Measuring the unmeasurable? A method to quantify adoption of integrated pest management practices in temperate arable farming systems

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Title: **Measuring the unmeasurable? A method to quantify adoption of Integrated Pest Management practices in temperate arable farming systems**

Running title: **Quantifying adoption of Integrated Pest Management in arable farming**

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Abstract

BACKGROUND: The impetus to adopt integrated pest management (IPM) practices has re-emerged in the last decade, mainly as a result of legislative and environmental drivers. However a significant deficit exists in the ability to practically monitor and measure IPM adoption across arable farms; therefore the aim of the project reported here was to establish a universal metric for quantifying adoption of IPM in temperate arable farming. This was achieved by: (a) identifying a set of key activities that contribute to IPM; (b) weighting these in terms of their importance to the achievement of IPM using panels of expert stakeholders in order to create the metric (scoring system from 0-100 indicating level of IPM practiced); (c) surveying arable farmers in the UK and Ireland about their pest management practices; and (d) measuring level of farmer adoption of IPM using the new metric.

RESULTS. This new metric was found to be based on a consistent conception of IPM between countries and professional groups. The survey results showed that, while level of adoption of IPM practices varied over the sample, all farmers had adopted IPM to some extent (minimum 27.2 points, mean score of 65.1), but only 13 of 225 farmers (5.8%) had adopted more than 85% of what is theoretically possible, as measured by the new metric.

CONCLUSION. We believe that this new metric would be a viable and cost-effective system to use to facilitate the benchmarking and monitoring of national IPM programmes in temperate zone countries with large scale arable farming systems.

Keywords: Integrated Pest Management, IPM metric, IPM score, arable farming, farmer survey, sustainable agriculture.

1. Introduction

Significant increases in crop production over the last century have resulted primarily from advancements in crop agronomy, including crop protection and nutrition, plant breeding and mechanisation of husbandry practices. These advances have largely been predicated on intensive use of inorganic chemical inputs, including fertilisers for plant nutrition and pesticides (collectively fungicides, herbicides, insecticides, molluscicides and nematicides) for crop protection. At the present time, commercial agriculture globally remains dependent on continued use of these synthetic crop protection products to prevent significant crop losses from pests.[1] Furthermore, prophylactic application of pesticides has become common across many intensive crop production systems.[2] However, input-intensive agriculture can and does result in unwanted consequences, including, adverse impacts on human and environmental health, development of pesticide resistance, all of which potentially reduce the sustainability of these systems.[3,4] With increasing awareness of these risks, there is now widespread acknowledgement for the need to move towards more sustainable methods of agricultural production. One such method, which was first proposed in the 1950s,[5] but that has gained significant traction and political support in recent years, is integrated pest management (IPM). IPM is regarded by many as a necessity for ensuring the optimum control of pests in an economically and environmentally sustainable manner. [5-10] Whilst the precise definition of IPM can vary between studies and stakeholders,[11-13] it can broadly be categorised as an approach that considers the crop, the production system, the target pest(s) and their potential risks to production, as a whole system. IPM simultaneously employs multiple pest-control solutions, targeting different parts of this system, as a means to minimise the use of pesticides and ensure the long-term sustainability of pest control measures [10,14,15].

Whilst IPM can be readily understood in terms of such generalised statements and objectives, the diversity of pest control practices that exist across all scales of an individual production system makes identifying a definitive set of IPM practices extremely difficult. European Union Directive 2009/128/EC, on the sustainable use of pesticides, which requires each member state to encourage the use of IPM, identifies eight principles of IPM and a number of specific crop management activities within each.[7] These eight principles (Table 1) have been further expanded upon by Barzman et al.[10] to provide the basis from which IPM can be approached by all those involved in crop production. However, as Barzman et al.[10] concede, even with this level of specification, it is difficult to provide a definitive checklist of IPM practices, or even recommendations for approaches to implementing the eight principles. However, most commentators would agree that the over-arching principle must be preventing or suppressing the pest as opposed to intervening after the pest has become established, and that the implementation of each of the eight principles should involve a continual process of management plan redesign, implementation and evaluation.[10,15] The perceived difficulties associated with quantifying adoption of IPM practices has influenced some countries, such as Denmark, to rely on pesticide usage as a proxy. In Denmark a pesticide tax system, which is based on the wider impacts of pesticide use, is employed in an attempt to encourage adoption of IPM practices. However, approaches to encourage adoption of IPM that rely heavily on a single measure, such as pesticide usage, do not account for differences in the need for pesticides between different cropping systems experiencing different pest challenges.

In arable farming there are a range of fairly ubiquitous crop management practices that are consistent with these eight principles of IPM, but which are simply understood as good husbandry. It is reasonable to assume, therefore, that most arable farmers may already be practicing some form of IPM[16,17] even when they do not appreciate that fact. Arable famers tend to adopt IPM practices, in part, or incrementally over time by assessing the impacts of individual components and slowly building up to a fully integrated approach to pest control at which point complementarities between components occur.[18,19] The practice of IPM, therefore, can be seen as a continuum, with some farmers further than others along that continuum to complete adoption.[20] Previous attempts to establish a metric of IPM, which would allow for an assessment of where individual farmers lie on this continuum, have failed, largely due to the lack of an objective approach to assessing the relative importance of different IPM components and a lack of involvement of IPM practitioners in further pursuing the development of such a metric.[21-23]

Before informed efforts to increase the adoption of IPM in arable production systems can be successfully implemented, accurate information on the current level of IPM practiced across a diversity of systems is required. To achieve this, it is a necessity to be able to place both individual farms and farm system typologies on some agreed metric of IPM. Such a metric requires two attributes: first, it must capture a core of IPM management activities, based on a consensus about what these are; and, second, the metric, must be able to use information on adoption of these activities to create a continuum of degree of IPM adoption. Hence, the IPM metric must be defined in terms of low-order, specific, actionable management activities. As such, it must be a compound measure, capturing multiple IPM management activities simultaneously.

The over-arching goal of this study therefore was to design and test a compound metric of IPM with sufficient flexibility to be applied to a variety of farm situations and with sufficient resolution to capture the continuum of degree of IPM adoption in a meaningful way. To reach this goal, the achievement of a number of sub-objectives are necessary: identify the main IPM activities that can be carried out on temperate arable farms; use stakeholder views to weight these activities based on their relative contribution to achieving IPM; construct a composite

IPM measure based on these activities; test the efficacy of the IPM measure on a representative sample of arable farms in England, Scotland, Northern Ireland and Ireland; validate the outputs of the measure; and identify potential drivers of IPM involvement from among the sociodemographic data collected from each participating farm business. Finally, some conclusions are drawn of prime relevance to both practice and policy.

2. Methods

The study used a multi-stage process to achieve the objectives set out above, as outlined in Figure 1; Tasks 1-3: design, optimisation and piloting of the data collection instrument; Task 4: data collection; Task 5-6: developing the IPM metric; Task 7: use, validation and secondary analysis of the IPM metric.

2.1. Design, piloting and optimisation of the farmer survey (Tasks 1-3)

Following a review of the IPM literature, including the general principles of IPM as outlined by the EU's Sustainable Use Directive 2009/128/EC (Table 1), a list of IPM practices associated with temperate arable agriculture was identified. This list was then used to inform the design of a farmer questionnaire to record level of involvement with IPM. The farmer questionnaire consisted of three types of question, first, questions which captured information on farmer engagement with specific IPM activities; second, farm and farmer sociodemographic information; and finally, information in farmer attitudes towards, and perceptions of, IPM. Questions were a mix of: multiple choice, 5-point rating scales, and some open-ended questions, as appropriate to the type of information being elicited. The draft questionnaire was tested via two rounds of piloting with farmers, agronomists and arable researchers. Following the pilot, the number of questions was reduced from 44 to 22 by removing questions that proved too complicated to answer fully, and combining questions to reduce repetition in the survey.

The final questionnaire contained a total of 22 questions; nine questions relating to individual IPM activities, based on the eight principles of IPM (Table 1), and a further five questions relating to perceptions of IPM. The remaining eight questions collected sociodemographic information (a copy of the questionnaire is available in Supplementary Materials; Appendix 1). On average the questionnaire took 10-15 minutes to complete. To protect against any biases that farmers may have concerning IPM, whether these be positive or negative, the survey was described as addressing best pest management practice in arable farming generally, rather than IPM specifically.

2.2. Farmer survey sampling strategy (Task 4)

Arable farmers were selected for interview at random using national datasets as a sampling frame in each of the four study countries. Each national research partner was set a target of collecting 50 completed responses to ensure a sufficient number of responses for robust statistical analysis within each country. All responses were collected between 2016 and 2017. Data collection was by face-to-face interviews in England, Northern Ireland and Ireland, these being carried out by experienced farm data recorders, while data collection in Scotland was by means of a postal questionnaire.

2.3. Developing a metric for the adoption of IPM on temperate arable farms (Tasks 5-6)

The raw data collected from the survey on levels of adoption of each of the activities contributing to IPM contained no indication of the relative importance of these individual activities towards IPM. This weighting information was derived from a panel of industry stakeholders, all of whom are actively involved in the practice of pest management in arable crops, using a two-stage Delphi style approach. The Delphi technique uses data from a panel of informed people and builds this data, using an iterative process, towards a consensus. The strength of the technique lies in the fact that at each iteration the stakeholders have the opportunity to amend their original judgements in light of the data and arguments supplied by others.[24] In the first stage, a consultation with 11 stakeholders in Ireland was held in the form of a workshop (see Table 2 for details). At the workshop, stakeholders were given a guidance document (Supplementary material; Appendix 2) and a copy of the farmer questionnaire (Supplementary material; Appendix 1) in addition to a verbal explanation of the project and the aims and structure of the meeting.

The stakeholders were then asked to weight each of the six pre-selected questions relating to adoption of IPM in the farmer questionnaire, on the basis of the importance of the pest management activity that it captured, for IPM as a whole. The weighting process was undertaken in two parts. First, where questions had sub-components, i.e. the question captured multiple activities of a certain type, stakeholders were asked to provide ranks on a 1-5 scale for these. The ranks were generated through an open discussion of the relative importance of each sub-component to the question as a whole. Discussion continued until a consensus was reached around a rank score. Second, each question was then awarded a weight based on its importance to IPM. This involved allocating a total of 100 points over all six questions to decide on the percentage contribution each question made to the overall IPM score. All six questions were then combined, after applying the appropriate question weights, and divided by five (each measure in the composite represents a 5-point scale) to form a composite Likert-type rating scale[25] with a 100-point range representing level of IPM uptake, i.e. the IPM score.

The provisional set of weights derived from this workshop were then presented to a larger stakeholder panel (see Table 2 and Table 3), by email and postal surveys across the study countries in late 2017. Stakeholders were targeted in attempt to gather responses from those actively involved in the practice of IPM. A total of 174 surveys were distributed and 46 responses collected. The group of stakeholders were informed of the original provisional set of weights and then asked to provide their own estimate for each weight. To ensure consistency of approach between participants in these surveys, each was sent a guidance document, providing instructions for completing the questionnaire (Supplementary material; Appendix 3). A total of 46 responses were collected and weights collected used on a one vote per stakeholder basis. All data collected for this study, i.e. from the stakeholder workshop, and stakeholder and farmer surveys were transcribed into electronic datasets and checked for errors (survey data input file can be found in Supplementary material; Appendix 4). All statistical analyses of the survey data were undertaken using the data analytics package SAS version 9.4.[27]

2.4. Validation and secondary analysis of the IPM metric (Task 7)

A probability-probability plot was used to determine whether the distribution of the composite IPM variable was normal or otherwise before other statistical operations were performed. Cronbach's alpha was used to test for internal consistency in the composite IPM measure, by measuring the inter-correlation between items, where an Alpha score of >0.7 is assumed to indicate that the component questions cohere, i.e. they co-vary together.

To test the extent to which there is a common understanding of IPM between countries and subgroups of stakeholders, the weights awarded by these different stakeholder groups were compared. For the purposes of the analysis four different classes of stakeholder were identified: Farmers, Independent agronomists (defined as those who do not directly benefit financially from pesticide sales), Merchant agronomists, and Others. As degrees of freedom in some of these groups were low, t-test comparisons were performed with aggregated stakeholder groups, i.e. Farmer + Independent agronomist + Merchant agronomist compared with 'Other', where 'Other' represents researchers, agricultural college educators and policy makers. The rationale for dividing the stakeholders into these two groups is that the first group comprises those that have a commercial interest in pest management, whilst the 'Other' group are unlikely to have such commercial interest.

To test for country understanding of IPM, an ANOVA was carried out to determine whether stakeholders from the different countries applied different weights to the questions. For the purposes of this analysis, Northern Ireland was combined with the data for Ireland due to low observation numbers for Northern Ireland and the authors' perception of cultural and agricultural similarities between the countries.

3. Results

3.1. The farmer survey sample

A total of 225 responses were collected for the farmer survey: Northern Ireland (71), Ireland (58), England (53), Scotland (43) (Table 4). The majority of respondents to the survey were owners of the farm businesses. Farms varied considerably in size between countries, with the largest farms found in Scotland, with an average size of 362 ha, and the smallest in the Ireland, with an average farm size of 101 ha. 67% of the land on farms in the England sample was arable land, with the remainder being improved grassland. Land cover on farms in the other countries was much more heterogeneous, with smaller percentages of arable land and more grassland (Table 4).

3.2. The weighting of the components of the IPM metric

The final set of weights provided by stakeholders for each question is outlined in Table 5, whilst the final weights for sub-elements within each question are available in Appendix 3 of the supplementary material. Overall, the weights awarded by stakeholders at the workshop differed from the final stakeholder weights by between 1.6% and 17.8% for all questions, with the exception of question 5, where the variation was 75.4%. However, there was an inverse relationship between the absolute size of the weights and the percentage variation, with the bigger weights showing the smallest variation (Table 5). Question 8, which focussed on activities designed to prevent weeds, disease and insects/molluscs, was judged to account for 47% of the achievable IPM score, with factors influencing pest management plans (Question 9) coming in second, with a relative contribution of 15% to the IPM score.

3.3. Validation of the IPM metric

Farmers IPM scores were relatively normally distributed (Supplementary materials; Appendix 5) with a range of 27.2 – 91.3, a mean of 65.1 and a standard deviation of 13.8 (Coefficient of Variation 21%), i.e. exhibiting a normal bell-shaped curve, although the distribution is somewhat skewed towards higher IPM scores (Figure 2), suggesting that the majority of farmers are already implementing at least some measures that would be seen as characteristic of IPM. However, while all farmers are practicing some of level of IPM, only 13 out of 225 farmers (5.8%) scored more than 85 on a possible scale of 100. Any responses containing a high amount of unanswered questions, leading to a score of less than 20, would have been removed from the survey but none of our respondents fell into that category.

3.4. The coherence of the IPM metric

Cronbach's Alpha was used to test the coherence of the questions combined, after weighting, to create the IPM metric. There are no hard and fast rules about what Alpha value is required to show adequate coherence in the sets of measures used to form composites, but it is widely held that the higher the value the better (although extremely high values might be suggestive of redundancy among the measures). A precedent has become established that Cronbach's

Alpha values in excess of 0.7 are classed as good or better, so this convention and threshold has been followed here.[26] When undertaking this testing of the internal consistency of the composite IPM measure, the three components of Question 8, relating to the choice of pest prevention measures, were separately tested for coherence. Each of these three questions, a) measures for prevention of weeds; b) measures to prevent diseases; and c) measures to prevent insect pests/nematodes/molluscs, was itself a composite measure, made up of a number of sub-components. With the exception of Question 8b – 'What measures are used to control diseases', all questions had a Cronbach's Alpha >0.7 (Table 6) strongly suggesting that these composite questions were also coherent. Question 8b had a Cronbach's Alpha of 0.68. While obviously falling below the 0.7 threshold set above, the literature suggests that this value is still acceptable.[26] Overall these results suggest a high degree of internal consistency in the composite IPM measure.

3.5 A consensus as to what constitutes IPM practice across groups and countries

For four of the six questions, there were no significant differences in the weights attributed by the two stakeholder consultation classes (Table 7). This lack of significant difference between the weights awarded by the two stakeholder classes indicates that there was a consensus on what constitutes IPM practice. For two questions, there were significant differences between the two stakeholder classes; Q5 – 'What influences your choice of cereal variety?', and Q14 – 'Membership of an agronomy/crop discussion group'. However, these two questions only account for, a combined weight of, 14.6% of the overall IPM score. In both instances, those stakeholders with commercial interest in pest management (farmers and agronomists) weighted the questions higher in importance than those stakeholders that are commonly considered to have no commercial interest (researchers, regulators, educators), with Q5 seeing a 69% increase in weight and Q14 a 78% increase.

No statistically significant differences amongst countries in the weights applied by stakeholders to any of the IPM questions were identified (Table 8). In the case of Q4 – 'Why do you typically use an arable rotation?' differences were close to being significant (P=0.07), but this is a question with a relatively small weighting. The national differences in weight on this question occurred between England (12.1%) and Scotland (9.9%), and also the island of Ireland (14.0%) and Scotland.

4. Discussion and conclusion

IPM is a knowledge-intensive process in which scientifically proven measures are selected for use, based on the specific set of biotic threats affecting the crop and the financially viable approaches available to the grower, to reduce risk associated with these threats.[10,28] As such IPM does not necessarily rely upon individual control mechanisms in isolation but seeks to use a complexity of inter-related strategies. It is this complexity that makes capturing levels of IPM practiced at the farm scale difficult. This difficulty can be further compounded by unintentional perspective bias, for example relating to what does and does not constitute an IPM activity, imposed by observers via both the methods used to collect such data and the assessment process.[23] Such bias can result in the exclusion of activities which legitimately contribute to IPM being from the survey and other IPM activities being attributed irrational weights.

The development of a metric to assess the extent of adoption of IPM described here differs in approach from those currently in existence. This is because the generation of the weighting system for the various elements of IPM was, in this case, rigorous, and involved a number of IPM practitioners from various professional backgrounds. Many previous attempts to develop such a metric have not been able to garner widespread support due to the fact that the process of determining which activities to include in the metric and the weights attributable to these has remained solely in the hands of researchers, with little or no reference to industry stakeholders such as farmers and professional agronomists.[21-23] The carefully controlled approach to developing a metric for IPM reported here, together with the observed clear within-sector and between-country consensus about what constitutes IPM suggests that this IPM metric has potential for use in an international context.

Currently, gaps exist between farmer perception of the value of IPM and their actual practice. Whereas farmer attitudes towards IPM are often positive, the practicalities and perceived financial implications associated with IPM adoption can act as barriers.[29,30] Gaps may also exist between actual and perceived practices i.e. farmers may believe they are practicing IPM when in reality they are not, and vice versa.[16,31] Such a phenomenon may have contributed to differences between weightings awarded to certain questions at the workshop, and then later at the stakeholder survey. Whilst the perceived importance of the majority of questions as contributors to IPM were not viewed differently amongst the different stakeholder groups, differences did exist for perceived importance of some of the lesser contributors, i.e. factors influencing variety choice and membership of discussion groups. Likewise, with the exception of the question relating to cereal rotations (Question 4), stakeholders from the different countries ranked questions in equal importance. Stakeholders from the island of Ireland and England considered the question on rotations to be relatively more important for IPM than did stakeholders from Scotland. This could be due to the dominance of spring barley in the Scottish arable sector. With a single, premium crop dominating the market, alternative suitable cropping options are potentially reduced and, thus, growing different crops in rotation may not be considered a viable option. Regarding the other differences between the two stakeholder groups, those stakeholders who have a commercial interest in pest management weighted discussion group membership as being more important for IPM than the stakeholder group who are unlikely to have a commercial interest in pest management. This indicates that they recognise a greater value in this form of knowledge exchange which may lead to an increase in adoption of IPM practices. There were also differences in the weights awarded to the question on varietal selection, with stakeholders who have a commercial interest in pest management weighting the question more important for IPM. Selecting varieties based on their disease resistance rating, in particular, has long been promoted as a major tool for disease management. Scottish barley growers have claimed to select and grow disease resistant varieties, yet on consulting the Agriculture and Horticulture Development Board (AHDB) disease resistance ratings, the varieties grown are often rated much weaker than others for the major disease threats such as rhynchosporium.[31] This finding was mirrored in the survey of UK growers undertaken by ADAS consulting limited.[16] The lower weighting awarded to this question at our expert workshop could have been, in part, due to discussions involving stakeholders in Ireland who may consider themselves restricted in their choice of varieties due to a lack of suitability of commercial cultivars to Irish growing conditions owing to an absence of cereal breeding programmes in Ireland. The fact that these differences were not observed when investigating differences in weighting between the stakeholders from different countries may suggest that this may, in fact, be an artefact of the consultation method. As such only the aggregate score from the survey panel of stakeholders was used in the creation of the IPM metric.

By combining the targeted survey of arable farms with a stratified sampling method and the consensual development of a metric to capture IPM in arable production systems, it is anticipated that current levels of IPM adoption, and perception of it, in both the UK and Ireland can be determined and if the survey were to be repeated changes in adoption could be tracked. If the barriers or, indeed, the limitations of IPM in such systems are to be identified, this is a key step in the process. Although all respondents were considered to be practicing IPM (of the 225 respondents all scored >20 of a total score of 100), a wide range of scores within a broadly normal distribution was recorded. This distribution opens the possibility of identifying such barriers/limitations to further adoption. This process could be further enhanced by including, in subsequent analysis of drivers and barriers, various questions relating to IPM perception and/or socioeconomic data. As the data set obtained for both Ireland and England contained official national farm business survey statistics, it may also be possible to delve further into financial components of the farm enterprise that may directly or indirectly influence IPM practice.

The applicability of the metric to arable farming in other temperate zone countries is as yet, unknown. However, it is foreseeable that the metric and the phenomena it captures will be relevant elsewhere. Using the approach reported here, modification of the metric, by re-weighting questions based on expert opinion, according to the challenges and opportunities for IPM in each country, may render the metric widely applicable. This would result in a locally-weighted IPM metric approach. Furthermore, the process by which the survey and metric were developed can be easily adapted to cover additional crops and cropping systems requiring different approaches to pest control.

Despite a considerable body of legislation relating to pesticide practice and use, both nationally and at EU level, there has been, to date, no agreed upon metric available that would allow the measurement of the effectiveness of IPM at reducing pesticide usage or increasing adoption of sustainable crop protection methods. The study reported here provides a novel and useful metric to assess the extent of adoption of IPM practices and the possible development of a sustainable plant protection system for arable cropping in temperate climates.

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Table 1: The eight principles of IPM and their components as defined by the European Union, (2009b) and expanded by Barzmann et al. (2015). Also, the alignment of questions from the study questionnaire with each principle.

Principle	Description	Components	Survey Questions[1]
1.	Prevention and suppression	Crop rotation, cultivation techniques, varietal resistance, phytosanitary measures, beneficial organisms	3, 5, 7, 8 (a, b, c), 9
2.	Monitoring	Field monitoring, forecasting, seeking expert advice	8 (a, b, c,), 9, 14
3.	Informed decision making	Protection measures based on expert advice, action thresholds	8 (a, c) , 9,
4.	Non-chemical methods	Preference for biological and physical control methods over chemical.	3, 5, 7, 8 (a, b, c)
5.	Pesticide selection	Using pesticide that minimise negative effects on human health and the environment	8 (a, b, c)
6.	Reduced pesticide use	Reduced doses, reduced application frequency considering the risk for development of pesticide resistance	8 (a, b, c)
7.	Anti-resistance management	Alternation/mixing pesticides containing multiple modes of action.	9
8.	Evaluation	Assessment of the efficacy of control treatments used to inform future management decisions.	9

[1]Only questions used to generate the IPM score are highlighted. The full questionnaire can be found in Supplementary materials.

Table 2: Number of participants in the initial stakeholder workshop and subsequent stakeholder consultation panel, their principal occupation and their stakeholder class.

[1]Stakeholder workshop held on June 27th 2017 at Teagasc Oak Park, Ireland.

Principal Occupation	Stakeholder Workshop[1]	Stakeholder Panel[2]	Stakeholder class for weighting analysis
Farmer	2	18	Farmer
Independent Agronomist	2	11	Independent Agronomist
Merchant agronomist	1	8	Merchant agronomist
Researcher	5	0	Other
Agricultural college lecturer	0	9	Other
Agricultural Regulator	1	0	Other
Total	11	46	

[2]Stakeholder panel completing the survey from which the final weighting were derived.

Table 3: Number of stakeholder panel participants from each country involved in construction of the IPM metric.

Country	Participants
England	11
Ireland	12
Northern Ireland	4
Scotland	19

Table 4: Overview of respondents to the survey and means of data collection in each of the participating countries.

	England	Scotland	Northern Ireland	Republic of Ireland
Method of data collection	Farm Business Survey recorders	Postal	Census and Single Farm Payment data recorders	Teagasc National Farm Survey recorders
Sample size	53	43	71	58
Percent owned	54.6	83.7	97.2	68.6
Farm size (ha)	202.19	361.5	109.2	101.07
Of which arable (ha)	135.32	198.2	59.1	63.6

Table 5: Relative contribution of each question (% weight) awarded by stakeholders at the workshop (n=11), the survey panel (n=46), and the final combined set.

Specific question within the survey	Weights produced at workshop	Final set of weights (produced by survey panel)	Variation from the workshop weights (%)
Q3. Proportion of land in continuous cereal production	10	11.46	14.6
Q4. Why do you typically use an arable rotation?	10	11.78	17.8
Q5. What influences your choice of cereals variety?	5	8.77	75.4
Q8. What preventive measures are used to control weeds, disease and insects/molluscs?	55	46.93	14.7
Q9. What factors do you consider when deciding on your pest management plan?	15	15.24	1.6
Q14. Membership of an agronomy / crop discussion group?	5	5.82	16.4
Total	100	100	

Table 6: Correlation of component questions with overall IPM score and Cronbach's Alpha test.

Specific question within the survey	Correlation with total (standardised scores)	Alpha[1]
Q3. What proportion of land on your farm is in continuous cereals production?	0.412456	0.720713
Q4. Why do you typically use an arable rotation?	0.395048	0.724010
Q5. What influences your choice of crop variety?	0.407890	0.721580
Q8a. What preventive measures are used to control weeds	0.500479	0.703677
Q8b. What preventive measures are used to control diseases	0.602404	0.683182
Q8c. What preventive measures are used to control insects	0.471783	0.709298
Q9. What factors do you consider when deciding on your pest management plan?	0.362842	0.730049
Q14. Membership of an agronomy / crop discussion group?	0.343871	0.733569

[1] High Alpha scores (>0.7) for a specific question indicate a high correlation of that question with the overall score.

Table 7: Impact of stakeholder occupations on the specific weighting for each of the identified questions relating to IPM practice.

Specific question within the survey	Difference between groups[1]	T value	Variances	Pr>T
Q3. What proportion of land on your farm is in continuous cereals production?	-0.9535	-0.40	Equal	0.6943
Q4. Why do you typically use an arable rotation?	1.5240	0.76	Equal	0.4535
Q5. What influences your choice of crop variety?	2.9339	1.71	Unequal	0.0130
Q8. What preventive measures are used to control weeds, disease and insects/molluscs?	-4.6727	-1.16	Equal	0.2522
Q9. What factors do you consider when deciding on your pest management plan?	0.3784	0.25	Equal	0.8070
Q14. Membership of an agronomy / crop discussion group?	1.3303	1.71	Unequal	0.0041

[1]Groups as per Table 2.

Table 8: Impact of stakeholder country of origin on the specific weighting awarded for each of the identified questions relating to IPM practice.

Specific question within the survey	F value	Pr > F	R-Square
Q3. What proportion of land on your farm is in continuous cereals production?	0.90	0.4128	0.040318
Q4. Why do you typically use an arable rotation?	2.76	0.0743	0.113889
Q5. What influences your choice of crop variety?	0.78	0.4631	0.035174
Q8. What preventive measures are used to control weeds, disease and insects/molluscs?	1.70	0.1942	0.073393
Q9. What factors do you consider when deciding on your pest management plan?	0.35	0.7067	0.016016
Q14. Membership of an agronomy / crop discussion group?	0.06	0.9397	0.002890

Figure 1. Overall approach used to develop and validate the IPM metric, divided into seven tasks.

Figure 2. Distribution of sample by IPM score.

Supplementary materials.

Appendix 1: Best arable farming practice survey

This survey is part of a wider study which aims to improve farmer awareness and adoption of Integrated Pest Management (IPM) in the UK and Ireland. IPM is widely regarded as offering benefits to farmers in their efforts to control pests, including reducing pollution risk and costs.

The study objectives will be achieved by:

1. collection of information (through this survey) on current IPM practices in arable farming;
2. analysis of this information to identify best practice; and
3. transfer of this knowledge back to farmers and advisors through various knowledge transfer activities, including publications in trade magazines.

The findings will be reported at a group level only i.e. data collected from individual growers, discussion groups, facilitators or advisors will not be published. This study is not concerned with, and does not collect data relating to, farm support payments, Cross Compliance activities or Agri-Environment schemes. The survey should take between 10-15 minutes to complete and you should not need to consult farm records.

All data supplied will be treated in the strictest confidence, will be used solely for the purposes of this study, and will not be passed on to third parties. If you submit a completed survey form you can withdraw at any time. If you should wish to withdraw please contact me using the contact information provided on this letter. Please retain this letter for your records. This survey has passed all ethical clearance procedures at the co-ordinating institution.

Thank you for participating in our survey.

Best arable farming practice survey

- *Please answer the questions as accurately as you can. Good data is needed to provide reliable advice back to farmers and advisors.*
- *Please note that the term ‘**pests’ relates to diseases, weeds and invertebrate pests** (insects and molluscs). Similarly, ‘**pesticides’ refers to fungicides, herbicides, insecticides and molluscicides**.*
- *Please read question instructions carefully as the type of response required may vary from question to question.*
- *Please complete the survey in full.*

1. How familiar are you with Integrated Pest Management (IPM)? *Please tick one answer only.*

- ☐ Not at all familiar (if this answer, please move direct to Question 3.)
- ☐ Somewhat unfamiliar
- ☐ Moderately familiar
- ☐ Familiar
- ☐ Very familiar

2. Which of the following factors do you consider to be important components of IPM? *Please tick one box in every row.*

	Very unimportant	Not important	Neither important or unimportant	Fairly Important	Very important
Preventative measures (hygiene practices such as cleaning equipment, sourcing clean seed etc.)					
Biological control methods (growing competitive crops, beetle banks etc.)					
Cultural control methods (altering drilling dates to reduce disease, increasing seeding rate to control weeds, rotating crops etc.)					
Monitoring and surveillance of insect pest, weed and disease levels (crop walking, reacting to high disease/pest pressure alerts etc.)					
Minimum use of pesticides					

3. What proportion of your land is in continuous cereal production i.e. growing cereals on the same land for 5 or more consecutive years without growing a break crop (e.g. oilseed rape, beans, peas, grass)? *Please circle the relevant proportion below.*

None	1 – 25%	26 – 50%	51 – 75%	76 – 100%

4. Why do you practice continuous cereal production? *More than one answer may be provided.*

- ☐ I don’t practice it
- ☐ Land unsuitable for other crops
- ☐ Climate unsuitable for other crops
- ☐ No access to machinery/equipment/storage facilities required to grow non-cereal crops
- ☐ Greater risks associated with growing different crops
- ☐ End-market requirements

5. **If you typically use an arable rotation, why do you do this?** *Please skip this question if you do not practice a rotation. Otherwise please answer every row.*

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
To control weeds					
To control disease					
To control insect pests					
To improve and maintain soil structure and fertility					
To spread financial risks					
Largely because it's necessary to comply with regulations					

6. **Please indicate your tillage practice.** *More than one answer may be provided.*

☐ Regular ploughing ☐ Direct drilling (no tillage) ☐ Strip tillage

☐ Reduced (minimum) tillage ☐ Rotational ploughing (every few years)

7. **What influences your choice of cereal or oilseed variety grown?** *Please tick the factors you consider most important for each crop you grow. More than one answer may be provided.*

	Important factors
Recommended lists (where available)	
Availability of seed	
Advisor recommendation	
End-market	
Disease resistance	
Weed competitiveness	
Insect pest resistance	
Abiotic stress resistance (e.g. drought/flooding/cold tolerance)	
Yield potential	
Quality potential	
Consistency of performance	

8. **Which preventative measures do <u>you</u> currently employ to control the introduction and spread of pests on <u>your farm?</u>** *Please tick all the boxes below that apply.*

a) <u>To control weeds</u>

☐ Stale seedbeds
☐ Full inversion ploughing to control low dormancy weeds
☐ Min-till to control high dormancy weeds
☐ Pre-emergence herbicide applications
☐ Spot spraying weeds (if necessary)
☐ Hand rogueing/hoeing weeds
☐ Manage headlands differently to remainder of field
☐ Fields with high weed levels are harvested last

- ☐ Crop inspections, please indicate frequency; once or twice per *(please circle one of the following options):*

week	month	season

b) To control disease

- ☐ Grow resistant varieties
- ☐ Use certified seed
- ☐ Test non-certified seed and treat if required
- ☐ Regularly test soils for soil borne pathogens
- ☐ Use seed treatments to control disease
- ☐ Crop inspections, please indicate frequency; once or twice per *(please circle one of the following options):*

week	month	season

c) To control insects, nematodes and molluscs

- ☐ Encourage beneficial insects through planting habitat
- ☐ Avoid broad spectrum insecticides
- ☐ Use seed treatments
- ☐ Preparations for control of molluscs e.g. avoiding direct drilling or preparation of fine seed bed
- ☐ Regularly monitor above ground pest populations
- ☐ Set action thresholds
- ☐ Regularly test soils for nematodes
- ☐ Regularly test soils for insect pests
- ☐ Frequently clean harvesting and storage equipment
- ☐ Crop inspections, please indicate frequency; once or twice per *(please circle one of the following options):*

week	month	season

9. What factors do you consider when deciding on a pest management plan at the start of the season?
Please tick those that apply.

- ☐ I don't use pest management plans
- ☐ Crop walking data from last season, used to assess the performance of various control measures
- ☐ Technical research on pesticide product efficacy
- ☐ Weed maps, created and monitored for changes between seasons
- ☐ Yield maps, used to identify areas requiring specific attention
- ☐ Cost-benefit analysis of management options
- ☐ End-market requirements
- ☐ Variety resistance
- ☐ Soil borne pathogens
- ☐ Position in rotation
- ☐ Anti-resistance strategies
- ☐ None of the above
- ☐ Other (please specify)____________________

10. What factors influence your decision to adjust your spray programme (e.g. changes in timings, rates, products) throughout the season? *Please answer every row by ticking in one of the columns.*

	No/low influence	Moderate influence	High influence
Growth stage of the crop			
Calendar date			
Weather conditions and forecasts			
Crop monitoring information, such as CropMonitor (where available)			
Predictions of Decision Support Systems (where available)			
Observed levels of pest presence in the field			
Advisor recommendation			
Actions of/advice from other farmers in the area			
None of the above, I operate a fixed spraying programme			

11. Name the specific pests (weeds, diseases, insects or molluscs) which you see as being of the greatest concern to crop production on your farm. *Start with 1 = greatest concern.*

Current threat

1.	
2.	
3.	

Future threat (5+ years' time)

1.	
2.	
3.	

12. How valuable are the following sources of pest (weeds, diseases, insects or molluscs) management advice?
Please rank the top 3 sources of pest advice starting with 1 being the most valuable. After listing the top 3, please leave the rest blank.

	Rank top 3 sources
Open days/crop walks	
Farmer discussion groups	
Other farmers (not including discussion groups)	
Independent agronomist	
Chemical company representative	
Merchant agronomist	
Contractors	
Past experience	
Farming press	
Other (please specify)	

13. Which of the following statements best describes your relationship with your main crop protection advisor? *Please tick one only.*

- ☐ I rely on them and act on their suggestions
- ☐ I tell them what I want from them and they respond to meet my wishes
- ☐ We decide on the pest management strategy together
- ☐ I listen to their advice but will always consult other sources of information
- ☐ I listen to their advice but adjust if needed when in the field
- ☐ I don't use an advisor

14. Are you a member of an agronomy or crop discussion group? *Please tick.*

- ☐ Yes
- ☐ No

If Yes, please specify

____

15. What is your position on the farm? *More than one box may be ticked.*

- ☐ Owner
- ☐ Tenant
- ☐ Farm worker
- ☐ Contractor

16. How much land do you farm or manage?

Total area: ____________ hectares:

Of which – arable ____________ hectares

grassland ____________ hectares

rough grazing ____________ hectares

fallow ____________ hectares

biodiversity scheme ____________ hectares

How much of the area farmed is rented/leased: ________ hectares

How much of the area farmed is shared: ______________ hectares

17. Which description best fits your farming type? *Please tick one box only.*

- ☐ Predominantly arable
- ☐ Predominantly livestock
- ☐ Mixed
- ☐ Horticulture

18. Your age. *Please circle.*

20 - 30	31 – 40	41 - 50	51 – 60	61 and over

19. Which qualifications have you achieved? *Please tick one only.*

- ☐ Certificate in farming (e.g. BASIS)
- ☐ O levels/GCSEs/Junior certificate
- ☐ A levels/Leaving certificate
- ☐ Diploma
- ☐ Bachelor’s Degree
- ☐ Higher degree (Master’s degree/PhD)

20. Does the main decision-maker of the farm business have an off-farm income source? *Please tick.*

- ☐ Yes
- ☐ No

21. Is there a successor identified to take over the farm business? *Please tick.*

- ☐ Yes
- ☐ No
- ☐ Uncertain at present

22. Are you involved in a scheme that promotes biodiversity e.g. Countryside Stewardship, LEAF, AEOS, GLAS? *Please tick.*

- ☐ Yes
- ☐ No

Thank you very much for your help in our research.

The information you have provided will be treated in the strictest confidence by us.

Appendix 2: Guidance for stakeholders attending the workshop designed to create an initial weighting system for IPM adoption.

Best arable farming practice survey

This survey is part of a wider study which aims to improve farmer awareness and adoption of Integrated Pest Management (IPM) in the UK and Ireland. IPM is widely regarded as offering benefits to farmers in their efforts to control pests, including reducing pollution risk and costs.

The study objectives will be achieved by:

1. collection of information (through this survey) on current IPM practices in arable farming;
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All data supplied will be treated in the strictest confidence, will be used solely for the purposes of this study, and will not be passed on to third parties. If you submit a completed survey form you can withdraw at any time. If you should wish to withdraw please contact me using the contact information provided on this letter. Please retain this letter for your records. This survey has passed all ethical clearance procedures at the co-ordinating institution.

Scoring system

Today we'll be collectively creating a point scoring system to quantify IPM adoption. The approach will involve weighting questions according to how important we decide they are for IPM. The method will involve allocating a total of 100 points over the questions we've pre-selected to contribute towards the point scoring system. These questions (Q3, 5, 7, 8, 9, 14) are highlighted in the survey.

- For Q3, 5, 7, 9, and 14 we will discuss the importance of the options, come to a consensus and rate them on a 1-5 scale.

- Q8 is probably the most important question in the set as it captures the IPM control measures actually being undertaken. For this question we will weight the individual control measures for importance using a weighting scale that really allows individual measures to stand out. So, the weighting for Q8 options will involve allocating 100 points over all the measures.

Thank you for your contribution to this project.

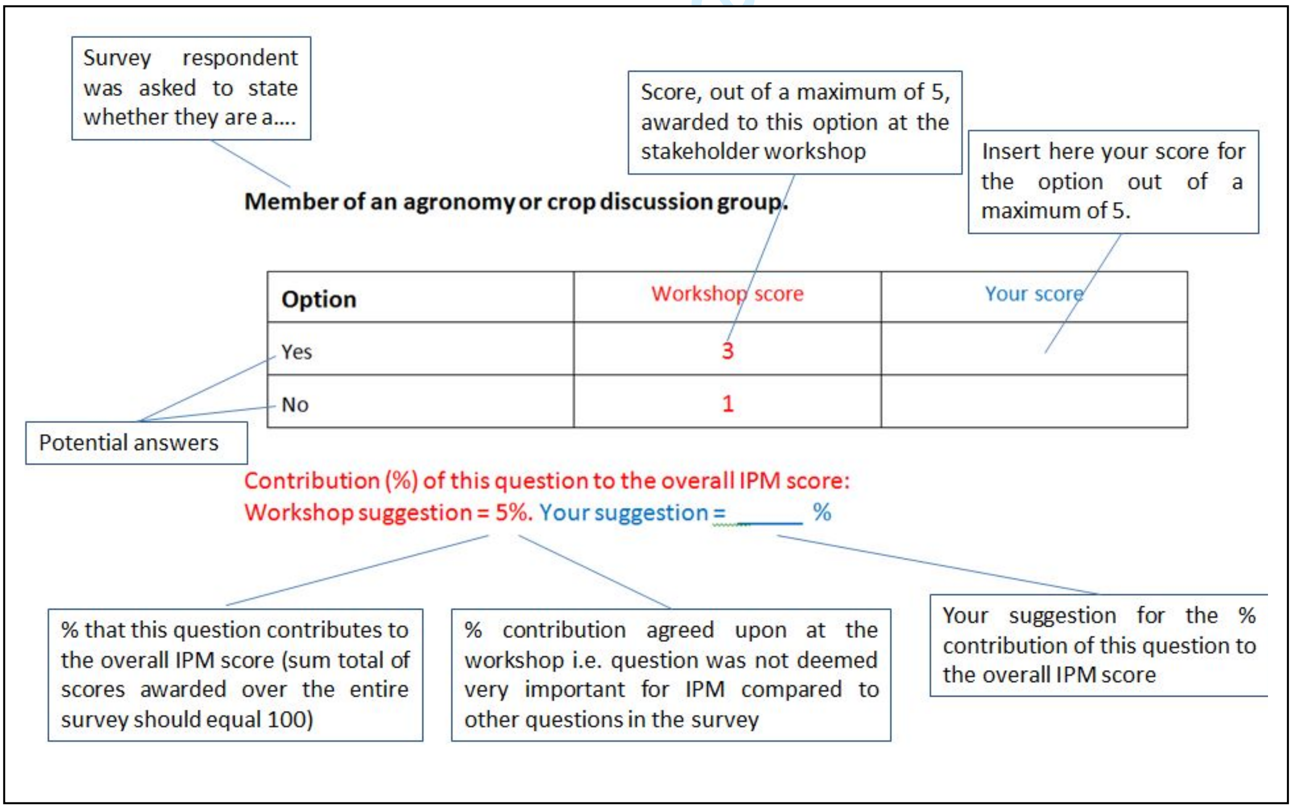
Appendix 3: Stakeholder guidance letter for consultation on scoring system for assessing farmers' IPM adoption

Best arable farming practice study

In early 2017, researchers from four institutions surveyed arable farmers in the UK and Ireland. This survey collected information on current Integrated Pest Management (IPM) practices in arable farming. To facilitate our analysis of the responses we would like you to help us identify what best IPM practice is.

At a recent workshop, stakeholders were asked to score each survey question (and options within questions) relating to IPM practice. By creating an IPM scoring system, we can apply these scores to the survey responses and, in this way, rate each respondent in terms of their IPM activity. We need your help in validating the proposed scoring system. Below is a worked example showing what we want you to do.

At the workshop, agronomic and IPM issues relating to key survey questions were discussed in detail to capture the contribution (%) of each to the overall IPM score. Separate scores are applied on a 1 to 5 scale (from 1 being not at all important to 5 being very important) to capture the relative importance of specific management activities within each question. Initial scores for each possible answer were suggested, and were then agreed upon during the discussions. If a clear consensus was not reached, a vote decided the final score. Survey participants' responses to each question will determine what share (%) of the maximum contribution for the question makes to the IPM score.



Option	Workshop score	Your score
Yes	3	
No	1	

To validate the proposed scoring system, we are consulting stakeholders to ask them to modify our scores if they wish. We would appreciate it if you could take the time to consider the questions attached, together with the scores given to each at the workshop. Please examine each question and all possible answers and adjust the scores as you see fit. Once you are finished, please send the document back to us.

This is part of a wider study aimed at improving farmer awareness and rates of adoption of IPM. Once we have identified best practice, we will communicate with farmers and advisors through various knowledge transfer activities. Thank you for your contribution to this project. Your responses will remain entirely confidential and individual answers will not be identified in any report we may produce.

Dr Henry Creissen Henry.creissen@sruc.ac.uk

Stakeholder consultation on scoring system for assessing farmers' IPM adoption

NB: In this file the final weights for sub-elements within each question have been inserted in the columns labelled 'Your score', which were of course blank when the file was distributed to the stakeholder panel.

Instructions:

- The original scores from the stakeholder workshop are shown in red. Please insert your score in the blue columns next to the workshop scores. Please indicate the relative contribution of each question to the final IPM score which should total to 100% for all questions combined.
- Please rate each option within each question on a 1 to 5 scale with 1 being not at all important for IPM, to 5 being very important for IPM.

Key questions:

3. Proportion of land in continuous cereal production i.e. cereals on the same land for 5 or more years without a break crop (e.g. OSR, beans, grass)?

Option	Workshop score	Your score
None	5	4.93
1 – 25%	5	4.46
26 – 50%	3	2.98
51 – 75%	2	1.98
77 – 100%	1	1.13

Contribution (%) of this question to the overall IPM score:
Workshop suggestion = 10%. Your suggestion = 11.51%

5. If you typically use an arable rotation, why do you do this?

	Strongly disagree		Disagree		Neither agree or disagree		Agree		Strongly agree	
Option	Work-shop score	Your score	Work-shop score	Your score	Work-shop score	Your score	Work-shop score	Your score	Work-shop score	Your score
To control weeds	1	0.87	2	1.61	3	2.39	4	3.26	5	4.13
To control disease	1	0.95	2	1.63	3	2.39	4	3.29	5	4.13
To control insect pests	1	0.92	2	1.63	3	2.39	4	3.18	5	4.03
To improve and maintain soil structure and fertility	1	0.97	2	1.63	3	2.45	4	3.29	5	4.15
To spread financial risks	5	3.34	4	2.89	3	2.32	2	1.47	1	1.18
Largely because it's necessary to comply with regulations	5	3.53	4	2.92	3	2.24	2	1.55	1	1.18

Contribution (%) of this question to the overall IPM score:
Workshop suggestion = 10%. Your suggestion = 11.84 %

7. Influences on choice of cereal or oilseed variety grown?

Option	Workshop score	Your score
Recommended lists (where available)	5	4.41
Availability of seed	1	1.67
Advisor recommendation	2	3.09
End-market	1	2.48
Disease resistance	5	4.59
Weed competitiveness	2	2.59
Insect pest resistance	2	2.78
Abiotic stress resistance (e.g. drought/flooding/cold tolerance)	2	2.22
Yield potential	1	2.65
Quality potential	2	2.80
Consistency of performance	3	3.52

Contribution (%) of this question to the overall IPM score:
Workshop suggestion = 5%. Your suggestion = 8.80 %

8. Preventative measures currently employed to control the introduction and spread of pests on <u>their farms?</u>

a) <u>To control weeds</u>

Option	Workshop score	Your score
Stale seedbeds	5	4.57
Full inversion ploughing to control low dormancy weeds	5	4.24
Min-till to control high dormancy weeds	5	4.52
Pre-emergence herbicide applications	3	3.65
Spot spraying weeds (if necessary)	5	4.26
Hand rogueing/hoeing weeds	5	4.39
Manage headlands differently to remainder of field	5	4.33
Fields with high weed levels are harvested last	4	3.57
Weekly crop inspections	5	4.52
Monthly crop inspections	3	2.72
A single crop inspection per season	1	1.09

b) To control disease

Option	Workshop score	Your score
Grow resistant varieties	5	4.85
Use certified seed	5	4.20
Test non-certified seed and treat if required	5	4.70
Regularly test soils for soil borne pathogens	2	2.63
Use seed treatments to control disease	5	4.63
Weekly crop inspections	5	4.67
Monthly crop inspections	4	3.24
A single crop inspection per season	1	1.02

c) To control insects, nematodes and molluscs

Option	Workshop score	Your score
Encourage beneficial insects through planting habitat	4	3.93
Avoid broad spectrum insecticides	5	4.57
Use seed treatments	5	4.70
Preparations for control of molluscs e.g. avoiding direct drilling or preparation of fine seed bed	5	4.50
Regularly monitor above ground pest populations	5	4.87
Set action thresholds	5	4.61
Regularly test soils for nematodes	3	3.04
Regularly test soils for insect pests	1	1.63
Frequently clean harvesting and storage equipment	5	4.89
Weekly crop inspections	5	4.61
Monthly crop inspections	4	3.15
A single crop inspection per season	1	1.02

Contribution (%) of this question to the overall IPM score:
Workshop suggestion = 55%. Your suggestion = 47.13%

9. Factors considered when deciding on a pest management plan at the start of the season.

Option	Workshop score	Your score
I don't use pest management plans	0	0.48
Crop walking data from last season, used to assess the performance of various control measures	5	4.52
Technical research on pesticide product efficacy	4	4.35
Weed maps, created and monitored for changes between seasons	4	3.98
Yield maps, used to identify areas requiring specific attention	4	3.96
Cost-benefit analysis of management options	2	2.80
End-market requirements	2	3.02
Variety resistance	4	4.46
Soil borne pathogens	5	4.50
Position in rotation	5	4.83
Anti-resistance strategies	5	4.89
None of the above	-5	-1.11

Contribution (%) of this question to the overall IPM score:
Workshop suggestion = 15%. Your suggestion = 15.30%

14. Member of an agronomy or crop discussion group.

Option	Workshop score	Your score
Yes	3	3.39
No	1	0.87

Contribution (%) of this question to the overall IPM score:
Workshop suggestion = 5%. Your suggestion = 5.85 %

Appendix 4:

For survey data input file see separate Excel file.

Appendix 5: Normal probability-probability plot of the data

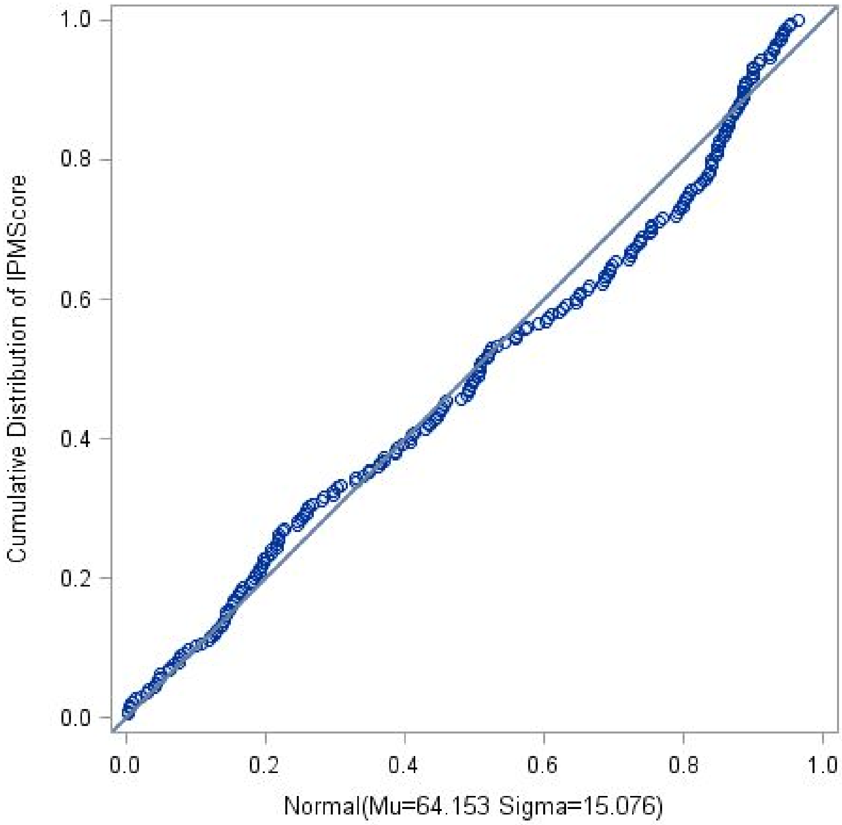


Figure shows a Normal probability-probability plot indicating that the distribution of scores over the IPM metric key variables was close to normal.