Exceptional Adjustment Aid Soil Sampling and Analysis Scheme (EU EAA SSAS) in its application to Northern Ireland (UK). The process of preparing a nutrient management plan involves a conscious assessment of a wide range of factors, an iterative and reflective process that allows the developer to make sound decisions (Adusumilli and Wang, 2018, Oenema et al., 2003, Maguire and Sims, 2002). This process can help farmers to learn over time, enhance ownership of the final product (i.e. the nutrient plan) and their confidence in it. It could therefore be argued that farmers who go through the experience of preparing their own plans, enhance their experiential learning.

The Nutrient Action Programme Regulations (Northern Ireland) stipulates that farmers must comply with all land and water related regulations, to avoid prosecution and penalties such as possible fines, but also to help them meet the requirements of Cross-compliance. These regulations require farmers to keep records of fertiliser application to all fields. Therefore, although these regulations and financial incentives tied to the EU's Common Agricultural Policy are expected to trigger the preparation of nutrient management plans and adoption of BMPs, Posthumus *et al.,* (2011), have noted that some farmers do not feel necessarily threatened by prosecution. Other studies have shown that while incentives could encourage to adopt BMPs, many farmers do not find them attractive due to their inflexible nature, often with many constraints (Macgregor and Warren, 2006a, Barnes et al., 2009, Okumah et al., 2019a).

Examining whether this more "hands-on" engagement with nutrient management planning leads to higher adoption of BMPs can advance our understanding of the role of experiential learning in support of land management strategies. Therefore, while the study is set in the context of the EU EAA SSAS in Northern Ireland it aims to provide insights that are of broader relevance with respect to the role of experiential learning in awareness-based land management policies.

2. METHODOLOGY

2.1 Case Study Description

In Northern Ireland, 75% of land use is for agriculture, with 93% of this being grassland and only 7% arable. While livestock farming is largely grass based, 68% of the agricultural area is classed as 'Less Favourable Area' where agricultural activity is constrained due to adverse physical conditions such as high soil moisture, frequent rainfall or steep slopes. There are approximately 25,000 farms in Northern Ireland with meat, dairy and poultry being the largest sectors, accounting for over 80% of agricultural output. The average farm size is 41 ha, with an average income of £26,000 (Department of Agriculture Environment and Rural Affairs, 2019). A significant proportion of farm income comes from the EU Common Agricultural Policy (CAP) subsidies such as the basic payment scheme (£194 million in 2018 ~£7700/farm on average) and greening payments (£88 million in 2018 ~£3520/farm on average), depending on farm size. The agri-food industry contributes £5 billion to the Northern Irish economy each year and is responsible for 23,000 jobs in the food and drink processing sector and input supply sectors (Department of Agriculture Environment and Rural Affairs, 2019). This background information demonstrates the important contribution of agriculture in Northern Ireland, and the need for sustainable management practices to maintain these benefits while reducing its negative impact on the environment.

The EU EAA SSAS was a voluntary advice-centred scheme that places the focus on knowledge transfer via nutrient management plans and soil testing. The implementation of the EU EAA SSAS (2017-18) by Northern Ireland's Department of Agriculture, Environment and Rural Affairs (DAERA) consisted of two sub-schemes: (i) an open soil sampling scheme to which all Northern Ireland livestock farmers were eligible to apply (hereafter referred to as NI Wide Scheme), and (ii) a catchment scheme where livestock farmers within 11 sub-catchments of the Upper Bann catchment (hereafter referred to as the UBC Scheme), an intensively farmed area in the east of the country (Barry and Foy, 2016) (Figure 1), were eligible to apply. The NI Wide Scheme received applications from 3,030 farms (100,000 fields); however only 522 farms (12,629 fields) could be accommodated within the EU EAA budget and these were selected using a randomised lottery system. The UBC Scheme included 513 farms and a total of 7,340 fields with 73% of eligible farmers participating. In all, the two schemes covered 1035 farms and 19,969 fields; 4.2% of the 24,900 farms and 2.7% of the 733,932 fields in Northern Ireland. The total area sampled for soil was 33,767 ha (22,220 ha in NI Wide Scheme and 11,547 ha in UBC Scheme).

Soil sampling was managed by the Agri-Food and Bioscience Institute (AFBI[2]) from November 2017 to February 2018. Samples were sent to an accredited laboratory where they were tested for soil pH (in a 1:2.5 volume ratio of soil to water), Olsen Phosphorus (P) (in a 1:20 volume ratio of soil to sodium bicarbonate), potassium (K), Magnesium (Mg) and Calcium (Ca) (all extracted with a 1:5 volume ratio of soil to ammonium acetate or ammonium nitrate), and Loss-on-Ignition (LOI), which can be used to provide an estimate of soil organic matter content. Soil test results were sent directly to participants from the laboratory in a standardised tabular format, with recommendations on lime and nutrient application rates, the latter only where farmers had provided detail on current and planned cropping. All farmers were provided with the opportunity to participate in training, which was developed and delivered by the College of Agriculture, Food & Rural Enterprise (CAFRE), covering interpretation of the soil test results and associated recommendations regarding fertiliser and lime application and nutrient management planning. Participants who did not attend the training events were provided with the training materials by post. In total, 583 (371 in NI Wide and 212 in UBC) farmers attended training events across the two schemes (56% of the total participants).

Tabulated soil test results were supplemented by field-scale orthophotographic maps with colour-coded overlays based on the nutrient status (Olsen P and K) and lime requirement (pH) (above, below and within the respective optimum ranges) (Fig 2). In addition, UBC Scheme participants also received P runoff risk maps (Fig 3) (modelled using LiDAR topographic datasets and soil hydraulic properties (Cassidy et al., 2019)) which indicate areas within fields at high risk of generating runoff during storm events and thus the potential for losing nutrients (primarily P) from applied slurry and fertilisers, and soil P where Olsen P concentrations were elevated.

By providing a free soil sampling service, nutrient management advice and training to generate nutrient management plans in these schemes, DAERA aimed to improve farmers' understanding of the agronomic and environmental benefits of soil testing, which included recommendations on how much lime, and nutrients to apply to each field in order to maximise the quantity of crop produced. The nutrient management advice included information on how to better manage P (such as inclusion of

[2] AFBI conducts high quality research and development, statutory, analytical, and diagnostic testing functions for DAERA and other Government departments, public bodies and commercial companies in Northern Ireland.

buffer strips and changing application rates of slurry or farmyard manure) in order to reduce risks of P losses from soil to watercourses.

During training sessions, there were demonstrations on how to use online crop nutrient calculators to generate a nutrient management plan (using soil analysis results). The output from the online calculators feeds into a systematic and structured record (written document) on one or more of the following: crop requirement (i.e. how much N, P and K your crop needs to grow), how much N, P and K is supplied from slurry and how to minimise the need for chemical fertiliser by using the right type and rate of fertiliser application. After demonstrating and sending training materials to farmers, they were encouraged to generate nutrient management plans for their farms (based on their soil analysis results). Therefore, though the scheme did not fund the preparation of nutrient management plans, it was expected to have increased awareness on the preparation and use of nutrient management plans and could contribute to the preparation of nutrient management plans. Through the preparation and use of such plans, farmers are expected to reflect on the process and benefits associated with the use of the nutrient management plan which could in turn reinforce their awareness and subsequently trigger behavioural changes, for example, through altering the type and amount of chemical fertiliser applied, and the application rates of slurry or farmyard manure. This, therefore highlights an opportunity to explore how awareness and experiential learning could contribute to behavioural changes (i.e., the adoption of BMPs).

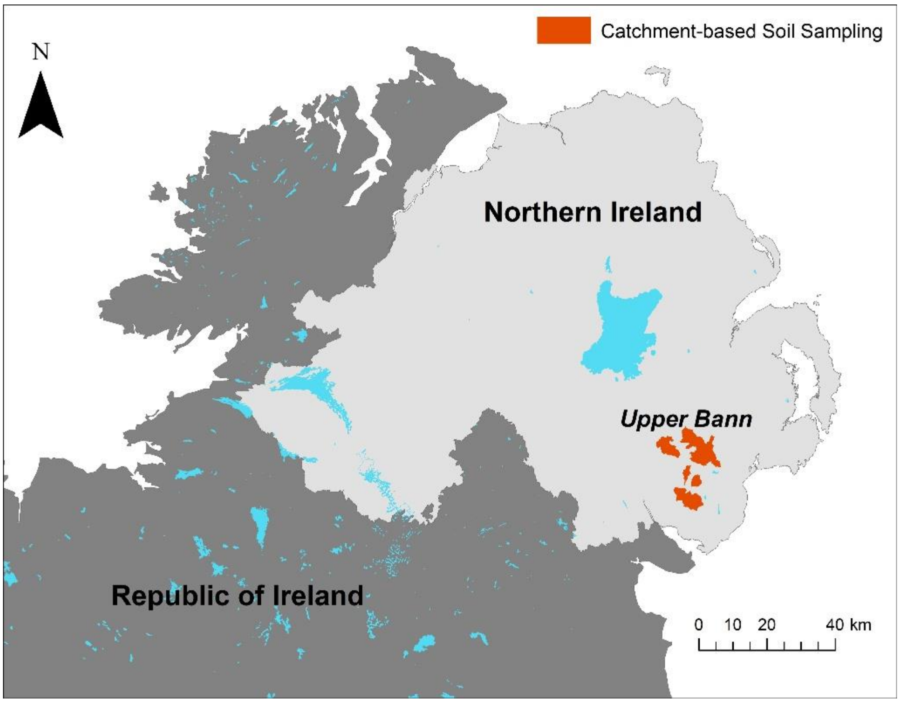

Figure 1: Locations of the soil sampling undertaken as part of the EU EAA SSAS. A Northern Ireland (NI-Wide) sampling scheme covered 522 farms chosen at random from applicants across Northern Ireland, while a catchment-based scheme (UBC) sampled 513 farms in 11 sub-catchments of the Upper Bann river system.

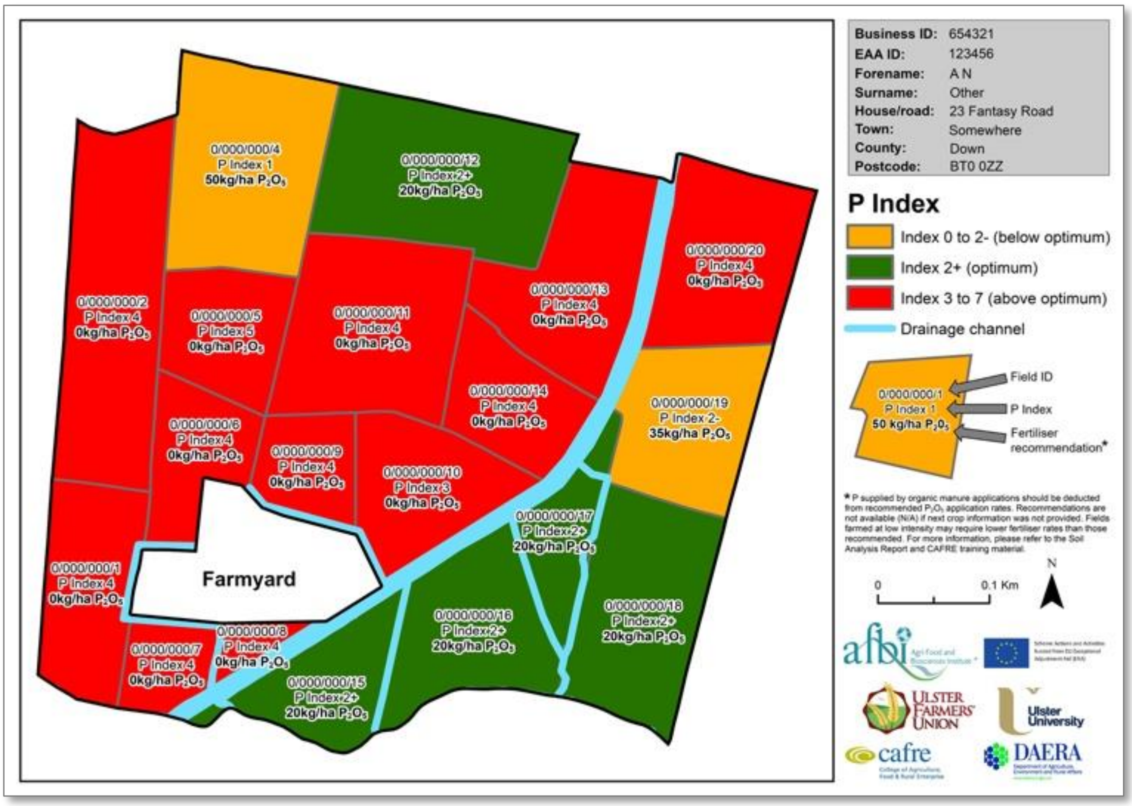

Figure 2: An anonymised example of a farm phosphorus map showing soil P Indices (colour-coded and labelled) for each sampled field with amendment recommendations (kg/ha P_20_5).

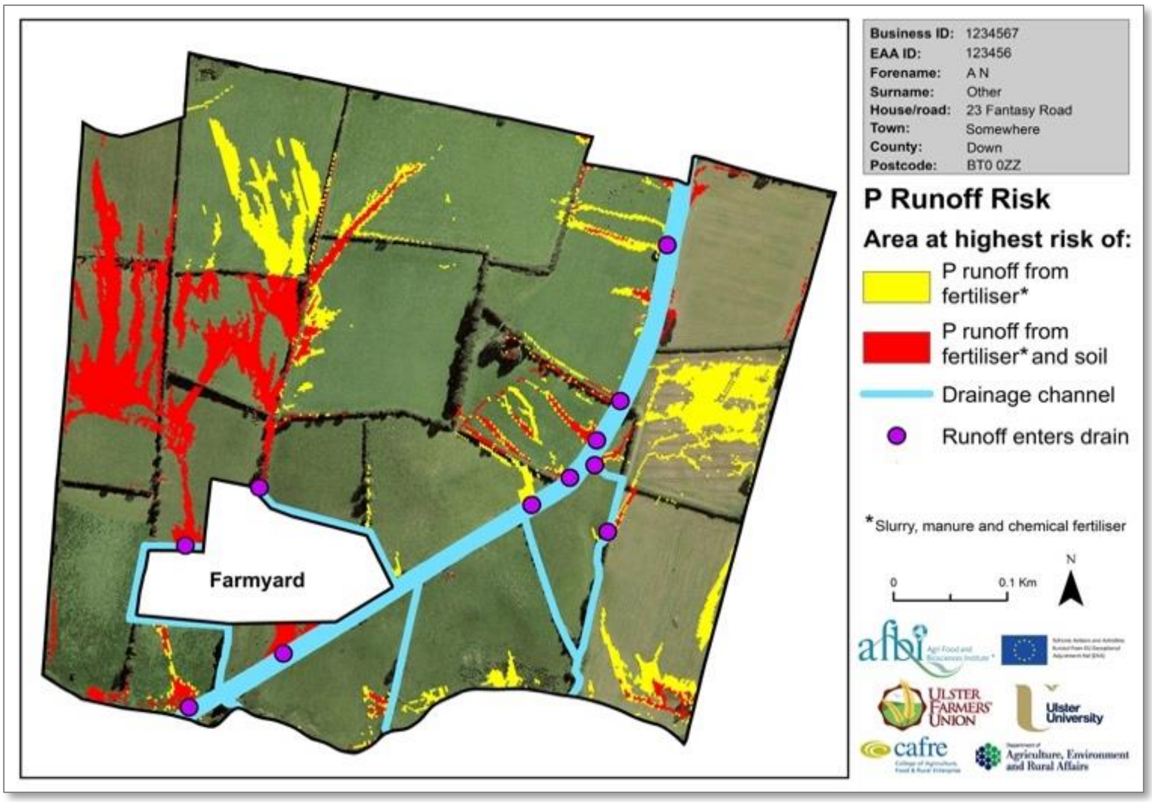

Figure 3: An anonymised example of a farm P runoff risk map showing areas at high risk of P runoff from both fertiliser (chemical or organic manures) and soil P. Delivery points indicate locations where runoff inflows to drainage ditches and watercourses.

2.2 Data and methods

We applied a mixed methods approach using a questionnaire-based survey (N=408) and qualitative semi-structured in-depth interviews (N=21) to explore farmers' awareness of the link between nutrient management and water quality and the role of experiential learning in adoption of BMPs. A mixed methods approach has an advantage over purely qualitative or quantitative approaches, as quantitative surveys provide generalizable findings while qualitative interviews provide deep and rich contextual information about the phenomenon being studied (Silverman and Patterson, 2015). Quantitative data were available from a post-scheme questionnaire targeting scheme participants carried out by DAERA twelve months after farmers had received their soil test results (in March/April 2019). Follow up semi-structured in-depth interviews were designed expressly for this research and conducted in October 2019.

2.2.1 Post-scheme questionnaire

The post-scheme questionnaire (that had been carried out previously by DAERA and made available to the authors) focussed on evaluating actual behavioural changes (see Appendix 1 for the questionnaire used for the survey). For this, a twelve-month lag after receiving the soil test results is a reasonable time for farmers to have changed their nutrient management practices in light of the recommendations. The questionnaire contained questions on farmers' awareness of the link between nutrient management and water quality, the preparation of nutrient management plans, and whether farmers had changed nutrient management practices or not as a result of the soil test recommendations. Overall, 1,035 questionnaires were sent out and 408 were completed by farmers (39.4% response rate).

Although the post-scheme questionnaire had been prepared by DAERA with the intention of merely checking whether the scheme had been successful in increasing awareness and uptake of the measures, it contained information that could be conceptualised as experiential learning, and that we use here to explore its role in the adoption of BMP. To operationalise the concept of experiential learning, we focussed on whether the farmer prepared their own nutrient management plan or whether the plan was prepared by a farm adviser; the nutrient management plan functioning here as the boundary object through which the experiential learning takes place (i.e. the object through which the 'hands-on' experience possibly occurs[3]). This conceptualisation and operationalisation was inspired by past empirical studies (e.g., Suškevičs et al., 2019) that suggested that hands-on activities can reinforce awareness and contribute to the adoption of BMPs.

[3] A boundary object refers to information – such as plans, field notes, and maps – that could be used in diverse ways by different social groups.

Questionnaire data from farmers were consequently grouped into two – those who prepared their own nutrient management plans and those whose plans were drawn up by a farm adviser. We then applied conditional process modelling on these two groups to analyse their differential adoption of BMPs. Conditional process modelling is a statistical technique that allows the researcher to identify direct, indirect and conditional relationships (Hayes, 2013). Accordingly, it is best suited where the researcher is interested in identifying the mechanisms through which a variable directly or indirectly transmits its effects onto others as well as the conditions under which such relationships operate (referred to as moderators). Moderators are variables that potentially influence the statistical significance, direction and/or strength of the link between two or more other variables (Hayes, 2013).

Here, we were interested in whether experiential learning (operationalised through the preparation of nutrient management plans) influenced the link between having a nutrient management plan and the adoption of BMPs. Therefore, in this context, the variables of interest are (Table 1): (1) nutrient management plan (whether the farmer had a nutrient management tool or not) – independent variable capturing the boundary object; (2) preparation of a nutrient management plan (if the plan was prepared by the farmer themselves or by a farm adviser) – moderator capturing the role of experiential learning; and (3) adoption of BMPs (whether the farmer changed nutrient management practices as a result of the soil test recommendations or not) – dependent variable reflecting the behavioural change. This study focussed on five BMPs: changing the type of fertiliser purchased (e.g. changed from compound to straight fertiliser), changing the amount of fertiliser purchased, increasing lime usage, importing or exporting slurries, and using P runoff risk maps to help decide where to establish a buffer strip. The first four BMPs applied to farmers in the NI Wide scheme while the last one (using P runoff risk maps to help decide where to establish a buffer strip) applied to only farmers in the UBC scheme.

We combined SPSS IBM version 24 and the lavaan package within RStudio (0.5-23.1097) to perform the conditional process modelling in three stages. First, we analysed the measurement model for validity. This involved using a mix of indices to appraise model fit (Hooper et al., 2008, Hu and Bentler, 1999, Brown, 2006). Then, we tested the hypothesised relationship, regressing effect of the boundary object (i.e. availability of a nutrient management plan – independent variable) on behavioural change (i.e. adoption of BMPs - dependent variable); and establishing whether this link was dependent on whether the plan was prepared by the farmer (experiential learning) or by a farm adviser (i.e., the moderator). This moderator was tested by running the same model for the overall sample and also for the multi-groups. We used an alpha (α) = 0.10 as our primary statistical criterion because the risk of a type II statistical error (i.e., a false negative) is relatively high when using a small sample (Schumm et al., 2013); (>200 cases is often considered large for typical structural equation modelling or conditional process modelling depending on the number of variables) (Jackson, 2001, Jackson, 2003).

Table 1: Constructs and variables used in the conditional process modelling

Constructs	Variable category	Variable	Question	N
Boundary object	Independent variable	Nutrient management plan	Whether a farmer has a nutrient management plan (1) or not (0).	386
Experiential learning	Moderator	Preparation of nutrient management plan	Whether the plan was drawn up by a farm adviser (1) or not (0).	128
Behavioural change	Dependent variable	Adoption of BMP	Whether the farmer has changed the type of fertiliser purchased (1) or not (0).	392
			Whether the farmer has changed the amount of fertiliser purchased (1) or not (0).	375
			Whether the farmer has increased lime usage (1) or not (0).	388
			Whether the farmer has imported or exported slurries (1) or not (0).	349
			Whether the farmer has used their P Risk Run-Off Map to help decide where to establish a buffer strip (1) or not (0).	76*

Notes: N= Number of responses; * = farmers in Upper Bann catchment (UBC) scheme only.

2.2.2 Qualitative semi-structured interviews

The semi-structured interviews aimed at deepening our understanding of the results obtained from the questionnaire and providing further meaning and context to results of the conditional process modelling. This also gave us the opportunity to include relevant issues that were not captured in the questionnaire (e.g. although the questionnaire included questions on whether farmers had changed practices or not, it did not ask for the direction of change, for example, whether the farmer increased or reduced the amount of fertiliser applied). The key topics covered in the interviews included: farmers' understanding of factors influencing diffuse pollution from agriculture and how to mitigate it, preparation and use of nutrient management plans and changes in nutrient management practices. See Appendix 2 for the script used for the qualitative interviews.

The interview script was collaboratively designed by the authors and DAERA. Co-designing the script helped in ensuring that it focussed on addressing key issues within the scheme's context (Devisscher et al., 2016, Kench et al., 2018, Jagannathan et al., 2020). To recruit interview participants, researchers from AFBI contacted farmers who had participated in the Post-scheme survey (described in section 2.2.1) via phone call and emails. Where farmers agreed to be interviewed, a date and time was scheduled for the interview session. Twenty-one farmers (who were all part of the scheme) were interviewed in October 2019. These were conducted by interviewers specifically trained for the task. All interviews were conducted through phone calls and lasted up to one hour. We applied descriptive respondent validation (Byrne, 2001) to improve the credibility and validity of the data. This process involved summarising aspects of the interview and asking participants if the summaries represented their views or not. This was implemented at the end of the interview session. Qualitative data, (i.e. transcripts or notes) from the interviews were analysed using content analysis (Mayring, 2004, Stemler, 2000), using NVIVO version 11. This was done by carefully reading through the interview notes and identifying key topics that emerged from the texts rather than on the basis of pre-defined topics. We also identified key statements that provided plausible explanations to the results of the quantitative analysis. This analysis was iteratively reviewed by members of the research team to establish trustworthiness in the results (Cypress, 2017).

2.3 Limitations

The survey data was gathered by DAERA as part of the EU EAA SASS scheme to evaluate the impact of the scheme on nutrient management practices and not specifically to explore farmers' awareness and the role of experiential learning in behavioural changes. As a result, it does not cover information on variables such as farm type and years of experience, that are known to potentially influence farmer decisions and behaviours (Buckley et al., 2015, Okumah et al., 2018). Moreover, because of the lack of a baseline study, we cannot categorically conclude that improvements in knowledge and behaviour would not have happened without the scheme. We attempted to mitigate these limitations by complementing the data with semi-structured in-depth interviews – where we collected data covering some of these aspects. In any case, this does not invalidate the results, since the aim is not to assess the effectiveness of the scheme itself but the role that experiential learning played in the awareness-behavioural link.

Second, the research may be prone to social desirability bias given that we relied on self-reported behaviours (Schuman and Presser, 1981, Jackman, 1973), i.e. it is possible that some farmers reported pro-environmental practices to project themselves as environmentally minded people, when these reports may not be a true reflection of their practices. It is important to note that self-reported behaviours are widely accepted in the behavioural sciences (Kormos and Gifford, 2014). This potential limitation was partly addressed through the in-depth interviews as farmers' spontaneous description of their practices could reveal their understanding and engagement in them.

Another potential limitation stems from the interviewers. Due to cultural sensitivities (i.e., most of the farmers were reluctant to be recorded) it was not possible to voice record the interviews and conversations were recorded by means of note taking. Taking only notes implies that some information could be lost in the process and the decision to consider which information was important could have been influenced by interviewers' biases (Agar, 1986). We attempted to resolve aspects of this limitation by providing thorough training to the interviewers and asking them to send (at the end of each day) immediate impressions, their thoughts, and things that appeared to be surprising and confusing, as this could help provide some context to the data and provide additional informational relevant for interpreting results (Agar, 1986). Moreover, it is worth noting that the interviewers had very good knowledge of farming practice in Northern Ireland, which helped them to understand the key issues that farmers raised during the interviews.

3. RESULTS

This section presents results of the questionnaires and the semi-structured qualitative interviews based on the objectives of the study. First, we present results on farmers' awareness of link between nutrient management practices, yield and water pollution. Following this, we explore whether exposure to advice changed farmers' practices and how experiential learning plays a role in behavioural change (section 3.2).

3.1 Are farmers aware of the link between nutrient management and water quality?

The questionnaire data show that 85.8% of responding farmers acknowledged a link between good healthy soil and good water quality. From the qualitative interviews, farmers provided explanations on the link between nutrient management and water quality, demonstrating a good understanding. For instance, they explained that without knowledge of the nutrient status of their soils, a farmer could apply nutrients in excess of crop requirement, and this could be transferred from the soil to watercourses. To reduce the risk of nutrient runoff, most farmers explained that a farmer needs to sample and to test their soils; i.e. they understood that soil testing highlights the nutrient status of soil and is the basis for fertiliser rate recommendations required for optimum yield for a given crop. By following such recommendations, farmers realised they could maximise yield while helping to reduce risk of water pollution.

Because we did not conduct a pre-scheme evaluation of farmers' understanding of the link between nutrient management and water quality, we cannot (categorically) attribute their awareness to the advice or training provided in the EU EAA SASS scheme. However, further qualitative evidence from the in-depth interviews suggest that the training or advice provided in the scheme had contributed to consolidating a high level of understanding of nutrient management, and of the link between soil management practices, grass yield and water pollution. For instance, some farmers reported that prior to participating in the scheme, they had a poor understanding of these issues but following their participation, they were now generally aware, as illustrated by these quotes: "*[I] went to the meeting, got [soil analysis] results explained and gained a greater understanding*" (Farmer 8) and "*[I] went to the meeting, got a broader understanding and found it very useful. [I] would recommend it to others*" (Farmer 19). While these farmers emphasised general awareness, others pointed out specific areas of knowledge improvement. For example, some farmers mentioned awareness regarding nitrogen, phosphorus, and potassium requirements:

> "*Yes [I] attended 2 meetings. [I] found them useful for determining fertiliser requirements. Now I feel more informed regarding which type of fertiliser to use rather than solely going on the fertiliser merchants recommendations*" (Farmer 18).

> *"Yes [I] went to the meeting and found it very valuable. [It] helped me to understand the analysis and to implement a nutrient management plan. Previously didn't understand N, P, K requirements; only understood the pH before the [training] course* (Farmer 10).

Additional evidence obtained from the in-depth interviews suggests that the P runoff risk maps had contributed to farmers' understanding of the link between P application and water pollution and had made them more conscious of nutrient loss in runoff in general. Some farmers noted that the "*maps had made them conscious of the P content of the land*"; making them "*less careless*". This improved awareness could be attributed (in part) to the colour coding of the maps as the first interviewee noted that they "*understood the colour coded maps"* and *"realised low lying fields were most at risk*".

3.2 Does awareness contribute to uptake of BMPs? The role of experiential learning

Descriptive statistics from the questionnaire show that the majority of farmers reported behavioural changes in relation to type of fertiliser purchased, amount of fertiliser purchased, amount of lime used, while less than 30% reported changes in import and export of slurries (Figure 4). Evidence from the qualitative interviews corroborate this finding as some farmers noted that "*previously,[I] applied grazing ground with 20:10:10 [compound fertiliser] based on historical practices, but now [I] apply just [straight] nitrogen [fertiliser] based on soil test results*" (Farmer 1). Another farmer added that I "*would have applied 20-10-10 [compound fertiliser] but now I use straight N fertiliser*" (Farmer 8). Straight fertilisers supply only one primary nutrient. Therefore, by switching from compound fertilisers (those with two or more primary nutrients) to straight fertiliser (using only nitrogen where P and K indexes suggest no additional amendments are required), farmers are able to avoid over applying other nutrients or avoid applying more nutrients than the crop requires.

Next, we focus on the potential role that experiential learning played in the adoption of BMPs (i.e., in leading into actual behavioural change). Results of the conditional process modelling revealed that having a nutrient management plan alone did not influence the uptake of any of the BMPs (p-value>0.1, overall sample models in Table 2). However, this relationship is moderated by the experience of preparing their own nutrient management plan (as opposed to having it drawn up by a farm adviser); we observe statistically significant effects (through multi-group analysis models in Table 2). For two of the BMPs (importing/exporting slurries and use of runoff maps for establishing buffer strips), we find a positive significant effect of the plan having been drawn by the farmers themselves (p-value <0.1). For two of the other BMPs (change of fertiliser type and increase in lime use), we also observe the significant negative effect of the plan having been drawn by the farm advisor (p-value<0.1). For change in the amount of fertiliser purchased, there was no statistically significant relationship betwen amout of fertiliser purchased and who had prepared the nutrient plan (p-value >0.1).

While nuanced, these results yield a clear picture of the effect of experiential learning on the adoption of BMPs: who prepares a nutrient management plan influences the relationship between having a nutrient management plan and adopting BMPs, and if the plan is prepared by the farmer themselves it is more likely that this adoption happens. These results indicate that there are positive benefits when a farmer prepares their own nutrient management plan, highlighting the crucial role of experiential learning as a moderator of behavioural change. To be able to prepare and to update their nutrient management plans, farmers explained they needed a good understanding of their soils, crop requirements and how to use the online nutrient calculator. By following these processes and reflecting on them, farmers acquired tacit knowledge (knowledge that could not be articulated) and this contributed to the creation of explicit knowledge: the realisation that they could maximise yield while helping to reduce risk of water pollution. Another farmer who applied the nutrient calculator to prepare their nutrient management plan indicated that, through the process, they realised that the plan "*needs to be updated based on crop rotations"* (Farmer 2). It is therefore reasonable to assume that, engaging in the plan preparation process helps farmers to gain both tacit and explicit knowledge and the interaction of these 'knowledges' contribute to uptake of BMPs, thus reinforcing the value of experiential learning.

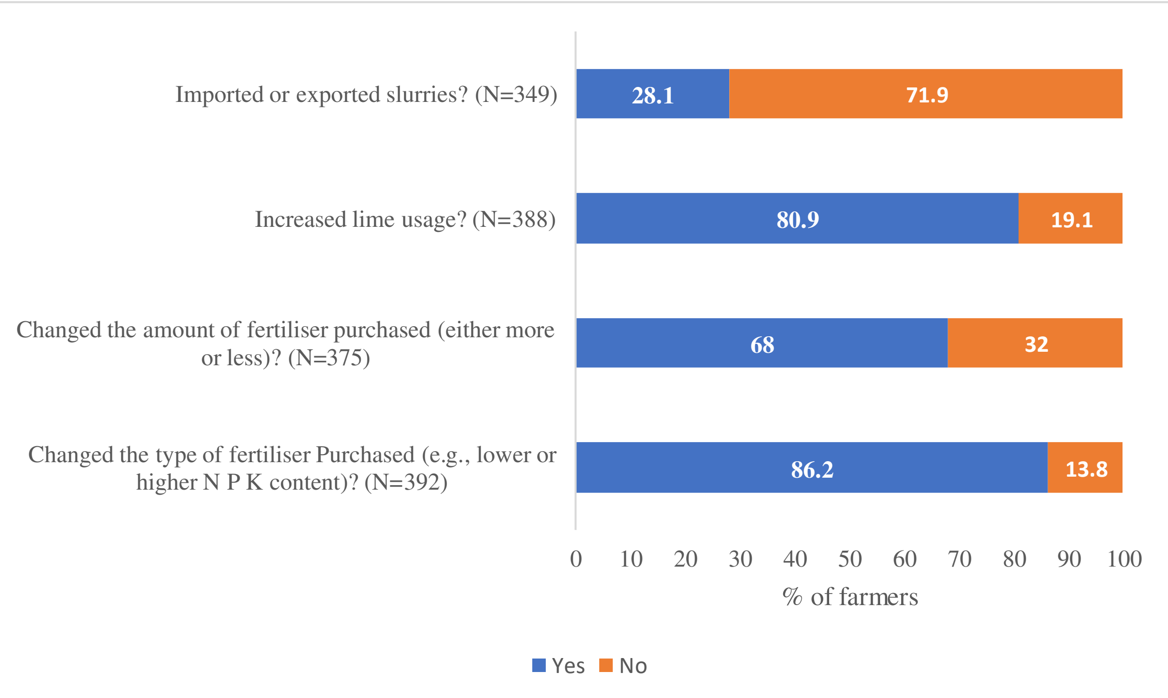

Figure 4: Survey participants who reported changes in various nutrient management practices

Table 2: The moderating effects on preparation of nutrient management plan on uptake of BMPs

Independent variable	Dependent variable	N	Estimate	Std. Err	P-Value	Model fit indices	Model fit Judgement
BMP 1: Changing fertiliser type							
Overall Sample						$\chi2 = 1$, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.000	Satisfactory
Nutrient Management Plan	Changing the type of fertiliser purchased	371	-0.046	0.167	0.784		
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Changing the type of fertiliser purchased	116	-0.610	0.169	0.001***		
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Changing the type of fertiliser purchased	116	0.130	0.393	0.741		
BMP 2: Changing the amount of fertiliser purchased							
Overall Sample						$\chi2 = 1$, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.000.	Satisfactory
Nutrient Management Plan	Changing the amount of fertiliser purchased	356	-0.020	0.140	0.888		
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Changing the amount of fertiliser purchased	109	0.000 0.025	0.120	0.838		
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Changing the amount of fertiliser purchased	109	-0.711	0.450	0.114		
BMP 3:Increasing lime usage							
Overall Sample						$\chi2 = 1$, df = 1; p>0.05; CFI = 1;	Satisfactory
Nutrient Management Plan	Increasing lime usage	367	-0.935	0.152	0.306		
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							

Nutrient Management Plan	Increasing lime usage	116	-0.626	0.138	0.059*	TLI = 1; RMSEA =0.000; SRMR = 0.000.	
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Increasing lime usage	116	0.489	0.369	0.186		
BMP 4: Importing or exporting slurries							
Overall Sample							
Nutrient Management Plan	importing or exporting slurries	331	0.196	0.149	0.189	χ2 = 1, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.00.	Satisfactory
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Importing or exporting slurries	109	0.004	0.111	0.972		
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Importing or exporting slurries	109	0.928	0.532	0.081*		
BMP 5: Using P runoff risk map to decide where to establish a buffer strip							
Overall Sample							
Nutrient Management Plan	Decide where to establish a buffer strip	68	0.069	0.351	0.834	χ2 = 1, df = 1; p>0.05; CFI = 1; TLI = 1; RMSEA =0.000; SRMR = 0.000.	Satisfactory
Multi-group Analysis							
Group 1: Plan drawn up by farm adviser							
Nutrient Management Plan	Decide where to establish a buffer strip	68	-0.486	0.319	0.128		
Group 2: Plan drawn up by farmer							
Nutrient Management Plan	Decide where to establish a buffer strip	68	6.804 0.949	0.191	0.001***		

Notes: ***p-value < 0.001, * *p-value < 0.01, *p-value < 0.1.

4. DISCUSSION

As calls for research on the key role of farmers transforming global agriculture toward sustainability and the need for farmers' perception of effective information provision strategies to eliminate polluting practices intensify (Vrain and Lovett, 2019, Okumah et al., 2020), it is critical to understand the mechanisms that enhance farmers' awareness and uptake of best management practices (BMPs). Our results have shown how farmers had a good understanding of the link between nutrient management practices, yield and water pollution, and that the training and materials provided to farmers have been useful in that regard. However, more importantly, our findings corroborate the emerging literature that information provision alone may not be enough for this to translate into actual behavioural change (e.g., (Brédart and Stassart, 2017, Okumah et al., 2018, Nguyen et al., 2019). We observed that while advice could encourage behavioural changes, experiential learning plays a critical role in this process leading to farmers' adoption of BMPs. For instance, while access to advice and nutrient management plans had a role to play in the adoption of BMPs, farmers were more likely to have changed practices if they prepared their own nutrient management plans. This evidence suggests that there are greater benefits when farmers 'practise what they are taught' rather than being provided with advice only, and relying solely on farm advisers. This finding is consistent with previous studies on factors influencing adoption of BMPs and reinforces the role of experiential learning (Brédart and Stassart, 2017, Franz et al., 2010, Foster and Rosenzweig, 1995). It is worth noting that none of these previous studies investigated how advice interacts with experiential learning to trigger behavioural changes; they only established direct connections between advice and adoption of BMPs. Okumah et al. (2018) attempted to model the interaction between advice, experiential learning and behavioural changes among Scottish farmers although the study provided quite speculative results due to data limitation.

This research refines existing knowledge through its methodological approach. Conditional modelling allows us to statistically test the moderating role of experiential learning and helps to consolidate the evidence that while advice is important, there are greater benefits when farmers engage in the process. This relates to the reflective process from experience which underpins learning and active experimentation (Kolb, 1984). Thus, experiential learning enhances farmers' awareness of the link between their practices and environmental outcomes. As found in this study, where farmers followed nutrient management advice, they highlighted that they were convinced that knowledge of the nutrient status of their soil yielded a win-win situation: helped them maximise their yield while reducing production costs and risks of water pollution, resonating with previous studies that have found knowledge to be useful in the identification of pollution sources (Boiral, 2002). A deeper understanding of pollution sources and mitigation measures boosts farmers' self-efficacy and increases their chances of adopting BMPs (Sewell et al., 2017). This could explain why experiential learning reinforces awareness and contributes to behavioural changes not just in this study but also in previous works on the establishment of wildlife friendly habitats (Science for Environment Policy, 2017) and adoption of measures to tackle diffuse pollution from agriculture (Okumah et al., 2018).

Our results also confirm the findings of previous studies on action-oriented learning in the broader context of natural resources management. For instance, previous studies in this area have shown that boundary objects and intentional experimentation enabled learning as it opened up stakeholders' minds to new ideas (Suškevičs et al., 2019). Further evidence suggests that while this 'experiential knowledge' may reflect in cognitive or relational advancement at the individual level, and in the adoption of BMPs (Suškevičs et al., 2018), such changes may not be readily observed and clearly articulated (Fazey et al., 2006, Suškevičs et al., 2019). Over time, the experience of engaging in BMPs shape individuals' understanding of the complex socio-environmental systems within which they operate (Whiteman et al., 2004) and this understanding has implications on their decisions and behaviours (Woodwell, 1989, Adams and Sandbrook, 2013, Sutherland et al., 2004). Nonetheless, how contextual factors and time influence learning and the acquisition of knowledge remains poorly understood and addressed vaguely. For intervention-based learning such as the case of the present study, Suškevičs et al. (2019) suggests that future studies employ research designs that integrate ex-ante and ex-post assessments. Such research designs could provide further understanding of the specific links between time, action-oriented learning and what has been learnt over time, as well as the retention of such knowledge (Noguera-Méndez et al., 2016, Environment Agency, 2014). Farmers are important stakeholders in land management and their knowledge could influence organisational learning. For instance, farmers acquired knowledge through the EU EAA SASS. As DAERA interacts with farmers, the farmers' knowledge of BMPs together with their knowledge of their farm environment may be important knowledge source to DAERA, and this could help to generate new knowledge and/or refine existing knowledge (Nonaka, 1994). Therefore, in future, it will be useful to explore the potential interaction between farmer learning and organisational learning.

The finding on the role of experiential learning suggests the need to consider a two-way relationship between awareness and behaviour rather than the one-way relationship (from awareness to behaviour) often considered in existing models (Dwyer et al., 2007, Floress et al., 2017, Nguyen et al., 2019, Okumah et al., 2019). Specifically, the results show that awareness could be improved via experiential learning (i.e. doing some actions can lead to reflecting on them, which in turn leads to a better understanding and subsequent changes in such behaviours). So rather than being a unidirectional relationship (the notion that the relationship always starts from awareness to behaviour), it could be a bidirectional one (i.e. also occurring from behaviour to awareness) and that such interactions need to be understood through analysing the feedback loops overtime. It is also important to explore other benefits of action-oriented learning such as improved trust and ownership. Stakeholders' active participation in conservation actions contributes to co-ownership of the process and the product of such practices (in this case, the nutrient management plan) (Suškevičs et al., 2019). This is likely to increase their trust in the plan and their commitment to meeting conservation objectives.

Another relevant finding is that, while the preparation of the nutrient management plans has significantly influenced farmers' behaviour in relation to the import and export of slurry, these changes were less compared to other recommendations (28.1% reported changes in the import and/or export of slurries). This might suggest that the impact of experiential learning on behavioural changes is still affected by other circumstantial factors that may vary across the type of BMP. Situational factors (such as cost and infrastructure) may modulate the effect of different variables on adoption of BMPs (Barnes et al., 2011, Macgregor and Warren, 2006a, Okumah et al., 2019a, Okumah et al., 2018, Inman et al., 2018, Baumgart-Getz et al., 2012, Okumah and Ankomah-Hackman, 2020). In this particular case study, this could be due to the large surplus of slurry in Northern Ireland and a limit on suitable area for its redistribution (Cassidy et al., 2019). Another important situational factor concerns the economic value in transporting slurry from farm to farm or one sub-catchment to another. While this option is feasible, some farms may not have the required vehicles for conveying slurry over long distances cost effectively. In such cases, the services of a contractor may be needed to transport the slurry, adding cost to the exportation of slurry. Evidence from the Republic of Ireland suggests that transporting manure from livestock farms to arable farms may yield limited economic benefits beyond 50–75 km in cases where trucks are used and even worse when tractors are used (Fealy and Schröder, 2008).

As explained in section 2.3, other factors may also influence the relationship between awareness and behavioural change. For instance, Buckley et al. (2015) reported that a wide range of variables impacted on adoption of nutrient management plans on Irish farms including farmer age and off-farm employment. While including these variables in the statistical analysis is valuable, we did not include this in our analysis due to lack of data. Therefore, there is abundant room for further progress in exploring factors that drive farmers' decisions and behaviours regarding soil testing, preparation and use of nutrient management plans, and uptake of BMPs. This could help advance our understanding of the topic as the limited empirical studies have often focussed on behavioural intentions (Daxini et al., 2018, Daxini et al., 2019a, Daxini et al., 2019b), and not on actual adoption. While these studies provide insights into determinants of adoption, their focus implies a lack of the complete picture on the drivers of behavioural change. For instance, these studies may fail to provide a full account of the adoption process as intentions do not always translate into actions (Hines et al., 1987, Kollmuss and Agyeman, 2002). Past studies have shown that there could be a gap between intentions and actual implementation of BMPs due to the moderating roles of cost, time, institutional support, flexibility of schemes and farm characteristics (Barnes et al., 2011, Macgregor and Warren, 2006a, Okumah et al., 2019a, Okumah et al., 2018, Inman et al., 2018, Baumgart-Getz et al., 2012).

Finally, our study provides a detailed example of a specific process and set of tools for provoking pro-environmental change among farmers in a highly livestock dependent Northwest European context. However, such a hands-on approach may well be successful elsewhere, specially in the Global North, and future research could examine the efficacy of adapting this or identifying analogous schemes to develop a versatile tool-kit for operationalising lasting food-water systems transformations at the farm-level in-line with urgent calls from scientists and policy initiatives (Steiner et al., 2020).

5. CONCLUSIONS

In order to address existing and potential environmental impacts of agriculture, policymakers are increasingly focussing on influencing farmers' behaviour to adopt best management practices (BMPs). One of the strategies adopted is the provision of advice aimed at raising awareness on environmental pollution and mitigation measures. By improving farmers' awareness, policymakers expect changes in behaviour that would reflect in the adoption of BMPs, suggesting a straightforward link between awareness and uptake of BMPs. So far, however, the limited empirical research examining whether awareness-focussed strategies influence uptake of BMPs has shown that while there is a link between awareness and adoption, this link is indirect – and is mediated and moderated by other factors. One of the potential intervening factors that remains poorly understood is the enabling capacity that experiential learning brings. Overall, we found that farmers had a good understanding of the link between nutrient management and water quality as well as the agronomic and environmental benefits of engaging in BMPs. While advice seems to have contributed to uptake of BMPs, we found that likelihood of adoption increased if the farmers had prepared the nutrient management plans themselves. This is interpreted as the effect of experiential learning that deepens farmers' understanding, and increase their chances of adopting BMPs. This provides support for the conceptual premise that while information provision is important, farmers need to actively engage in and be able to reflect on the practice for it to lead to behavioural changes. The role of experiential learning also suggests the need to move from the predominant unidirectional relationship being modelled (the notion that the relationship always starts from awareness to behaviour), as the relationship could be a bidirectional one (i.e. from behaviour to awareness) and such interactions need to be understood through analysing the feedback loops overtime.

Given that farmers who had attended or received nutrient management training were more likely to have prepared nutrient management plans for their farms, we encourage policymakers to incentivise farmers to attend training events and to engage in practical interventions, such as the preparation of farm nutrient plans. On the other hand, it is important to note that while low adoption might be related to knowledge, other contextual factors could be responsible. Understanding the role of situational factors could help policymakers tailor their policies to different BMPs and contexts. More research on this could offer insights into effective ways to help farmers manage their soils sustainably and ultimately contribute to reducing the environmental impacts of (agricultural) land management.

6. REFERENCES

ADAMS, W. & SANDBROOK, C. 2013. Conservation, evidence and policy. *Oryx,* 47**,** 329-335.

ADUSUMILLI, N. & WANG, H. 2018. Analysis of soil management and water conservation practices adoption among crop and pasture farmers in humid-South of the United States. *International Soil and Water Conservation Research,* 6**,** 79-86.

AGAR, M. H. 1986. *Speaking of ethnography*, Sage.

ANONYMOUS 2011. Adaptive Water Management and Policy Learning in a Changing Climate: a Formal Comparative Analysis of Eight Water Management Regimes in Europe, Africa and Asia. *Environmental Policy and Governance,* 21**,** 145-163.

BARNES, A. P., WILLOCK, J., HALL, C. & TOMA, L. 2009. Farmer perspectives and practices regarding water pollution control programmes in Scotland. *Agricultural Water Management,* 96**,** 1715-1722.

BARNES, A. P., WILLOCK, J., TOMA, L. & HALL, C. 2011. Utilising a farmer typology to understand farmer behaviour towards water quality management: Nitrate Vulnerable Zones in Scotland. *Journal of Environmental Planning and Management,* 54**,** 477-494.

BARRY, C. & FOY, R. 2016. Assessing the success of regional measures for lowering agricultural nutrient pollution in headwater streams. *Journal of environmental quality,* 45**,** 1329-1343.

BAUMGART-GETZ, A., PROKOPY, L. S. & FLORESS, K. 2012. Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of environmental management,* 96**,** 17-25.

BLACKSTOCK, K. L., INGRAM, J., BURTON, R., BROWN, K. M. & SLEE, B. 2010. Understanding and influencing behaviour change by farmers to improve water quality. *Science of the Total Environment,* 408**,** 5631-5638.

BOIRAL, O. 2002. Tacit knowledge and environmental management. *Long Range Planning,* 35**,** 291-317.

BRÉDART, D. & STASSART, P. M. 2017. When farmers learn through dialog with their practices: A proposal for a theory of action for agricultural trajectories. *Journal of Rural Studies,* 53**,** 1-13.

BROWN, T. 2006. Confirmatory factor analysis for applied research. The Guilford Press. *New York*.

BUCKLEY, C., HOWLEY, P. & JORDAN, P. 2015. The role of differing farming motivations on the adoption of nutrient management practices. *International Journal of Agricultural Management,* 4**,** 152-162.

BYRNE, M. M. 2001. Evaluating the findings of qualitative research. *AORN journal,* 73**,** 703-703.

CASSIDY, R., THOMAS, I. A., HIGGINS, A., BAILEY, J. S. & JORDAN, P. 2019. A carrying capacity framework for soil phosphorus and hydrological sensitivity from farm to catchment scales. *Science of the total environment,* 687**,** 277-286.

D'ANGELO, M. J. & BRUNSTEIN, J. 2014. Social learning for sustainability: supporting sustainable business in Brazil regarding multiple social actors, relationships and interests. *International Journal of Sustainable Development & World Ecology: Managing Organizations for Sustainable Development in Emerging Countries,* 21**,** 273-289.

DAXINI, A., O'DONOGHUE, C., RYAN, M., BUCKLEY, C., BARNES, A. P. & DALY, K. 2018. Which factors influence farmers' intentions to adopt nutrient management planning? *Journal of environmental management,* 224**,** 350-360.

DAXINI, A., RYAN, M., O'DONOGHUE, C. & BARNES, A. P. 2019a. Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behaviour. *Land Use Policy,* 85**,** 428-437.
DAXINI, A., RYAN, M., O'DONOGHUE, C., BARNES, A. P. & BUCKLEY, C. 2019b. Using a typology to understand farmers' intentions towards following a nutrient management plan. *Resources, Conservation and Recycling,* 146**,** 280-290.
DEVISSCHER, T., VIGNOLA, R., BESA, M. C., CRONENBOLD, R., PACHECO, N., SCHILLINGER, R., CANEDI, V., SANDOVAL, C., GONZALEZ, D. & LECLERC, G. 2016. Understanding the socio-institutional context to support adaptation for future water security in forest landscapes. *Ecology and Society,* 21.
DPMAG 2015. Strategy to reduce diffuse pollution. Edinburgh: Scottish Environment Protection Agency.
DWYER, J., MILLS, J., INGRAM, J., TAYLOR, J., BURTON, R., BLACKSTOCK, K., SLEE, B., BROWN, K., SCHWARZ, G. & MATTHEWS, K. 2007. Understanding and influencing positive behaviour change in farmers and land managers. *CCRI, Macaulay Institute*.
ENVIRONMENT AGENCY 2011. Catchment Sensitive Farming - ECSFDI Phase 1 & 2 Evaluation Report. Bristol: Environment Agency
ENVIRONMENT AGENCY 2014. Catchment Sensitive Farming: A clear solution for farmers. . Bristol: Environment Agency.
FAZEY, I., FAZEY, J. A., SALISBURY, J. G., LINDENMAYER, D. B. & DOVERS, S. 2006. The nature and role of experiential knowledge for environmental conservation. *Environmental Conservation,* 33**,** 1-10.
FEALY, R. & SCHRÖDER, J. J. 2008. *Assessment of manure transport distances and their impact on economic and energy costs*, IFS.
FOSTER, A. D. & ROSENZWEIG, M. R. 1995. Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of political Economy,* 103**,** 1176-1209.
FRANZ, N., PIERCY, F., DONALDSON, J., RICHARD, R. & WESTBROOK, J. 2010. HOW FARMERS LEARN: IMPLICATIONS FOR AGRICULTURAL EDUCATORS. *Journal of Rural Social Sciences,* 25**,** 37-59.
HINES, J. M., HUNGERFORD, H. R. & TOMERA, A. N. 1987. Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. *Journal of Environmental Education,* 18**,** 1-8.
HOOPER, D., COUGHLAN, J. & MULLEN, M. R. 2008. Structural equation modelling: Guidelines for determining model fit. *Electronic journal of business research methods,* 6**,** 53-60.
HOSONUMA, N., HEROLD, M., DE SY, V., DE FRIES, R. S., BROCKHAUS, M., VERCHOT, L., ANGELSEN, A. & ROMIJN, E. 2012. An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters,* 7**,** 044009.
HU, L. T. & BENTLER, P. M. 1999. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling: a multidisciplinary journal,* 6**,** 1-55.
HUTCHINS, M. G. 2012. What impact might mitigation of diffuse nitrate pollution have on river water quality in a rural catchment? *Journal of Environmental Management,* 109**,** 19-26.
INMAN, A., WINTER, M., WHEELER, R., VRAIN, E., LOVETT, A., COLLIN, A., JONES, I., JOHNES, P. & CLEASBY, W. 2018. An exploration of individual, social and material factors influencing water pollution mitigation behaviours within the farming community. *Land Use Policy,* 70**,** 16-26.
JACKMAN, M. R. 1973. Education and prejudice or education and response-set? *American Sociological Review***,** 327-339.
JACKSON, D. L. 2001. Sample Size and Number of Parameter Estimates in Maximum Likelihood Confirmatory Factor Analysis: A Monte Carlo Investigation. *Structural Equation Modeling: A Multidisciplinary Journal,* 8**,** 205-223.
JACKSON, D. L. 2003. Revisiting Sample Size and Number of Parameter Estimates: Some Support for the N:q Hypothesis. *Structural Equation Modeling: A Multidisciplinary Journal,* 10**,** 128-141.

JAGANNATHAN, K., ARNOTT, J. C., WYBORN, C., KLENK, N., MACH, K. J., MOSS, R. H. & SJOSTROM, K. D. 2020. Great expectations? Reconciling the aspiration, outcome, and possibility of co-production. *Current Opinion in Environmental Sustainability,* 42**,** 22-29.

KENCH, P. S., RYAN, E. J., OWEN, S., BELL, R., LAWRENCE, J., GLAVOVIC, B., BLACKETT, P., BECKER, J., SCHNEIDER, P. & ALLIS, M. 2018. Co-creating resilience solutions to coastal hazards through an interdisciplinary research project in New Zealand. *Journal of Coastal Research,* 85**,** 1496-1500.

KOLB, D. A. 1984. Experience as the source of learning and development. *Upper Sadle River: Prentice Hall.*

KOLLMUSS, A. & AGYEMAN, J. 2002. Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research,* 8**,** 239-260.

KORMOS, C. & GIFFORD, R. 2014. The validity of self-report measures of proenvironmental behavior: A meta-analytic review. *Journal of Environmental Psychology,* 40**,** 359-371.

KUMLER, L. M. & LEMOS, M. C. 2008. Managing Waters of the Paraíba do Sul River Basin, Brazil a Case Study in Institutional Change and Social Learning. *Ecology and Society,* 13.

MACGREGOR, C. J. & WARREN, C. R. 2006a. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm. *Agriculture, Ecosystems & Environment,* 113**,** 108-119.

MACGREGOR, C. J. & WARREN, C. R. 2006b. Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: the view from the farm. *Agriculture, ecosystems & environment,* 113**,** 108-119.

MAGUIRE, R. O. & SIMS, J. T. 2002. Soil testing to predict phosphorus leaching. *Journal of environmental quality,* 31**,** 1601-1609.

MAYRING, P. 2004. Qualitative content analysis. *A companion to qualitative research,* 1**,** 159-176.

MERRILEES, D. & DUNCAN, A. 2005. Review of attitudes and awareness in the agricultural industry to diffuse pollution issues. *Water Science and Technology,* 51**,** 373-381.

NOVOTNY, V. 2013. Diffuse pollution from agriculture — A worldwide outlook. *Water Science and Technology* 39**,** 1-13.

OECD 2012. Water quality and agriculture: meeting the policy challenge. OECD Studies on Water. . Paris: Organisation for Economic Co-operation and Development.

OENEMA, O., KROS, H. & DE VRIES, W. 2003. Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. *European Journal of Agronomy,* 20**,** 3-16.

OKUMAH, M. & ANKOMAH-HACKMAN, P. 2020. Applying conditional process modelling to investigate factors influencing the adoption of water pollution mitigation behaviours. *Sustainable Water Resources Management,* 6**,** 17.

OKUMAH, M., CHAPMAN, P., MARTIN-ORTEGA, J. & NOVO, P. 2019a. Mitigating Agricultural Diffuse Pollution: Uncovering the Evidence Base of the Awareness–Behaviour–Water Quality Pathway. *Water,* 11**,** 29.

OKUMAH, M., JULIA, M.-O., PAULA, N. & PIPPA, J. C. 2020. Revisiting the Determinants of Pro-Environmental Behaviour to Inform Land Management Policy: A Meta-Analytic Structural Equation Model Application. *Land (Basel),* 9**,** 135.

OKUMAH, M., MARTIN-ORTEGA, J. & NOVO, P. 2018. Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: A conditional process modelling. *Land Use Policy,* 76**,** 36-45.

OKUMAH, M. & YEBOAH, A. S. 2019. Exploring stakeholders' perceptions of the quality and governance of water resources in the Wenchi municipality. *Journal of Environmental Planning and Management.*

OKUMAH, M., YEBOAH, A. S., NKIAKA, E. & AZERIGYIK, R. A. 2019b. What Determines Behaviours Towards Water Resources Management in a Rural Context? Results of a Quantitative Study. . *Resources,* 8.

PAHL-WOSTL, C. & HARE, M. 2004. Processes of social learning in integrated resources management. *Journal of Community & Applied Social Psychology,* 14**,** 193-206.

POSTHUMUS, H., DEEKS, L., FENN, I. & RICKSON, R. 2011. Soil conservation in two English catchments: linking soil management with policies. *Land degradation & development,* 22**,** 97-110.
SCHUMAN, H. & PRESSER, S. 1981. Questions and Answers in Attitude Surveys Academic Press New York. *SchumanQuestions and Answers in Attitude Surveys1981*.
SCHUMM, W. R., PRATT, K. K., HARTENSTEIN, J. L., JENKINS, B. A. & JOHNSON, G. A. 2013. Determining Statistical Significance (Alpha) and Reporting Statistical Trends: Controversies, Issues, and Facts1. *Comprehensive Psychology,* 2.
SEPA. 2015. *Diffuse Pollution* [Online]. Scottish Environment Protection Agency. Available: http://www.sepa.org.uk/water/diffuse_pollution.aspx [Accessed].
SEWELL, A., HARTNETT, M., GRAY, D., BLAIR, H., KEMP, P., KENYON, P., MORRIS, S. & WOOD, B. 2017. Using educational theory and research to refine agricultural extension: affordances and barriers for farmers' learning and practice change. *The Journal of Agricultural Education and Extension,* 23**,** 313-333.
SILVERMAN, R. M. & PATTERSON, K. L. 2015. *Qualitative research methods for community development*.
STEMLER, S. 2000. An overview of content analysis. *Practical Assessment, Research, and Evaluation,* 7**,** 17.
STRINGER, L. C., FRASER, E. D. G., HARRIS, D., LYON, C., PEREIRA, L., WARD, C. F. M. & SIMELTON, E. 2020. Adaptation and development pathways for different types of farmers. *Environmental Science & Policy,* 104**,** 174-189.
SUŠKEVIČS, M., HAHN, T. & RODELA, R. 2019. Process and Contextual Factors Supporting Action-Oriented Learning: A Thematic Synthesis of Empirical Literature in Natural Resource Management. *Society & Natural Resources,* 32**,** 731-750.
SUŠKEVIČS, M., HAHN, T., RODELA, R., MACURA, B. & PAHL-WOSTL, C. 2018. Learning for social-ecological change : a qualitative review of outcomes across empirical literature in natural resource management.
SUTHERLAND, W. J., PULLIN, A. S., DOLMAN, P. M. & KNIGHT, T. M. 2004. The need for evidence-based conservation. *Trends in Ecology & Evolution,* 19**,** 305-308.
UNCCD. 2015. *Land Degradation Neutrality: resilience at local, national and regional levels* [Online]. Bonn, Germany: United Nations Convention to Combat Desertification. Available: http://bit.ly/2vJ0ZJm [Accessed 23/10 2016].
UNITED NATIONS. 2015. *Transforming our World: the 2030 Agenda for Sustainable Development.* [Online]. New York: United Nations Available: http://bit.ly/1OTd4Sr [Accessed 20/10 2016].
UNITED NATIONS 2016. Global Sustainable Development Report 2016. New York, US: Department of Economic and Social Affairs.
UNITED NATIONS ENVIRONMENT PROGRAMME 2017. Towards a pollution free planet background report. Nairobi, Kenya: United Nations Environment Programme.
UNITED NATIONS WORLD WATER ASSESSMENT PROGRAMME 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris United Nations Educational, Scientific and Cultural Organization.
VRAIN, E. & LOVETT, A. 2019. Using word clouds to present farmers' perceptions of advisory services on pollution mitigation measures. *Journal of Environmental Planning and Management***,** 1-18.
WHITEMAN, G., FORBES, B. C., NIEMELÄ, J. & CHAPIN, F. S. 2004. Bringing feedback and resilience of high-latitude ecosystems into the corporate boardroom. *Ambio,* 33**,** 371.
WOODWELL, G. M. 1989. On Causes Of Biotic Impoverishment. *Ecology,* 70**,** 14-15.

7. APPENDICES

Appendix 1: Survey Questionnaire

2018 Soil Testing and Analysis Results – 1 year on – post scheme evaluation questionnaire (please tick the relevant boxes)

Q1. Do you have a Nutrient Management Plan for your farm? Yes ☐ No ☐

If yes is it: A plan drawn up by a farm adviser? Yes ☐ No ☐

A plan drawn up by yourself based on soil analysis results? Yes ☐ No ☐

Other (please state): ____________________

Q2. Did you take any of the following actions as a result of receiving your soil test results?

Changed the type of fertiliser Purchased (e.g. lower or higher N P K content)? Yes ☐ No ☐

Changed the amount of fertiliser purchased (either more or less)? Yes ☐ No ☐

Increased lime usage? Yes ☐ No ☐

Imported or exported slurries? Yes ☐ No ☐

Other (please state): ____________________

Q3. Do you expect a crop yield increase with better knowledge of your soils? Yes ☐ No ☐ Don't know ☐

Q4. Are you more likely to carry out further soil sampling in 4 years, on your own as a result of this soil testing?

Yes ☐ No ☐ Don't know ☐

Q5. Do you think if there were enough farmers taking part in soil sampling that water quality in your area would improve?

Yes ☐ No ☐ Don't know ☐

Q6. Do you recognise the link between good healthy soils and good water quality?

Yes ☐ No ☐ Don't know ☐

Q7 & Q8 for Upper Bann participants only

Q7. Do you understand your P Risk Run-Off Map? Yes ☐ No ☐

Q8. Have you used your P Risk Run-Off Map? Yes ☐ No ☐

If yes, have you used it to:

Identify fields where there may be a risk of nutrient run-off into a watercourse? Yes ☐ No ☐

Help decide where to establish a buffer strip? Yes ☐ No ☐

Other (please state): ____________________

Appendix 2: Interview script (Nationwide and Upper Bann Catchment)

My name is ……………………………I am calling on behalf of AFBI to have a chat with you regarding your involvement in the EAA Soil sample scheme and actions you have taken since your fields were tested. The information collected in this interview will be used exclusively for research purposes. Personal information will be kept secure in accordance with the Data Protection Act and General Data Protection Regulation under the Data Protection Act 2018 and will only be accessible to the research team. Results from this research will be published for academic purposes only and will be referred to anonymously. By proceeding with this interview, you are consenting to the above. You may withdraw at any point if you wish.

(Please tick the relevant boxes)

Q1. Primary Farm type: Dairy Sheep Pigs Poultry Arable Beef

Q2. Category of lands in your farm (tick all that apply): Owned Lands Lands taken in Conacre Lands taken on Long Term Lease

Q3. What is your total area farmed? …………………….. Acres/hectares (**Please tick the appropriate unit after writing the value**).

Q4. Have you taken part in the EAA Soil Sampling and Analysis Scheme (if yes, indicate name of scheme)? Yes No

Q5. Length of farming experience…………… **years**

Q6. Gender of farmer? Female Male Prefer not to say

Interviewer: Please add any additional contextual information that you find relevant.

#	Questions	Instruction(s) for interviewer
7	a) Do you believe that the more the nutrients you apply to your fields, the better your yields? If yes, Why? If no, why not? b) If yes, would you have any concerns about excess nutrients in your soil? c) Do you think applying fertiliser or slurry based on soil test results can help reduce water pollution? Why? d) Where on the farm do you think there is greatest potential for nutrient loss to surface water? Why? e) Are there any seasons where there is a high risk of run-off? When? Explain how this happens.	In relation to (b), you can ask: What happens to the excess nutrients?
8	a) Do you have a nutrient management plan? If yes, can you explain how your plan was prepared? If No – why not? b) If Yes – how do you use the nutrient management plan? c) Has the use of the plan changed your perception about nutrient loss to surface water? How?	Regarding how the plan was prepared, we are interested in the process, who drew the plan, and whether their application of the plan is or will be affected by who draws it, i.e., themselves or by an advisor, etc. Did they use the AFBI crop nutrient calculator to prepare their NMP, was the calculator helpful, how the process could be improved.
9	From November 2017 to February 2018, DAERA and AFBI offered free soil sampling and testing service to farmers in the Upper Bann. There was a training programme to help farmers interpret soil test results. Did you participate in the training or did you opt to receive training materials instead? If yes, why? If no, why not?	We want to know if they attended the training or received only the materials. Prompts on decision to participate in training: • *Availability of time* • *Time of day when training run (e.g. 4pm would be bad for dairy farmers/part-time farmers working during day)* • *Weather on day – (e.g., might have intended to come but weather was too good to miss 'cutting silage')* • *Trust in advice source/sender/training provider* • *Anxiety about public participation – level of training being too advanced/complex, having to speak*

		• *Peer opinion (other farmers say it's good/bad)*
10	a) If your soil test recommendation suggested a ***change to the type of fertiliser you normally apply***, did you change *it*? If yes, what did you apply before? What do you now apply? Why? If you haven't, do you intend to change? b) If your soil test recommendation suggested a change to the ***amount of fertiliser applied, did you do that?*** Do you now use more or less? Why? If you haven't, do you intend to change? c) If your soil test recommendation suggested ***applying Lime to raise the soil pH***, did you do that? Why? If you haven't, do you intend to change? d) Will you require any support to fully implement the recommendations? If yes, what type of support?	For those who'll respond yes, If their explanation to why they changed is "because of the soil test results", please ask if they think there could be any problems when they fail to follow the recommendations. ***This could help us assess their awareness*** *(i.e., revealed awareness)* ***and environmental consciousness.*** For those who'll answer no, please ask why they have not changed or intend not to.
11	Will you carry out further soil sampling, on your own as a result of this soil testing? If yes, Why? If No – why not?	For those who'll answer yes, if they fail to mention reasons spontaneously, please use the following prompts (***for motivations***): • *Increased yield* • *Regulations/government requirements* • *What my neighbours (farmers) think or do* For those who'll answer no, if they fail to mention reasons spontaneously, please use the following prompts (**for barriers**): • *Lack of awareness* • *Time consuming – other work takes priority* *Cost*
ONLY FOR UPPER BANN INTERVIEWEES		

12	As part of the soil sampling service in Upper Bann, AFBI provided farmers with maps showing areas most at risk of phosphorus loss to water in surface runoff. a) Did you receive one of those runoff risk maps? If yes, did you fully understand the map? Do you find the map useful? How? Why? b) Have you used the map? If Yes, what for? If no – do you intend to use it? If no why not? c) Do you think your knowledge of the maps has improved after using them over time? d) Has the use of the map changed your perception about phosphorus loss to surface water? How? Has this influenced how you apply slurry/manure/fertiliser? How? e) If you don't use the map now, would you use it if surrounding farmers were using it? If yes Why?	If they haven't used the map or don't intend to – explore whether this is because of: • *Don't know how to interpret/use it?* • *Need support to use it – advice or financial*
13	Is there anything else you would like to tell me about what we discussed today?	

Thank you very much for your time!!!

CYPRESS, B. S. 2017. Rigor or Reliability and Validity in Qualitative Research: Perspectives, Strategies, Reconceptualization, and Recommendations. 36**,** 253-263.

ENVIRONMENT AGENCY 2014. Catchment Sensitive Farming: A clear solution for farmers. . Bristol: Environment Agency.

EVANS, A. E., MATEO-SAGASTA, J., QADIR, M., BOELEE, E. & IPPOLITO, A. 2019. Agricultural water pollution: key knowledge gaps and research needs. *Current Opinion in Environmental Sustainability,* 36**,** 20-27.

HOUSER, M., GUNDERSON, R., STUART, D., DENNY, R. C. J. A. & VALUES, H. 2020. How farmers "repair" the industrial agricultural system. 1-15.

NOGUERA-MÉNDEZ, P., MOLERA, L. & SEMITIEL-GARCÍA, M. 2016. The role of social learning in fostering farmers' pro-environmental values and intentions. *Journal of Rural Studies,* 46**,** 81-92.

STEINER, A., AGUILAR, G., BOMBA, K., BONILLA, J. P., CAMPBELL, A., ECHEVERRIA, R., GANDHI, R., HEDEGAARD, C., HOLDORF, D., ISHII, N., QUINN, K., RUTER, B., SUNGA, I., SUKHDEV, P., VERGHESE, S., VOEGELE, J., WINTERS, P., CAMPBELL, B., DINESH, D., HUYER, S., JARVIS, A., LOBOGUERRERO RODRIGUEZ, A. M., MILLAN, A., THORNTON, P., WOLLENBERG, L. & ZEBIAK, S. 2020. Actions to transform food systems under climate change. . Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

SUŠKEVIČS, M., HAHN, T. & RODELA, R. 2019. Process and Contextual Factors Supporting Action-Oriented Learning: A Thematic Synthesis of Empirical Literature in Natural Resource Management. *Society & Natural Resources,* 32**,** 731-750.

NONAKA, I. 1994. A Dynamic Theory of Organizational Knowledge Creation. *Organization science (Providence, R.I.),* 5**,** 14-37.