Experts' estimates of future uptake of low-carbon agricultural practices

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Abstract

Greenhouse gas mitigation in agriculture has been so far relying mostly on voluntary implementation; policy, in their attempt to step up effort in agriculture, requires more reliable information on mitigation practices, including their current and potential future uptake. Expert elicitation techniques can estimates where otherwise the data gaps exist. A four stage Deplhi expert elicitation was carried out to estimate the uptake and its uncertainty for five mitigation practices under three policy scenarios in Scotland. The current uptake was estimated to be 5-68%, the uptake in 10 years' time with no policy change was between 10-70% and the future uptake with targeted policy was 50-83%. The uncertainty (difference between lower and upper quartile estimates) was between 6-40%. The highest policy effect was estimated to be expected from targeting nitrification inhibitor uptake. Policy supporting improved land drainage and regulatory approaches for nitrogen management practices could achieve only lower policy effect (13-22%) but with a higher confidence. The elicitation also highlighted that clear definitions of farming practices are very important and expert estimates would ideally involve stakeholders from different backgrounds.

1. Introduction

The decarbonisation of agricultural production as part of a global decarbonisation roadmap is an urgent, yet so far unresolved matter (Rockström *et al.* 2017). Potential transformative changes both in food production (Alexander *et al.* 2017) and food consumption (Hallström *et al.* 2015) will likely to be an important part of reducing greenhouse gas (GHG) emissions from the food chain. At the same time optimising agronomic practices and introducing new technologies to mitigate GHG emissions while maintaining food production will continue to be a key route towards reducing the emission intensity of our food. Policy action in the form of voluntary, economic and regulatory instruments is necessary to achieve widespread uptake of low carbon agronomic practices (Bustamante *et al.* 2014); the public decision making about implementing such instruments requires information on the likely policy impacts and costs.

Ex ante assessment of agri-environmental policy instruments relies upon information on the biophysical and economic changes likely to be induced. An inherent characteristic of this information is uncertainty, arising both from imperfect knowledge and stochastic processes (Walker *et al.* 2003), posing a considerable challenge in effective policy making (Hallegatte *et al.* 2012). Scientists and policy makers are responding to this challenge by including uncertainty in *ex ante* modelling (Refsgaard *et al.* 2007), improving ways of presenting it (Wardekker *et al.* 2008) and considering the uncertainty in the decision processes (Kunreuther *et al.* 2013).

The uncertainty which can be incorporated in quantitative modelling (input and parameter uncertainty in the classification by Walker *et al.* (2003)) is collected from various sources, determined by the parameter or input in question and the available quantitative information sources. At the low uncertainty range are observations in the form of sampling easily measurable existing populations, like the number of a certain livestock in a country with high level of agricultural record keeping or the price of agricultural commodities. Information about the effects of certain changes in the system can be relatively well described if the amount of experimental evidence is sufficient to conduct meta-analyses (like in the case of methane reducing feed additives to cattle (Veneman *et al.* 2016)) and the result of the meta-analysis can be applied to the system in question. The uncertainty increases with more sparse evidence: agronomic effects and costs of new technologies often belong to this category. In such cases the uncertainty reported by the experimental studies need to be augmented with (qualitative) uncertainty on the relevance of the experimental results to the study system. Sparse evidence can also be a result of sporadic or low-quality sampling – the uptake level of numerous agricultural practices provide good examples here. Furthermore, due to the nature of *ex ante* modelling, inputs and parameters about the future of the study system are used (often obtained from other modelling exercises), increasing the level of uncertainty substantially. With the decreasing level of evidence, the importance of experts and stakeholders in providing best judgement about the inputs, parameters and also about their uncertainty increases. However, quantitative uncertainty analysis in agri-environmental modelling is only a recent phenomenon, and obtaining information on the uncertainty of parameters estimated by experts have been particularly lacking.

Assessment of potential GHG mitigation in agriculture, as it aims to estimate the costs of future GHG reduction, relies on a diverse set of information about agricultural production and farming practices, agronomic, financial and environmental effects of alternative practices and technologies, and the efficacy of potential policy instruments in altering farmers' decisions. The uncertainty of these inputs and parameters are many and various, and most of them poorly characterised (Eory *et al.* 2018). Eory *et al.* (2018) presented a case study of Scotland, where the cumulative effect of the quantifiable uncertainties on the cost-effective national crop production related GHG abatement potential was estimated. The analysis also highlighted the most important drivers of this uncertainty: the uncertainty of the future uptake rates of the GHG mitigation practices and the uncertainty of their GHG effects. Reducing this uncertainty would allow more efficient policy formulation – an imperative given the ambitious Scottish GHG mitigation targets of 80% reduction by 2030 relative to 1990 levels (Climate Change (Scotland) Act 2009) and 17% of GHG emissions generated by agriculture (Salisbury *et al.* 2015).

Farmers' management decisions, including the uptake of certain practices, are a result of a complex system of interactions between personal, social, technological and financial factors (Edwards-Jones

2006). Predicting the effect of policies on this decision making is very challenging: historic information on compliance and policy scheme uptake rates can be used as an approximation, or choice experiments can be conducted to explore farmers' intentions (Christensen *et al.* 2011, Glenk *et al.* 2014). However, the former approach can be crude and the latter is expensive to conduct – as a middle ground experts' opinion can be used to estimate the future uptake of technologies and practices. Furthermore, expert estimation might be needed to obtain information on current uptake rates too if observational data does not exist.

One methodology to acquire quantitative information from experts is expert elicitation. It is a formal process whereby a group of experts provide their quantitative estimate of a parameter, often in an engineering or scientific setting. Though the information collected is subjective, and the results can suffer from cognitive biases (Kahneman *et al.* 1982, Morgan 2014), it is a valuable method to support decision making where existing scientific information is insufficient.

This work elicited information about current and future uptake rate of five agricultural practices from six experts, belonging to three different stakeholder groups. A key aspect of the elicitation was to obtain information on the uncertainty of the uptake rates beside the mean values. The resulting probability distributions and the narratives captured in the discussion provide valuable information to stakeholders in the agriculture and land use sector, including policy makers, farm advisors and consultants and researchers. The quantitative and qualitative information obtained can be used in agri-environmental policy assessments, in prioritising national policy initiatives and in improving the dialogue at the nexus of farmers, farm advisors, policy makers and researchers.

2. Methodology

2.1 Information to be elicited

The parameters to be elicited were selected based on previous work on the uncertainty of the agricultural GHG abatement in Scotland (Eory *et al.* 2018), which showed that the uncertainty in uptake rates was one of the biggest contributor to the uncertainty of agricultural GHG abatement potential from agricultural land in Scotland. Amongst the fifteen mitigation measures in that study the five which contributed the most to the uptake uncertainty were chosen to be included in the current work: MM1: Improved timing of mineral nitrogen (N) fertilisers; MM2: Improved timing of slurry and poultry manure application; MM3: Avoiding N excess; MM4: Nitrification inhibitors; and MM5: Land drainage. Table 1 provides a description of these measures.

Participants were asked to estimate the uptake rates of five GHG mitigation measures and the uncertainty of these uptake rates. They estimated the lower, middle and upper quartiles (Ql, Qm, Qu, respectively) of present and future uptake rates, the latter under two policy scenarios. Participants were given handouts with definitions of the statistical terms, parameters to elicit, mitigation measure descriptions and policy scenarios (see the Appendix).

Table 1 Key characteristics of the mitigation measures

Mitigation measure	Description[a]	Feasibility of implementation	Feasibility of monitoring
Improved timing of mineral N (MM1)	Apply the inorganic N fertiliser when the crop is actively growing, also considering soil and weather conditions at the time of the application.	It is difficult to get the timing right, and the right weather / soil conditions might not occur at all at the time when the crop requires the N	Difficult (e.g. self-reporting)
Improved timing of slurry application (MM2)	Apply the organic N fertiliser when the crop is actively growing, considering soil and weather conditions at the time of the application as well.	It is difficult to get the timing right, and the right weather / soil conditions might not occur at all at the time when the crop requires the N	Difficult (e.g. self-reporting)
Avoiding N excess (MM3)	Apply fertiliser according to fertiliser recommendations (like SRUC Technical Notes[1] or Nutrient Management Guide (RB209)[2]).	Easy in a simple form (based on fertiliser guidelines), but requires more learning if a software tool is used. (Soil analysis were not included in the definition.)	Difficult (e.g. self-reporting)
Nitrification inhibitors (MM4)	Use nitrification inhibitors (NIs) (chemicals which slow the rate of conversion of fertiliser ammonium to nitrate), leaving more N available to the plant.	Easy, and no extra effort required if a pre-mix is used (requires an additional field operation if bought separately	Moderate (e.g. proof of purchase)
Improved land drainage (MM5)	Ensure that land is adequately drained by repairing a non-functional drainage system or installing a new drainage system.	A major operation, carried out by contractors	Easy (inspection)

[a] see full description in the Appendix

[1] https://www.sruc.ac.uk/downloads/120451/crop_technical_notes
[2] https://ahdb.org.uk/projects/RB209.aspx

The uptake rates were defined to relate to the land area where a particular measure can be practically applied (e.g. land drainage cannot be improved where there is no need for drainage). The exercise only considered arable land on farms above 100 ha (this accounts for 55% of arable land area in Scotland).

The uptake rates and the uncertainties were estimated for three policy Scenarios: Current: in 2013, assuming no change in current policy; Future A: in 10 years' time, i.e. as in 2023 and also assuming no change in policy; Future B: in 10 years' time with policy changes. Future A scenario implied continuation of policy programs which were directly or indirectly encouraging the implementation of some of the mitigation measures. At the time these were the Farming for a Better Climate scheme[3] (farm advice about resource efficiency) and the Good Agricultural and Environmental Conditions and Nitrate Vulnerable Zone regulations embedded in the 2004-2013 Common Agricultural Policy. In the *Future B* scenario it was assumed that MM1, MM2 and MM3 would be made compulsory (included in CAP cross compliance with penalties for non-compliance and inspection rates defined) and financial incentives would be provided for those applying MM4 and MM5 (50% subsidy on the price of Nis and 50% government support on their capital costs of land drainage).

The uncertainty elicited was characterised using four metrics:

- Individual uncertainty (UC_{ind}): the difference between the individual's Ql and Qu estimates in any iteration step.
- Group average of individual uncertainty ($\overline{UC_{ind}}$): the average of the six UC_{ind} for any iteration step.
- Group variability (Var_{group}): the range between the highest and lowest individual Qm estimate in any iteration step.
- Total uncertainty (UC_{tot}): the range between the highest individual Qu and the lowest individual Ql estimate in any iteration step.

2.2 Elicitation method and expert selection

A common structured elicitation workflow is known as the Delphi method (Brown 1968). In this experts start from their own opinion and through a series of repeated elicitations and discussions update their own personal opinion until in the final elicitation round the group attempts to reach a consensus opinion.

The elicitation was a face-to-face, 5 hour long, one-off event. The structure and content was piloted with "quasi-experts". To ensure full involvement from all participants the number of experts was kept low.

The expert selection considered the expertise in the topic (high level familiarity with cropping practices in the study area, basic familiarity with GHG emissions from soil management, basic familiarity with agricultural policies), length of experience (over 10 years) and the stakeholder

[3] https://www.sruc.ac.uk/info/120175/farming_for_a_better_climate

background, covering three main stakeholder groups by two people from each group (farmers, soil researchers, farm advisors).

2.3 Elicitation process

The event started with an introductory talk explaining the task, elicitation process, common biases during elicitation and schedule of the day. All discussions were recorded and notes taken with permission of participants. A short profiling questionnaire recorded each participant's self-assessed knowledge about GHG mitigation measures and their recent interactions with farmers. Before the exercise a trial elicitation was carried out to demonstrate the stages of elicitation process.

The elicitation process was organised in four stages (Table 2). Iteration 1: independent stage, where experts elicited the upper, middle and lower quartiles for uptake rates of all five mitigation measures for all three policy scenarios, without sharing individual estimation with each other (clarifying questions to facilitators were allowed). In Iteration 2-3 experts could influence each other by discussing and augmenting their estimates. Iteration 2: the group discussed the terminology and assumptions for each measure and scenario and refined their individual estimates; Iteration 3: individuals shared and provide reasoning for their own estimates made in Iteration 2, and then refined their estimates. Iteration 4: the results from previous iterations were plotted and presented to the group for discussion and the experts were asked to try to reach consensus estimates. A timeline of the event was reminding the participants to the order of tasks.

Table 2 Structure of the elicitation procedure

Stage	Description	Order of tasks		
		Current scenario	Future A scenario	Future B scenario
Iteration 1	Overview of all measures and policy scenarios - individual predictions	1	2	3
Iteration 2	Discussion of terminology and assumptions for each measure and scenario - refined individual predictions	4	6	8
Iteration 3	Sharing of individual estimates (from stage II) - refined individual predictions	5	7	9
Iteration 4	Sharing of individual estimates (from stage III) – discussion of estimates to reach a consensus	10	11	12

3. Results

In total 1080 values were to be collected (4 iterations, 6 participants, 3 scenarios, 5 MMs and 3 values); 92.7% of these data points were obtained from the questionnaires. Forty eight values were missing from Iteration 1 and 2 (related to one participant); these were replaced by 25%, 50% and 75%, respectively, for Ql, Qm and Qu. Further 31 values were missing from Iteration 4; these were replaced with the relevant consensus values.

3.1 Current uptake and policy effect

The experts' estimates of Current, Future A and Future B scenarios provide three important pieces of information about each MM: the estimated current uptake, the estimated autonomous uptake (i.e.

future change in uptake due to effects other than additional mitigation policy; for example market forces, improving technologies) and the estimated policy effect (i.e. the effect the envisaged policies would have on uptake) (Table 3). The autonomous uptake is the difference between Qm of Future A and Qm of Current Scenarios, the policy effect is the difference between Qm of Future B and Qm of Future A Scenarios, all as estimated in the consensus (Iteration 4).

Table 3 Current uptake, autonomous uptake and policy effect as estimated by the experts (%) (group average values of Qm in Stage IV)

	Current scenario	Autonomous uptake	Policy effect	Future B scenario
Improved timing of mineral N (MM1)	68	2	13	83
Improved timing of slurry application (MM2)	50	12	16	78
Avoiding N excess (MM3)	60	0	22	82
Nitrification inhibitors (MM4)	5	5	40	50
Improved land drainage (MM5)	30	10	17	57

The estimated current uptake rates of MM1, MM2 and MM3 are above 50%, while for MM4 uptake is 5% and for MM5 is 30%, leaving less room for improvement in uptake for MM1, MM2 and MM3 then for the other two measures. The uptake of all five MMs is expected to autonomously increase by 0-12%, reflecting the estimated proportion of farmland where the measures might be implemented because the farmers consider them beneficial (e.g. for economic or agronomic reasons).

Experts estimated that farmers would not autonomously act to avoid N excess, or improve the timing of synthetic N applications or apply nitrification inhibitors much more than they are already doing (0%, 2% and 5% autonomous uptake, respectively). On the other hand, the uptake of improved timing of organic N spreading and land drainage was estimated to increase by 10-12% without policy intervention.

The estimated Scenario A uptake was between 60% and 70% for MM1-MM3, allowing for a theoretical maximum of 30% to 40% additional uptake to be achieved by policy intervention. MM4 and MM5 had low current uptake, which, together with the 5% and 10% future autonomous uptake, respectively, could offer 90% and 60% future policy opportunity, respectively.

Around two fifth of this policy opportunity was estimated to be achieved by the proposed policies for MM1 to MM4. Policy was expected to increase the uptake of MM5 by 17%, realising less than third of the policy opportunity.

3.2 Uncertainty of the uptake

The uncertainties of the final, consensus uptake estimates (Iteration 4) are represented via the probability density functions (PDFs) derived from the Ql, Qm and Qu values (Figure 1). The width of the PDFs for all scenarios for MM1, MM2 and MM3 were similar, $\overline{UC_{ind}}$ was between 17% and 24% in the last iteration. Improved land drainage (MM5) showed a somewhat higher $\overline{UC_{ind}}$ in the last iteration: 27% to 31% for the three different scenarios. $\overline{UC_{ind}}$ of Nitrification inhibitors (MM4) markedly increased from Current towards Future B scenario (6%, 12% and 40%, respectively for the three scenarios in iteration 4).

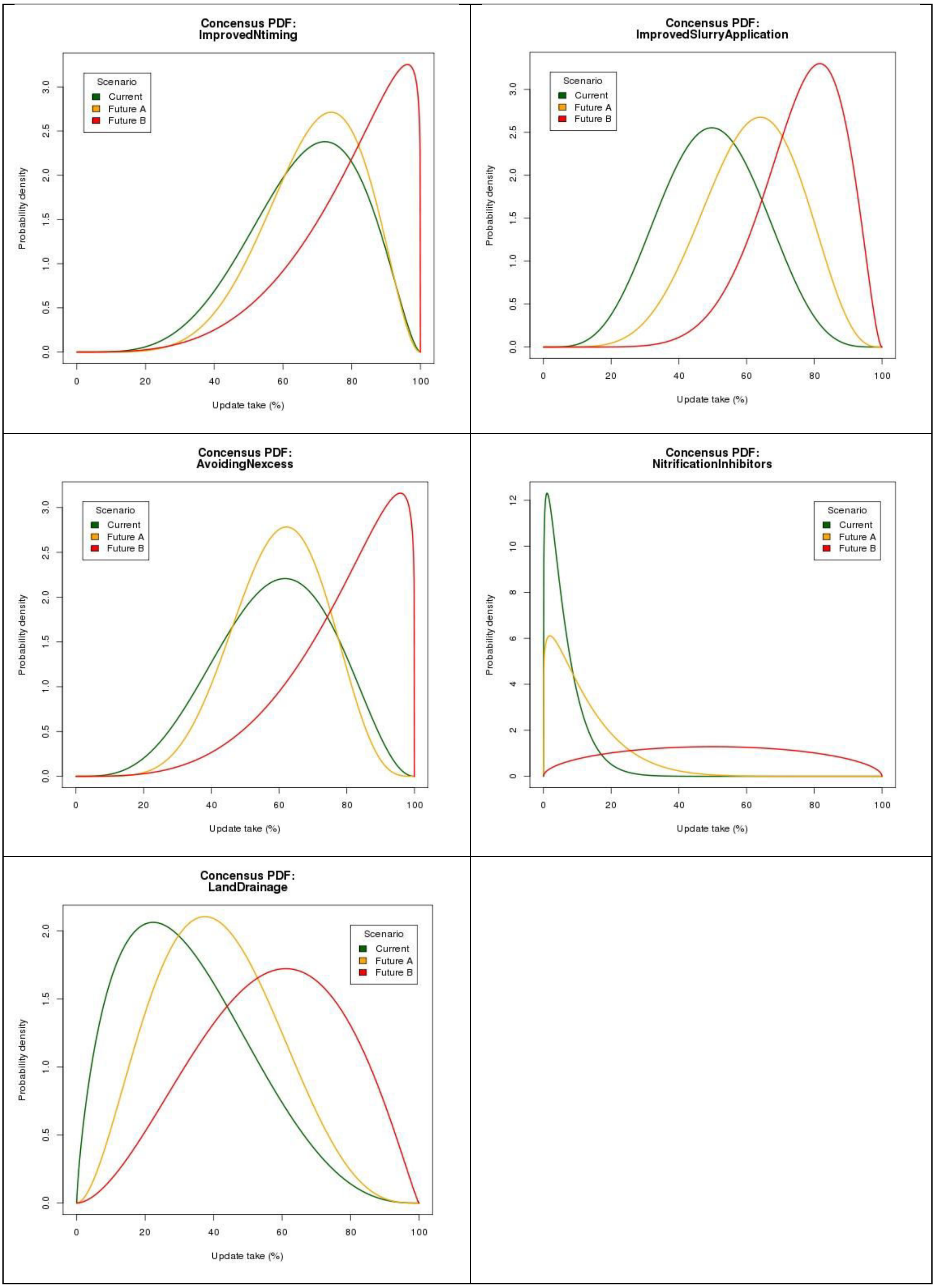

Figure 1 Consensus PDFs of the MMs in the three scenarios

3.3 The elicitation process

The total uncertainty in the group (UC_{tot}) has decreased through the elicitation process for most MMs in all scenarios (Figure 3). In the first iteration Future B scenario of avoiding N excess (MM3) had the lowest UC_{tot} (65%) and Nitrification inhibitors (MM4) in the Current scenario proved to be the most uncertain at the group level (89%). UC_{tot} dropped to a lower value by the consensus stage in all scenarios and MMs to between 6% (MM4, Current) and 62% (MM3, Future A scenario – in this case no consensus was achieved). Interestingly, no single iterations stage reduced UC_{tot}: between the first and second iteration and between the third and fourth all but one UC_{tot} decreased, and from iteration 2 to iteration 3 UC_{tot} increased in four cases out of the fifteen combination of MMs and scenarios.

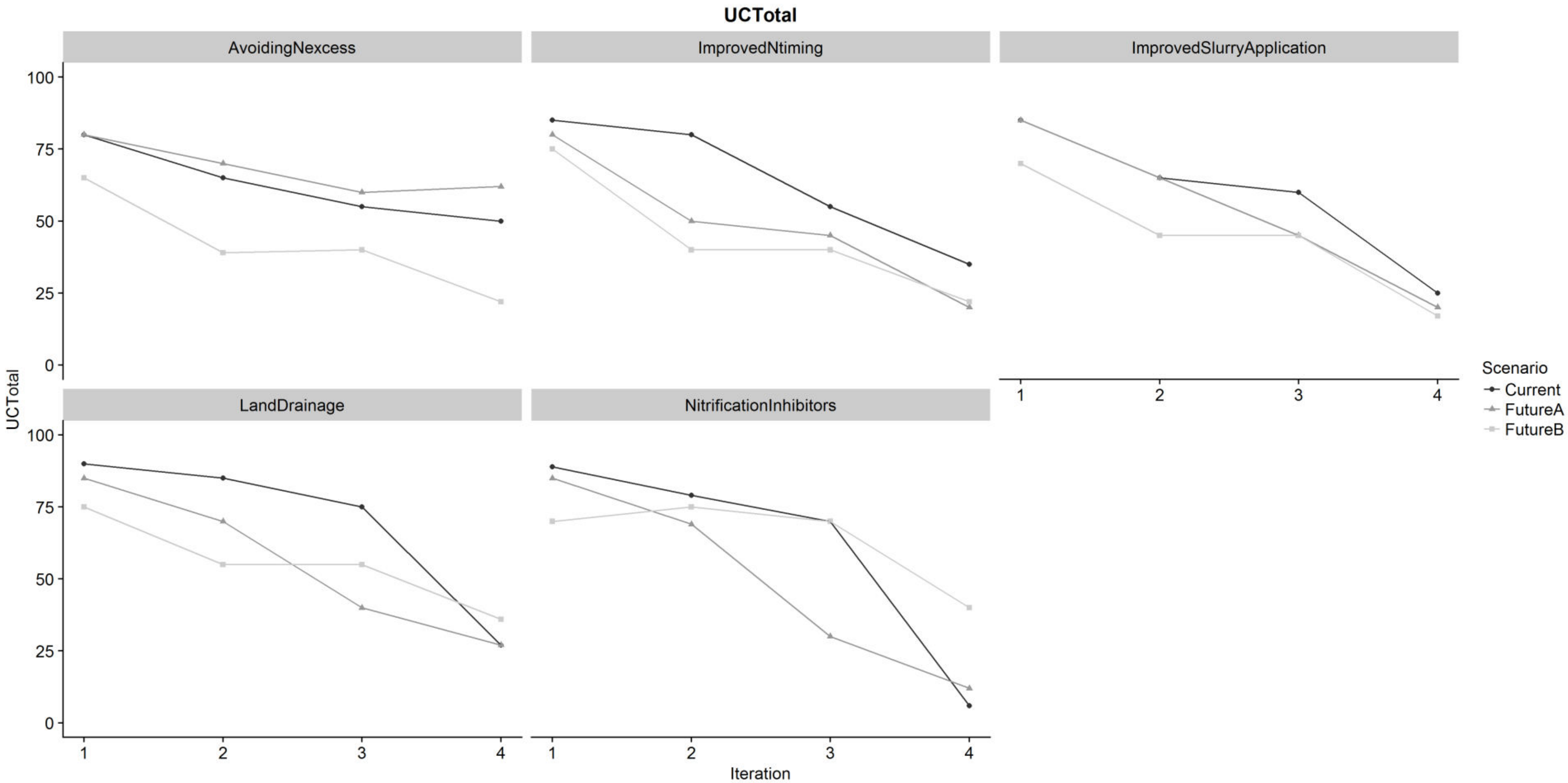

Figure 2 UC_{tot} for five MMs and three scenarios through the iterations

The decreasing pattern shown in Figure 2 is a composite of two processes: a) changes in the individuals' uncertainty and b) changes in the variability of the individuals' estimates (group variability). If either UC_{ind} or Var_{group} is large, the value of UC_{tot} is going to be high.

UC_{ind} was on a wide range, however, 58% of the values were between 15% and 25%. The biggest UC_{ind} values were mostly associated with i) the first iterations, ii) land drainage and nitrification inhibitors and iii) with two experts (E2 and E5).

Furthermore, through the elicitation individuals did not show a clear tendency of reducing their UC_{ind} from iteration 1 to iteration 4 (Figure 3). Out of the 90 cases in 38 cases they decreased their UC_{ind}, in 38 cases they increased, and in the remaining 14 cases their uncertainty range in iteration 4 was the same as it was for iteration 1. Both the largest drop and the largest increase in UC_{ind} was observed for nitrification inhibitors (MM4), the former for Current scenario, dominated by the high initial UC_{ind} of two experts, while the latter for Future B scenario, where the consensus uncertainty was very high (40%). Given the relative stability of UC_{ind} through the process, changes in UC_{tot} were greatly attributable to changes in Var_{group}.

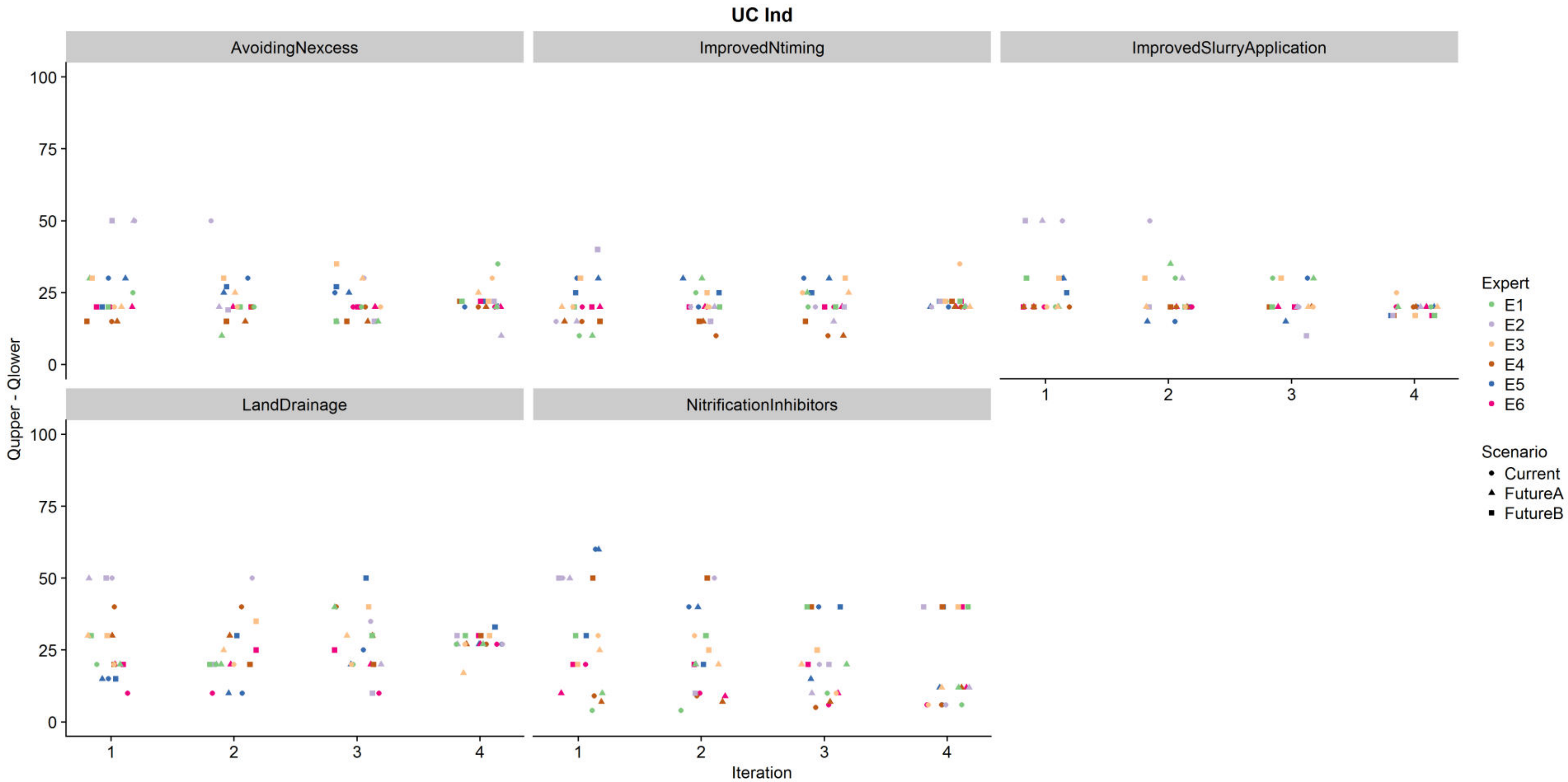

Figure 3 UC_{ind} of the five MMs in the three scenarios through the four iterations

Var_{group} was converging towards zero as the discussions between the iterations brought the individuals' estimates closer to each other's (Figure 4). The exceptions were Current and Future A scenarios of avoiding N excess (MM3), where no consensus was reached and Future B scenario of nitrification inhibitors (MM4), where one individual's value was different from the others'. For all MMs but avoiding N excess (MM3) the Var_{group} was the highest in the Current scenario through all stages and for all but two iteration steps Var_{group} was lowest for the Future B scenario.

The decrease in Var_{group} was not distributed equally between the four iterations (Figure 4). For MM1-MM3 Var_{group} decreased most between the first two and last two iterations, while sharing the numeric results before the third iteration resulted only in modest a decrease. Opinions on the uptake of land drainage (MM5) were more gradually approaching each other, while for nitrification inhibitors most of the disagreement disappeared only in the consensus seeking stage.

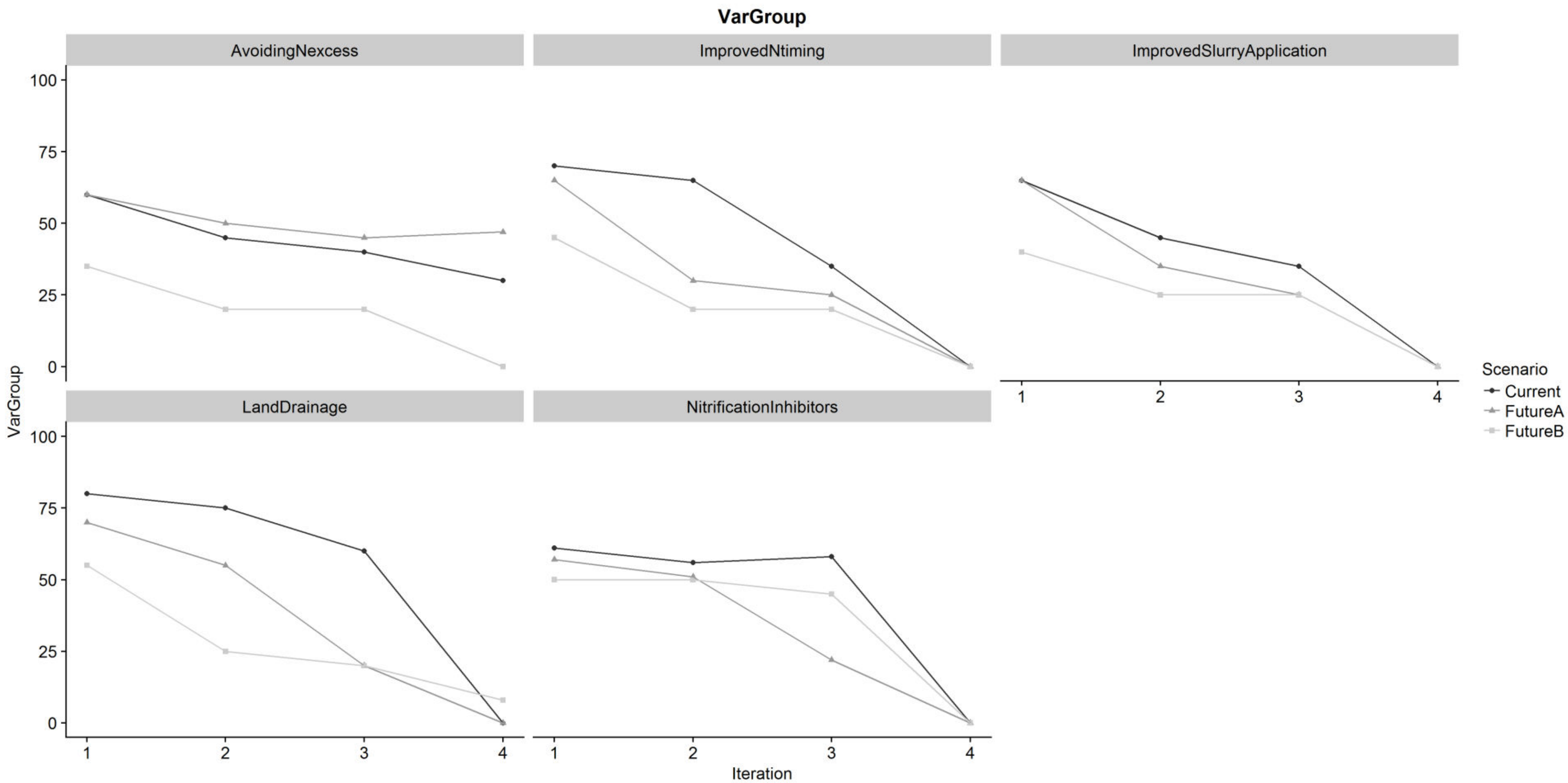

Figure 4 Var_{group} for five MMs and three scenarios through the iterations

3.4 Differences in the estimates related to the experts’ background

The estimates also varied with the experts’ backgrounds and with their prior knowledge of the MMs. For the three N management measures (MM1-MM3) the overlap between estimates of advisors, farmers and researchers were large (Figure 5: a and b), while for land drainage (MM5) and nitrification inhibitors (MM4) farmers usually estimated higher uptake rates than advisors and researchers (Figure 5: c and d). The differences between experts regarding their prior, self-reported familiarity on climate change are not well traceable in the elicitation results.

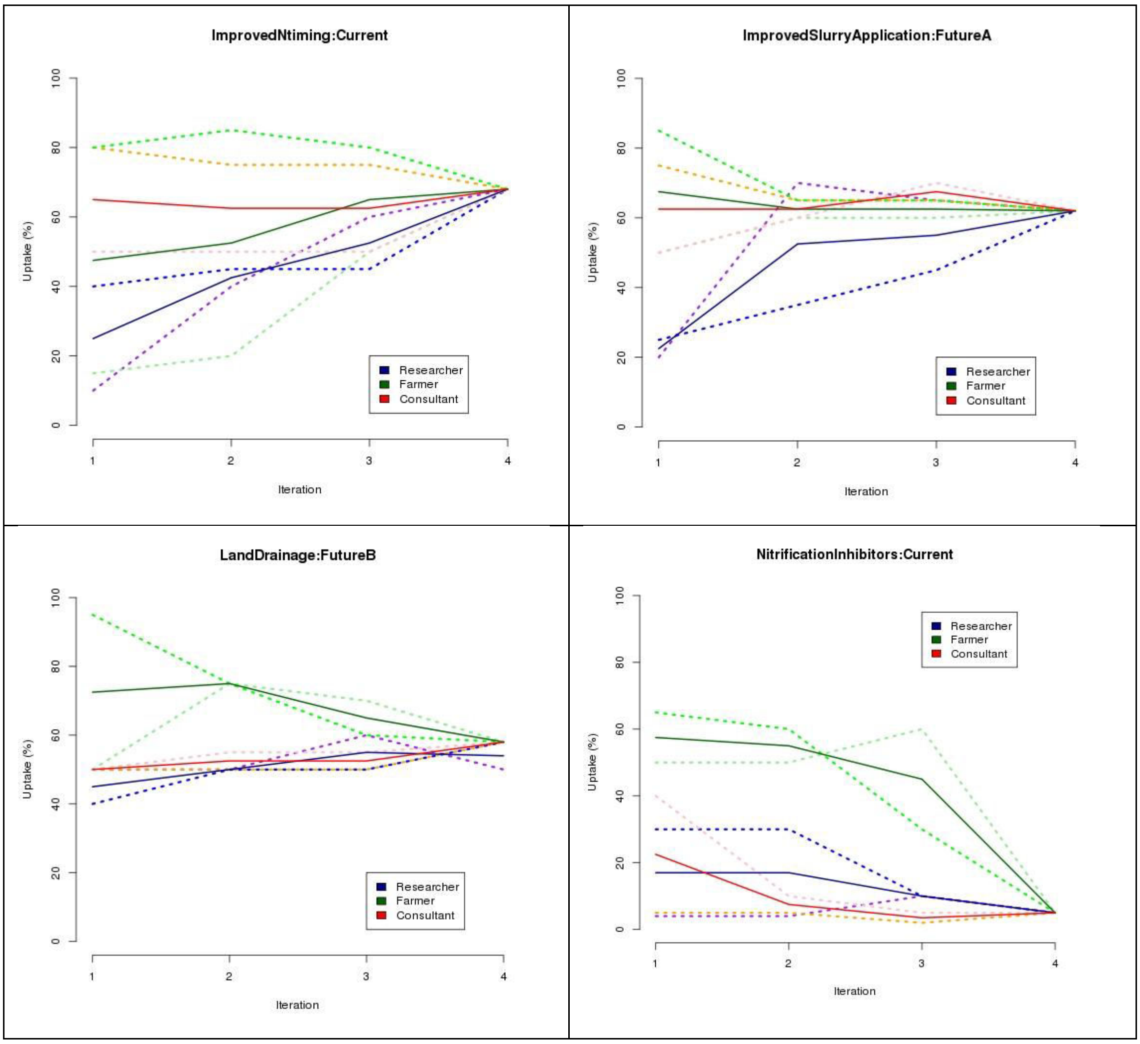

Figure 5 Examples of indiviudal uptake estimates (Qm) through the iterations

4. Discussion

4.1 Current uptake and uptake rate uncertainty

Experts believed that in Scotland farmers are already implementing the three N management measures assessed in the exercise (MM1-MM3) on 50-68% of cropping land situated on bigger (>100 ha) farms (Table 3). Though there are no statistics about exactly these farming practises, some relevant survey results are available from Scotland and also from England, where agricultural practices are comparable to those in Scotland.

The use of nutrient management plans and manure management plans is indicative of N management; in the sense that farms with management plans can be assumed to have a higher awareness of nutrient management and therefore paying more attention to timing of fertiliser and slurry applications and avoiding excess N application. According to statistics in Scotland, 52% of tillage land which is cultivated has nutrient management plans (Scottish Government 2014). English statistics show that 82% of land area on large farms (>3 Standard Labour Requirement; which is slightly bigger than the 100 ha threshold used in the current study) had nutrient management plans and 91% of them had manure management plans in 2013, in the year of the elicitation (Defra 2015). Nevertheless, as the relationship between having a nutrient management plan and improving the timing of N use or avoiding using N in excess is not established, these values can be only regarded as indicative maximum bounds.

The English statistics provides uncertainty on their estimates: the 95% confidence intervals of the values are between 2% to 4% - much lower than the range of 23%, 21% and 24% for MM1, MM2 and MM3, respectively, estimated by the experts. However, the uncertainty of the official statistics is based on the sample size and the return rates, and assumes no measurement bias, i.e. does not include the uncertainty arising from the possibility of self-reporting biases, neither the ambiguity embedded in any such questionnaire (e.g. how does having a nutrient management plan translate to best practice on N use).

Only anecdotal information exists about the current use of nitrification inhibitors (MM4), suggesting that it is not used in the UK (Gooday *et al.* 2014). The expert estimates in this study suggested a very low uptake rate (5%), with $\overline{UC_{ind}}$ of 6%.

Information on the status of drainage systems in Scotland and in the UK is limited. Drainage systems have been installed on large areas in the UK with available subsidies in the 1970s, but as the subsidies were phased out the maintenance of the drains and the installation of new systems halted. Experts in this elicitation estimated that 30% of the land area which would be suitable for drainage has a well-functioning system in place ($\overline{UC_{ind}}$ was 27%).

Policy measures were believed by the experts to increase the uptake level, with a clear difference between 'nudging' and 'budging': regulatory approaches were believed to achieve higher total uptake levels though with lower additional uptake.

4.2 Policy effect

Regulation was estimated to increase the uptake of MM1, MM2 and MM3 to 78-83% (Table 3) – slightly lower than the corresponding assumption of 85% used in the MACCs (Eory et al. 2015, MacLeod et al. 2010, Moran et al. 2008) and the 90% uptake assumption used by the Scottish Government (Scottish Government 2013). On the other hand, the estimated final uptake achieved by financial incentives for MM4 and MM5 (50-57%) is somewhat higher than the estimate used in the MACCs (45% - also mention original source).

Importantly for policy development, the highest uptake increase was estimated to be expected from targeting nitrification inhibitors via financial incentives (40% policy effect), though the uncertainty around this estimate is very high. Financial incentives for land drainage (MM5) and regulatory approaches for MM1, MM2 and MM3 could achieve only lower policy effect (13-22%), but with a higher confidence.

4.3 The elicitation process

The elicitation was successful in reducing the variability in the group by bringing the individual estimates closer to each other. The experts' opinions were further away from each other initially when assessing the current uptake rates than when giving estimates about future scenarios (Figure 4). This might be explained by a tendency to simplify future events which are inherently complex and uncertain and giving initial estimates closer to 50%. When thinking about future uptake under GHG mitigation legislation (either regulatory or voluntary), experts showed lower variability, arguably because they all estimated a higher uptake (i.e. choosing their values from a smaller range). Furthermore, Var_{group} for the Current scenario usually moved closer to each other at a slower pace than for Future A scenario, as can be seen by the Current curve being concave while the Future A curve being convex (Figure 4). This could indicate that people might be less movable in their opinions about current things which are regarded more certain.

The uncertainty range experts estimated correlated with Qm only weakly, i.e. experts have not increased their UC_{ind} proportionally for higher Qm values. They might have genuinely thought that the uncertainty for higher uptake rates is similar for those of lower uptake rates, or this finding can indicate a bias, as estimating the mean uptake rate could have already been a difficult exercise, potentially causing mental fatigue. If this was the reason behind t

The mostly constant individual uncertainty estimates could indicate that the exercise was not fully successful in eliciting the uncertainty of the uptake rates. Several processes might be behind the uniform uncertainties, amongst them is mental fatigue caused by the complex exercise.

Individuals' understanding of definitions inevitably vary. Discrepancy in understanding descriptions of the MMs and policy scenarios might affect numeric estimates, providing a potentially important source of group variability. The multi-stage elicitation process' advantage is that it gives opportunity to reduce this variability via discussions. Discussions before the second iteration were designed to allow communication happen about the definitions without letting the experts to share their numeric estimates with each other. This discussion caused the biggest convergence of opinions in the Future A scenario of improved timing of mineral N application (MM1) (Figure 3).

MMs related to N management (MM1-MM3) and land drainage (MM5) could suffer more from differences in interpretation than Nitrification inhibitors (MM4) as the latter involves clearer, more measurable changes in farm management. On one hand, there is ambiguity in exactly what practical changes some N management measures entail, for example improved timing of mineral N fertiliser (MM1) can be understood as no application in the autumn or as taking into account weather conditions for spring applications. On the other hand, changes required in farm management in MM1, MM2 and MM3 are difficult to describe (and measure) objectively. For example improved timing of fertiliser application requires assessments of crop growth, wind speed, soil water content and likely precipitation 3-4 days in advance. As there are no common metrics and guidelines to assess these characteristics (not to mention the in-field differences which commonly exist, e.g. one part of the field might be wetter than other areas), one farmer's decision on whether to apply the fertiliser or not can easily be different from another. Installing land drainage is a technically well-defined action, but there can be debate about the necessity of a drainage system on a given field. Furthermore, the quality of maintenance is difficult to describe, potentially causing alternative views of this MM.

This subjectivity confounds the understanding of what management changes the MM might mean on farms, and whether farmers are following these practices or not. It can explain that the reduction of group variability between iteration 1 and 2 was higher for MM1-MM3 and MM5 than for MM4 and highlights the importance of providing clear guidelines for the MMs in official statistics, in policy documents and in knowledge exchange activities.

4.4 Effects of the background of experts

For land drainage and nitrification inhibitors farmers' estimates were mostly higher than those of researchers and advisors. Advisors and researchers might have less realistic and at the same time pessimistic view on the pro-environmental behaviour of farmers . On the other hand, farmers can be expected to be more optimistic, as they were asked to report on the behaviour of a group they identify themselves with, and in such cases a self-reporting bias, called socially desirable responding (SDR) might occur. SDR is a tendency to give overly positive self-descriptions (Paulhus 2002), and it is a highly important potential bias in surveys based on self-reporting (Nederhof 1985).

5. Conclusion

The effectiveness of agri-environmental policies ultimately depends on the realised additional uptake of sustainable practices. Predicting what additional uptake a policy will generate is inherently difficult, resulting from a combination of gaps in baseline data and high uncertainty regarding the future behaviour of actors. Information sources for estimating the uptake are either very crude or resource intensive. Using a structured approach to elicit expert opinion both on current and future uptake can complement these sources, and is particularly useful for practices where baseline data are not available. Additionally, uncertainty information can be elicited to inform policy with an estimate of the likelihood of reaching the uptake goals.

Such information can directly inform policy formulation, like in this case the results suggested that the highest policy effect could be expected from targeting nitrification inhibitor uptake. Policy supporting improved land drainage and regulatory approaches for nitrogen management practices might achieve lower additional uptake, although with higher confidence.

Our elicitation process showed the importance of precise communication regarding agricultural practices: the practices must be explicitly defined before their potential uptake can be effectively assessed. Moreover, we assert that clarity in communication between the stakeholders (farmers, advisors, policy makers, researchers) will likely be beneficial in increasing uptake.

Communication also needs to consider the potential bias farmers might be subject to: a tendency to overestimate their efforts in sustainable land management. Policy and the researcher community have to adjust communication so that while recognising farmers' opinion, provide them tools to be able to make a more objective assessment of their current efforts and potential for improvement. This aligns well with the suggestion of Jansen et al. (2010), who argue for tailored communication strategies to reach "hard-to-reach" farmers, some of whom are "hard-to-reach" because they believe they are already following best practice regarding the environmental aspect in question.

The inclusion of stakeholder knowledge into the scientific advice can be a useful way as an alternative to missing observational or modelled information. The different groups of stakeholders might have very different opinions on the same "facts", it is important to recognise the existence of "multiple" objectivity, and consider the qualitative information emerging from the discussion.

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Appendix

General definitions

The geographic boundary is Scotland.

The timeframe is 2013 and 2023 (2023 is first year of the fourth carbon budget period).

Land Areas and Uptake Rates

(1) Land Area

We are considering the cropping and fallow land areas situated on bigger cereal, general cropping and mixed farms (farms above 100ha). This accounts for 55% of cropping and fallow land area in Scotland. (We neither consider other cropping land areas (e.g. on livestock farms), nor grassland areas.)

(2) Technically Feasible Land Area

Usually mitigation measures are not technically applicable on the whole Land Area (1) defined above. Technically Feasible Land Area refers to the proportion of the Land Area where a particular measure actually can be applied. During the exercise we are not going to quantify the Technically Feasible Land Area explicitly, but you will be asked to estimate the uptake rate *relative* to the land area where you think it is technically feasible to apply the measure.

(3) Current Uptake Rate

Current Uptake Rate is the percentage of the Technically Feasible Land Area (2) where the mitigation measure is currently regularly practiced. During the exercise you will be asked to give your uptake rate estimates as the percentage of the Technically Feasible Land Area.

(4) Future Uptake Rate

Future Uptake Rate is the percentage of the Technically Feasible Land Area (2) where the mitigation measure will be regularly practiced in 2023, given either Policy Scenario 1 or Policy Scenario 2.

Mitigation measures (MMs)

MM (1) Improved timing of mineral N fertilisers

Apply the inorganic N fertiliser when the crop is actively growing, also considering soil and weather conditions at the time of the application. Guidelines:

- Apply N when the crop requires it - when the crop is actively growing, AND
- Avoid windy days when ammonia losses are likely to be higher, AND
- Do not apply in wet or frozen weather or onto saturated soils, or when the weather forecast makes it likely that these conditions will appear within one week post application, AND
- Do not apply autumn N for winter cereals.

MM (2) Improved timing of slurry and poultry manure application

Apply the organic N fertiliser when the crop is actively growing, considering soil and weather conditions at the time of the application as well. Guidelines:

- Apply N when the crop requires it - when the crop is actively growing, AND
- Avoid windy days when ammonia losses are likely to be higher, AND
- Do not apply in wet or frozen weather or onto saturated soils, or when the weather forecast makes it likely that these conditions will appear within one week post application, AND
- Do not apply autumn N for winter cereals, AND
- Avoid making applications to dry soils in very warm weather, AND
- Incorporate manures or slurries as soon as practical, AND
- Have a minimum of 6 months slurry storage available – this allows the flexibility of applying manures and slurries when soil conditions are optimal and when crop demand is the highest.

MM (3) Avoiding N excess

Apply fertiliser according to fertiliser recommendations (like SRUC Technical Notes or Fertiliser Manual (RB209)). Guidelines:

- Have a nutrient budget for each field and each crop, AND
- Consider the soil type and the field's cropping, fertilising and manuring history, AND
- Consider the diminishing marginal return per unit of N given crop output value and fertiliser price, AND
- Do regular soil analysis for pH, P, K, Mg and adjust levels accordingly, AND
- Do soil mineral N analysis if the soil N could be unusually large or where organic N have been used regularly in recent years.

Please note that this measure does NOT include the assumption of maximising the use of organic nitrogen supply, as we have a separate measure for that, not included in this exercise. MM (3) therefore does NOT assume that:

- There is any improvement in adjusting the inorganic N fertilisation to the applied organic N, OR
- There is any increase in the use of organic fertiliser analysis, OR
- There is any improvement in practices to conserve N in the organic fertiliser.

MM (4) Nitrification inhibitors

Use nitrification inhibitors (NIs) (chemicals which slow the rate of conversion of fertiliser ammonium to nitrate), leaving more N available to the plant. Practicalities:

- NIs can be used both on arable land and on grasslands.
- NIs can be used both with inorganic and organic N fertilisers and on grazed land.
- NIs are available both in granulated and in liquid form, therefore can be pre-mixed and spread together with fertilisers. If they are not pre-mixed, they have to be spread/sprayed within one hour after fertiliser application.
- One of the most common NI is DCD, which is commercially available as DIDIN. The recommended rate is 6-20 l/ha, depending on fertiliser and soil type. The cost of DIDIN is £23-76 /ha.

MM (5) Land drainage

Ensure that land is adequately drained by repairing a non-functional drainage system or installing a new drainage system. Guidelines:

- Inspect existing drainage systems to ensure that they are functioning properly, AND
- Have maintenance and repair plan, AND
- In case of drainage problems repair the obvious faults. For further help contact a drainage consultant to carry out investigations, AND
- Undertake test excavations and a level survey to determine the most appropriate system to for your site, AND
- Carry out the required maintenance / install new drainage system as required.

Policy

Current policy landscape

Farming for a Better Climate (FFBC): The FFBC scheme encourages farmers to implement measures on their farm which improve the farm's performance, helps adaptation to climate change and reduces GHG emissions. It does so via voluntary Climate Change Focus Farms, events for farmers run by advisors, a website and practical guidance documents.

The mitigation measures promoted in FFBC and relevant to this exercise are:

- Apply nitrogen at optimum rates for the crop
- Improve the timing of nitrogen applications to meet crop requirements
- Improve your field drainage system

Scottish Rural Development Programme (SRDP): The SRDP is a programme of economic, environmental and social options, providing financial assistance for implementing the options.

There is only one option in the SRDP which might indirectly promote the uptake of one of the mitigation measures discussed in this questionnaire: 'Manure/Slurry Storage'. This option can result in increased capacity for storing slurry, which allows greater flexibility in the timing of the slurry application.

The new SRDP (2014-2020) is currently being negotiated, with no clear indication of including GHG mitigation measures in it.

Common Agricultural Policy (CAP) reform: The currently proposed changes in the CAP reform are likely to have no major direct effect on GHG emissions and mitigation in agriculture. There is no proposal to include GHG mitigation measures in the Cross Compliance rules, and the current Greening proposals would not promote mitigation activity either.

Policy Scenario 1

The assumed policy environment in 2023.

- There will be no specific policy changes to promote the uptake of any GHG mitigation measures.
- The FFBC scheme is going to continue.
- The SRDP and the currently proposed CAP reform will be implemented (i.e. with no specific changes to promote the uptake of GHG mitigation measures).

Policy Scenario 2

The assumed policy environment in 2023.

- MM (1), MM (2) and MM (3): compulsory. These mitigation measures will have been included in the Cross Compliance rules, since 2018 at the latest. Single Farm Payment (and some other direct payments: Scottish Beef Scheme, Less Favoured Areas Support Scheme, SRDP Land Managers' Options) might be reduced if the farmer breaches the rules. The inspections, enforcement and non-compliance penalties will be the same as currently, including:
    - In case of negligent non-compliance, direct payments are reduced by 3% (1%-5%), in case of intentional non-compliance, the reduction is 20% (15%-100%). Multiple and repeated breaches might result in higher penalties.
    - Inspection level: minimum 5% of the farms annually.

- MM (4): voluntary, with financial incentives. The mitigation measure will be directly subsidised, since 2018 at the latest.
    - The costs of the nitrification inhibitors will be subsidised by 50%.

- MM (5): voluntary, with financial incentives. The mitigation measure will be included in the SRDP Rural Priorities options, since 2018 at the latest.
    - Capital costs of the construction or enhancement of the drainage system will be supported up to 50%.
    - Success rate of applications is expected to be around 60%.
    - All selected claims will be inspected.
    - Inspection level after installation: minimum 5% of the farms annually.

Statistical definitions

The middle, lower and upper quartiles describe the probability distribution associated with the uptake rate. This probability distribution represents your uncertainty regarding the level of uptake.

Middle quartile: this is the value for which the statements "the true rate is greater than this value" and "the true rate is lower than this value" are equally likely.

Lower and upper quartiles: these are the values for which the following statements are all equally likely:

(a) the true rate lies between zero and the lower quartile

(b) the true rate lies between the lower quartile and the middle quartile

(c) the true rate lies between the middle quartile and the upper quartile

(d) the true rate lies between the upper quartile and one.

Lower, middle and upper quartiles might be abbreviated to Q1, Q2 and Q3, respectively.