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Integrated Pest Management adoption by grain farmers in Norway: A novel index method

Åsmund Lægreid Steiro[a,*], Valborg Kvakkestad[b], Tor Arvid Breland[a], Arild Vatn[c]

[a] Department of Plant Sciences, Norwegian University of Life Sciences, P.O. Box 5003 NMBU, 1432, Ås, Norway
[b] Norwegian Institute of Bioeconomy Research, Ås, Norway
[c] Department of International Environment and Development Studies, Norwegian University of Life Sciences, Ås, Norway

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ABSTRACT

Within the last decade, implementing eight key principles of Integrated Pest Management (IPM) has become mandatory for all professional users of pesticides in the European Union (EU) and European Economic Area (EEA). Meanwhile, evidence of the level of implementation is lacking. In this study, the adoption of IPM principles among Norwegian grain farmers was measured using a novel IPM index based on self-reported levels of performing IPM practices. Three IPM experts weighted the principles and practices included in the index. They found prevention and suppression to be the most important principle, followed by monitoring and decision-making, while pesticide selection and evaluation were deemed least important. A survey of 1250 farmers showed that the principles with the highest adoption rates were evaluation and anti-resistance strategies, while non-chemical methods and reduced pesticide use had the lowest adoption rates. The results support previous suggestions that more complex principles, requiring a larger set of practices, are less readily adopted than those that are less complex. Nevertheless, the index scores showed that most Norwegian grain farmers are extensively practicing IPM; 75% of the respondents obtained scores between 60 and 80 on a 100-point scale, with an average score of 68. In the Norwegian context, it is more relevant to discuss the varying use of IPM rather than how to increase adoption in general.

1. Introduction

Pest management is essential in any crop production system to prevent unacceptable reductions in crop quality and quantity caused by pest organisms. In this paper, the term “pest” includes plant pathogens, weeds and invertebrates. Introduction of large-scale use of chemical pesticides in the mid-1900s enabled farmers to efficiently control a wide variety of pests (Peshin and Pimentel, 2014). While use of chemical pesticides have been beneficial in many ways (Cooper and Dobson, 2007), it has also led to detrimental consequences for the environment, future opportunities for farming and human health (Millstone and Lang, 2013). Increased pesticide use contributes to a plethora of issues such as reduced biodiversity (van der Sluijs et al., 2015), smaller pollinator insect populations (Bijleveld van Lexmond et al., 2015) and poor farmer health (Lamichhane et al., 2016; Pimentel and Greiner, 1997). Therefore, integrating pest control into a cropping system less dependent on pesticides is necessary to ensure sustainable food production (Barzman et al., 2015; Chandler et al., 2011).

Integrated Pest Management (IPM) is a strategy for controlling populations of harmful organisms in crop production systems while reducing the associated environmental, economic and human health risks (Lefebvre et al., 2014). If optimally managed, this strategy can be used to improve the sustainability of crop production systems by reducing the negative impacts of chemical inputs while maintaining economically acceptable yield levels (Lamichhane et al., 2016; Lechenet et al., 2014, 2017). Furthermore, IPM has been endorsed as the future paradigm for crop protection by many national and intergovernmental bodies (Stenberg, 2017). In the EU, since 2014, all professional users of pesticides are obliged to follow the eight general principles of IPM as described in the Framework Directive (2009/128/EC) for the Sustainable Use of Pesticides (further referred to as the Sustainable Use Directive). However, most member states had not fully operationalized or implemented the directive by the target date (Hokkanen, 2015; van der Sluijs et al., 2015). IPM is quite common in orchards and protected production systems, but its reported adoption still seems marginal in arable and field crops (Lefebvre et al., 2014). To what extent this limited

* Corresponding author.
E-mail address: asmund.steiro@nmbu.no (Å.L. Steiro).

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adoption is because farmers do not practice IPM or because of insufficient assessment methods is not known (Puente et al., 2011).

In Norway, the Sustainable Use Directive was implemented in 2015, and the new bylaw made IPM practices mandatory for all crop farmers (Norwegian Ministry of Agriculture and Food, 2015; Kvakkestad et al., 2020a). Norwegian authorities have in recent years intensified their efforts to increase the use of IPM by offering farmers more opportunities to improve their knowledge about how to reduce dependency on pesticides (Barzman et al., 2014). Recent studies suggest that Norwegian grain farmers have in fact increased their knowledge of IPM (Kvakkestad et al., 2020b; Kvakkestad and Prestvik, 2016). However, as knowledge does not necessarily lead to action, to assess the effectiveness of policies for promoting the use of IPM, there is a need to investigate to what extent improved knowledge about IPM among Norwegian grain farmers is reflected in practice.

Several attempts to measure the use of IPM have been made across various regions and crop types, but the nature of IPM as a generic concept with multiple context-specific interpretations makes such measurements very difficult (Ehler, 2006). Assessment methods from a number of countries have included measuring the adoption of selected IPM practices and technologies (Chaves and Riley, 2001; Jayasooriya and Aheeyar, 2016; Sharma et al., 2010; Whitehouse, 2011), investigating components of IPM (Bailey et al., 2009; Farrar et al., 2016a, 2016b; Puente et al., 2011), using an IPM index (Creissen et al., 2019; Hammond et al., 2006) or simply by asking farmers which pest management strategy they use (Blake et al., 2007; Mzoughi, 2011). Most of these adoption studies have been conducted in the U.S. or in developing countries and may not be directly transferrable to the EU context. As Parsa et al. (2014) showed, obstacles to adopting IPM in developing countries are different from those faced in high-income countries. Consequently, there is a need to measure IPM adoption with a tool taking the local context into account.

The objective of this research was to develop a novel IPM index, based on the eight principles of IPM and formulated such that it could be adapted to different contexts. Further, the aim was to apply the index to explore 1) to what extent are Norwegian grain farmers practicing IPM, 2) which of the eight principles of IPM in the Sustainable Use Directive the farmers have adopted the most and 3) where is the largest potential to increase adoption? The research was based on a survey of grain farmers in southeast Norway to explore how they manage their pest situations. Regarding context-specificity of the index (i.e., selection and weighting of practices), IPM experts were consulted. This study was conducted during the winter and spring of 2017/18, more or less simultaneously to that of Creissen et al. (2019), who developed an assessment method which is similar to our approach. However, at the time of development, neither parties were aware of each other and the approaches were thus developed independently.

2. Methods

The survey was designed to measure farmers' use of practices deemed important indicators of IPM use. The survey responses were then used to calculate IPM index scores by using a weighted summation of measured practices and principles. In this chapter we first describe the farmers' local context before we present how the elements of the index were decided, and the scoring principles for the index. We then describe the survey design and how it was conducted.

2.1. The Norwegian grain farming context

Norwegian grain production is characterized by relatively small units producing mostly cereal grains for the domestic market with 70 percent being part-time farmers (Statistics Norway, 2018a). Norway has one of the world's most extensive policies for agricultural payments with high border protection to compensate for disadvantages regarding climatic conditions and to ensure production of collective goods (Kvakkestad et al., 2015). The country has an active policy for reducing risks from pesticides since the 1990s, and its pesticide consumption is low compared to other European countries (Eurostat, 2018). In 1999, an environmental tax on pesticides was introduced, taxing pesticides according to health and environmental risks. Certification has been compulsory for professional users of pesticides since 1997. An electronic risk warning system (VIPS) that provides forecast models for pests and diseases and a special application for dealing with weeds in cereals has been available for all farmers since 2001. A relatively large share of Norwegian grain farmers are members of the Norwegian extension service that provides advice on pest management and IPM. The extension service cooperates closely with agricultural research institutes and is partly funded by the Ministry of Agriculture and Food and partly by membership fees from farmers.

2.2. The IPM index

The choice of practices to include in the index was based on practices associated with the eight principles of IPM as listed in Table 1. To ensure that we included practices relevant for the Norwegian context, we reviewed literature, performed test interviews with members of the survey population and conferred with expert IPM academics and practitioners.

The index score is calculated on the basis of a weighted summation of farmers' practices. This is done in two steps. First, a score is calculated for each principle based on a weighted sum of scores on practices chosen to capture key aspects of each of the eight IPM principles, as described later. Next, the scores per principle are weighted and summed to calculate the total index score; see Equations (1) and (2):

$$Score\ principle_i = \sum_{j=1}^{n} \frac{(Practice_j * Weight_{jmax})}{Maximal\ score\ of\ principle_i} + \frac{(1 - Practice_j * Weight_{jmin})}{Maximal\ score\ of\ principle_i}, \quad (1)$$

$$Index\ score = \sum_{i=1}^{8} Score\ principle_i * Weight_i \quad (2)$$

"Score $principle_i$" refers to the score on $principle_i$, "$Practice_j$" refers to the score on the related practice, and "$Weight_{jmax/jmin}$" refers to the weights set for the practice. Data from the survey were entered into Eq. (1) as self-reported scores of each practice ("$Practice_j$"). As we mainly used a Likert scale for this assessment, the different questionnaire items

Table 1
The eight principles of IPM in the Sustianable Use Directive and examples of related generic practices (adapted from Barzman et al., 2015).

	Principles	Practices
I	Prevention and suppression	Crop rotation, adequate cultivation techniques, resistant cultivars, balanced fertilization, liming and irrigation/drainage.
II	Monitoring	Observations in the fields, scientifically sound warning, forecasting and early diagnosis systems.
III	Decision-making	Region and area-specific threshold values for intervention are essential.
IV	Non-chemical methods	Sustainable, non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.
V	Pesticide selection	If pesticides are necessary, they should be target specific and with limited side effects.
VI	Reduced pesticide use	The use of pesticides should be kept as limited as possible without increasing the risk of the development of resistance.
VII	Anti-resistance strategies	Strategies should be applied to maintain the effectiveness of products and may include rotating pesticides with different modes of action.
VIII	Evaluation	The success of the applied plant protection measures should be evaluated.

were translated into scores that were a fraction of 1 (e.g., a 5-point scale became 0, 0.25, 0.5, 0.75, 1). In order to avoid emphasizing certain principles inappropriately (e.g., the number of practices per principle varied), the score of each practice was divided by the maximal score of the principle, thus making 1.0 the maximum sum of Eq. (1).

The "max/min"-distinction of the weights of the practices was implemented because we assumed that certain practices are more essential than others in IPM. By setting a weight for minimum and maximum performance of a practice—e.g., using pest forecasting information—we could differentiate between cases where a practice would need to be only rarely used or used only on a limited part of the area, while in other cases a practice would need to be frequently used or on a large part of the area, to get desired results. This could be captured by defining small or large distances between the min and the max scores. A respondent reporting to perform a practice at level 2 on a 5-point scale would then receive a score of 0.75 times the weight of performing the practice minimally and 0.25 times the weight of performing the practice maximally. While linearity is a limitation, we found the gain from being even more sophisticated to be too small to defend the increased complexity.[1]

Three cereal advisors from the Norwegian agricultural extension service, hereafter referred to as IPM experts, were consulted before deciding which practices to include under each principle. The IPM experts were chosen due to their insight into the context-specific challenges of implementing IPM in practice in this region of Norway. They also determined the weights associated with the principles and the practices. To determine the weights, a variant of the Delphi-method, called Mini-Delphi (estimate-talk-estimate) was used. This method enables experts to collectively assess a set of questions and adjust their opinions based on structured discussions (Pan et al., 1996). The experts were first instructed to estimate weights individually. They were asked to assign weights to each principle, and thereafter to the practices selected under each principle according to how significant they considered the practice as indicator of the use of IPM in the local context. The experts were asked to assign the weight of "1", as a floor, to a) the least significant principle and b) to the least significant practice under each principle. Subsequently, they were asked to rank the other items according to these floors. No upper weight limit was set, such that an item weighted "2" is twice as significant as the least important item, and an item ranked "3" is three times as significant etc. The experts were asked to set two weights per practice; one weight was assigned for how significant performing the practice maximally is, and one weight was assigned for how significant not performing the practice is.

After the first round of estimation, which was done by each expert in isolation, a meeting was held where they could talk about their assigned weights. The goal of the meeting was not to establish a consensus on the estimation, but rather to clarify any misunderstandings regarding the instructions, or wordings of the items. Additionally, the experts were given the opportunity to discuss the particularities of the pest management practices and give reasons for their estimates. After the meeting, a final individual round of estimation was done, and the average weights from the three experts were calculated and used in the IPM index. The weights are reported in section 3.1. A detailed list of the calculation method is in Appendix C, which should be studied with the extended table of weights in Appendix B. Microsoft Excel was used as software to calculate the index scores.

Puente et al. (2011) warned against the method of using weighted sums of practices to measure the use of IPM primarily for two reasons; the first was that many previous attempts have divided the farmers in a binary fashion which does not reflect the complexity of IPM adoption; the second was that previous attempts at using weighted sums of practices have poorly addressed issues of weights and numbers of practices per aspect of IPM and thus arbitrarily landed on methods for calculating adoption rates. Addressing these warnings, we first designed the IPM index to measure the adoption of IPM as a continuous variable and relative only to itself. This means that there is no cut-off index score, which judges the farmers as either practicing IPM or not. Second, the number of practices used per principle was accounted for such that practicing any given IPM principle did not yield an unfair advantage over practicing another IPM principle.

2.3. Survey

In the survey, the farmers were asked to report their extent of performing practices related to each IPM principle on their land area of grain growing. Primarily, the extent of their practice was measured on two 5-point scales, one asking about the size of the area on which the practice is performed and the other how often the practice is performed. For both questions, the respondent was instructed to answer based on the average situation over the past three years. The relevant parts of the questionnaire are in Appendix A and the practices are reported in section 3.1.

The respondents were grain farmers in southeastern Norway[2] where 79% of the country's grain area is located and which accounts for 82% of the national grain production (Statistics Norway, 2018b). The respondents were randomly selected from a register of farmers applying for subsidy payments for the year of 2016 provided by the Norwegian Agricultural Agency. We surveyed grain farmers who grow grains on at least 10 ha to include only farmers where grain production had substantial economic importance. Due to the focus on IPM, only conventional farms or farmers with both organic and at least 10 ha of conventional production were surveyed. The application of these inclusion criteria reduced the number of the sample frame to around 6000 farmers. A request was added in the invitation letter asking the person in charge of the grain production on the farm to respond. Additionally, the opening question of the questionnaire enabled the inclusion of only those who reported managing the grain production on the farm. Furthermore, the 1000 farmers who had responded to a similar questionnaire in 2014 were excluded in order to avoid fatigue in the surveyed population.

Subsequently, 1250 farmers who passed the inclusion criteria were randomly selected to receive an invitation to participate in the survey. Distribution of the questionnaire was primarily done by sending the participants a link to the online questionnaire via e-mail (using the software Questback©). Those without an e-mail address, around 6% of the invitees, were given the option to participate via a mailed survey. As an incentive to answer, a lottery was hosted, where four of the respondents were randomly selected to receive a gift card valued at 5000 NOK each. The distribution of the survey started in November 2017 and after three rounds of reminders, the final responses were gathered in February 2018.

In total, 617 completed responses were registered. 27 invitees were removed from the sample, either because they reported no longer being a grain farmer, or due to a duplication of the invitations. This resulted in a response rate of 50.4%, which is high compared to similar studies both in Norway and in other regions. Informed consent was obtained from all individual participants included in the study. Compared to data retrieved both from Statistics Norway's (2017, 2018b, 2018c) public database and data provided by this agency on demand, our sample has characteristics similar to those of the actual grain farmer population in southeastern Norway. The mean age of the respondents was 53 years, 93% were male, and they had an average of 24 years of experience with grain farming. According to Statistics Norway, the average age of the population of grain farmers is 51 years and 89% are male. Furthermore,

[1] It would also be a challenge to define the form of this relationship with the necessary accuracy to make it meaningful.

[2] This includes the former counties of Østfold, Akershus, Hedmark, Oppland, Buskerud and Vestfold.

the farm income and occupation numbers are similar to the respondents' average farm income. Reported average farm income was 260 000 NOK, and 66% reported to be part-time farmers as compared to 280 000 NOK average farm income and 70% part-time farmers in the actual population. However, our sample had somewhat higher education level than the population; 35% of our sample reported having higher education compared to only 25% of the actual population. Furthermore, regarding the scale of the grain production and distribution of crop types, the respondents' characteristics were very similar to those of the actual populations. The respondents managed on average 45.1 ha of farmland with grain on average grown on 37.4 ha compared to 44.4 ha of farmland and 35.1 ha of grain for the actual population. The distribution of crops was similar in the two populations, with around 40% of the grain area used for barley, 29% for oats and 26% for wheat, leaving only around 5% for other grain species. Except for somewhat higher level of education and proportion of male farmers amongst the respondents, the sample can be assumed to represent the target population.

3. Results

First, the results of the development of the IPM index are presented, followed by responses to questions about measured practices related to each principle, which are listed and described. Finally, the scores of the index calculations are presented.

3.1. Weighted practices and principles included in the IPM index

The list of practices included under each principle and the average weights of the principles and practices assigned by the three IPM experts are shown in Table 2.

Principle I was ranked by the IPM experts as the most significant one for assessing the adoption of IPM. Principles II, III, IV and VI were weighted as being of 'medium' importance with only one weight point difference between the most and least important ones. Lastly, principles V, VII and VIII were ranked as less important.

For achieving principle I, using crop rotation, ploughing and growing resistant cultivars were about twice as important as using other tillage practices or trimming field edges. Direct sowing was weighted very low since it often leads to increased need for herbicides. To score these tillage practices, no minimum weight was assigned. Instead, we calculated an average score for all the reported tillage practices scaled to the weights assigned. The reason is that farmers reported the fraction of their area on which they performed the practice. In the case that a respondent did not report that their entire area involved the first three practices, the lacking fraction was covered by the "other tillage practices" category, which are mainly various types of harrowing. The experts deemed monocropped wheat to be slightly worse than monocropped barley, while avoiding monocropping (i.e., having crop rotation) was ranked as the most significant practice within this principle. Similar to the tillage practices, we ensured that the respondents were not awarded points for both avoiding monocropping wheat and barley on the same area. Additionally, we adjusted the crop rotation scores to fit the proportion of the area on which farmers grew wheat or barley. Since monocropping anything other than wheat or barley is rare among Norwegian grain farmers, for any area on which they did not grow wheat or barley, they were awarded full score for crop rotation.

Regarding the second principle, making field observations of fungal pathogens was deemed more important than making field observations of weeds before spraying. Also, not making field observations of fungal pathogen pressure was considered markedly worse than not making field observations of weeds before spraying. Making decisions based on pest models or advice from the extension service, the third principle, was highly rated by the IPM experts. However, during the mini-Delphi discussions, they explained that the crop-specific IPM guidelines are not that important. These guidelines are located on the websites of the Norwegian Institute of Bioeconomy Research and the experts explained

Table 2
Weights of the principles and chosen practices used in an IPM index measuring the use of IPM among Norwegian grain farmers.

Principles		$Weight_i$	Practices[question and response scale]	$Weight_j$ max	$Weight_j$ min
I	Prevention and suppression	8.0	-Spring ploughing[a]	6.3	–
			-Fall plouging[a]	7.7	–
			-Direct sowing[a]	1.7	–
			-Other tillage practices[a]	3.5	–
			-Avoiding monocropping barley in the same fields[a]	7.35	1.9
			-Avoiding monocropping wheat in the same fields[a]	7.35	1.7
			-Using cultivars with high resistance to fungal diseases[a]	6.0	2.3
			-Trimming field edges[a]	3.0	1.7
II	Monitoring	5.7	-Field observations for weeds before spraying with herbicides[b]	5.7	2.3
			-Field observations for fungal pathogen pressure before spraying with fungicides[b]	8.3	1.0
III	Decision-making	5.3	-Decide fungicide spraying based on pest models from an online decision support system (VIPS) or advice in newsletters from the extension service[b]	8.0	1.0
			-Get advice and knowledge about pest management from the extension service[c]	6.7	1.0
			-Get adivce and knowledge about pest management from crop-specific IPM-guidelines[c]	2.7	1.0
IV	Non-chemical methods	5.0	-Weed harrowing[a]	4.7	1.3
			-Manually remove patches of weeds[a]	4.3	1.0
V	Pesticide selection	1.3	-Importance of considering the environment when managing weeds and fungal diseases[d]	4.7	1.0
VI	Reduced pesticide use	4.7	-Spot spraying[b]	6.0	1.7
			-Choosing the lowest recommended label dose[b]	8.3	1.0
VII	Anti-resistance strategies	3.3	-Mixing remedies with different modes of action in order to prevent resistance development[b]	4.7	1.0
VIII	Evaluation	2.7	-Evaluating the effects of the pest management practices used[a]	4.0	1.0

[a] What is done on your grain area? Consider what has usually occurred the last three years. (1 = none of the area, 5 = the entire area).
[b] How often is the following performed on your grain area? Consider what has usually occurred the last three years. (1 = never, 5 = always).
[c] Where do you get advice and knowledge about pest management from? (0 = no, 1 = yes).
[d] Which conditions are important to you when you manage weeds and fungal diseases? (1 = not important, 7 = very important).

that farmers usually get information through other communication channels such as newsletters from the extension service and field days. For principles IV–VIII, the experts weighted the practices similarly apart from a strong emphasis on choosing the lowest recommended label dose.

When assessing the proposed questionnaire items related to principle V with test subjects and after confering with IPM experts, we discovered that this principle is so tied to decision-making and anti-resistance strategies that it is hard to isolate. Also, there are not that many remedy options to choose from and, therefore, it was difficult to formulate relevant questions directly related to remedy choice. Consequently, we substituted the proposed items with a proxy-question measuring the attitude towards considering the environment when performing pest management. This measurement uses a different scale (1–7) than the other questions (1–5). The IPM experts who set the weights also found this principle to be the least important, as they reported not being sure whether one farmer could perform this principle better than another, given the few options available.

3.2. The surveyed farmers' reported use of IPM practices

The results from the survey regarding farmers' practices are presented in Table 3. The number of responses varied mainly due to the option of not answering some of the questions.

The respondents reported that they till the soil primarily by either fall or spring ploughing, or a combination of both. Only one third of the farmers reported using just one of the tillage practices on all their grain area. In some cases, the scores on the tillage practice items did not account for their entire area. As indicated in the previous section, harrowing was assumed for these areas. This accounts for approximately 25% of the respondents. Only around 5% of these farmers used only these practices on more than a quarter of their area. Two percent of the farmers used direct sowing on all their area. A majority of the surveyed farmers reported avoiding monocropping of wheat or barley. Since these are two of the three most commonly grown grain types, it is likely that crop rotation is extensively practiced among Norwegian grain farmers. Growing resistant cultivars was reportedly used on most of the surveyed farmers' area, whereas trimming field edges was less commonly practiced; about half of the survey respondents reported that they did not perform this practice on any of their area.

Table 3
The surveyed Norwegian grain farmers' self-reported extent of using IPM-related practices.

Principle	Practices	Scale	Mean	Std dev	N
I	Spring ploughing	1–5	2.51	1.35	617
	Fall ploughing	1–5	2.94	1.37	617
	Direct sowing	1–5	1.16	0.66	617
	Growing barley three or more years in a row in the same field	1–5	1.78	1.28	617
	Growing wheat three or more years in a row in the same field	1–5	1.41	0.87	617
	Using cultivars with high resistance to fungal diseases	1–5	3.85	1.05	617
	Trimming field edges	1–5	2.26	1.45	617
II	Field observations for weeds before herbicide spraying	1–5	4.60	0.76	601
	Field observations for fungal pathogen pressure before fungicide spraying	1–5	4.25	1.08	598
III	Deciding fungicide spraying based on online decision support system (VIPS)	1–5	2.52	1.36	589
	Following the advice of newsletters from the extension service regarding fungicide spraying	1–5	3.67	1.29	594
	Get advice and knowledge about pest management from the extension service	0–1	0.95		432
	Get advice and knowledge about pest management from grain type-specific IPM-guidelines	0–1	0.22		617
IV	Use weed harrow	1–5	1.21	0.72	617
	Manually remove patches of weeds and/or wild oats	1–5	3.59	1.55	617
V	Importance of considering the environment when managing weeds and fungal diseases	1–7[a]	5.85	1.14	616
VI	Spot spraying	1–5	1.99	1.19	597
	Choosing the lowest recommended label dose	1–5	3.52	1.03	598
VII	Choosing or mixing remedies with different modes of action in order to prevent resistance from developing	1–5	4.38	0.83	595
VIII	Evaluating the effects of the pest management practices used	1–5	4.70	0.68	616

[a] See the body text for explanation of the scale.

Making field observations for weeds and fungal pathogen pressure before spraying appears to be a widespread practice among the respondents. However, there is potential for improvement as 42% of the farmers reported they do not always monitor ahead of spraying with fungicides.

The decision-making process leading to intervene or not in a pest situation is complex and may be guided by many sources of advice and previous experiences. Regarding this principle, the respondents' answers varied. One explanation may be that not all have equal access to inputs needed to perform the practices measured. The primary source of advice and guidance on pest management decision-making in Norwegian grain farming is the extension service. Sixty-seven percent of surveyed farmers reported being a member of the extension service and of those, nearly all receive advice or information about pest management from advisors via online newsletters, forecasting applications or, on demand, via direct contact with an extension agent. Only those who were members were asked that question; hence, the lower number of respondents. Only 22% of the farmers reported use of the grain type-specific IPM-guidelines. The results for principle II and III suggests that the majority of the farmers base their spraying decisions on what they observe in their fields in combination with advice from the online decision support system and/or advice from the extension service.

Almost none of the surveyed farmers reported using a weed harrow in grain production, whereas manual weeding was more widespread, with 48% of the surveyed farmers reporting that they manually remove patches of weeds on all their grain area. It should be noted that the Norwegian grain farmers do not have large insect pest pressure (Aarstad and Bjørlo, 2019), and therefore we did not include any non-chemical practices against insect pests.

The proxy-question used for principle V shows that most of the respondents found it very important to consider the environment when performing pest management, suggesting that most farmers take the environment into consideration when selecting pesticides. Regarding the principle of reduced use of pesticides, spot spraying is not particularly widespread among the respondents. Forty-eight percent of farmers reported that they never spot spray their grain fields. Furthermore, choosing the lowest recommended label dose was typically done just some of the time, with approximately 20% of the respondents claiming they always follow this practice. Thus, there may still be concerns among farmers that applying the lowest recommended label dose will not adequately deal with their pest problems. Finally, the farmers reported that they extensively practice anti-resistance strategies and evaluate the effects of their pest management practices.

3.3. The farmers' rate of IPM adoption

Before computing each farmer's index scores as described in section 2.1 from self-reported use of IPM practices, 17 of the 617 completed answers were removed because they lacked responses to critical questions. The farmers' scores on each IPM principle are presented in Table 4.

Principles I and II, which were weighted highly by the experts, also have high average adoption rates. This suggests that most Norwegian grain farmers are extensively monitoring and practicing preventive or suppressive IPM measures. The adoption rate is lower for principle III, as not all farmers reported using the most important tools that are available for supporting their decision-making. Regarding principle IV, using non-chemical methods is where the respondents have the lowest index

Table 4
Mean percentage of adoption of the eight principles of IPM among surveyed Norwegian grain farmers (percentage of maximal possible score).

Principle		Mean percentage of adoption
I	Prevention and suppression	83%
II	Monitoring	87%
III	Decision-making	70%
IV	Non-chemical methods	52%
V	Pesticide selection	87%
VI	Reduced pesticide use	58%
VII	Anti-resistance strategies	89%
VIII	Evaluation	93%

scores. This may be due to the lack of readily available alternatives to chemical methods. The high average score of principle V suggests that farmers think it is important to take into account environmental considerations when choosing pesticides. Principle VI is adopted to a low level compared to the other principles. The last two principles, VII and VIII, have high average scores, which suggests that farmers have good routines for preventing pest resistance and evaluating the effects of their pest management strategies.

The final index scores, presented in Fig. 1, shows the distribution of the respondents' individual index scores. As opposed to the mean percentage adoption of each principle (Table 4), this calculation also takes into account the weights of the principles. To ease interpretation of the results, the computed scores were linearly transformed to display the index scores in the range of 1–100, meaning that the worst (0) and best (100) possible responses to the questions result in these index scores.

The average index score was 68, with a standard deviation of 9.9 and the median score being 72. Three quarters of the farmers obtained scores within a 20-point window on the index between 60 and 80, which shows that most farmers have extensively adopted IPM. The distribution of farmers on the IPM index suggests that there is a large degree of similarity among farmers when it comes to the use of IPM. Nevertheless, the lowest score was 11, and the highest 92, indicating that the questionnaire data enabled a separation of the respondents along the index-scale.

To exemplify what it means to move on the index, a farmer who goes from never making field observations for fungal pathogen pressure before spraying to always performing the practice, increases the IPM score by 11 points. This practice is, however, highly weighted; to move 11 points by altering the behavior on less important practices requires altering several practices at once. For instance, going from never spot spraying to always spot spraying and simultaneously from not using resistant cultivars to only using resistant cultivars changes the score 9 points.

4. Discussion

With this study we have documented a novel method for developing an index to measure the adoption of IPM. Like many previous attempts of measuring IPM adoption, our method is based on measuring to what extent farmers use practices deemed important indicators of IPM in the local context, however, with the addition of a weighted index. While we recognize the concerns of Puente et al. (2011) regarding the subjectivity of pre-assigned weights, by including regional IPM experts and farmers from the target population in constructing the index, we ensured that the index is relevant and up to date in terms of what the principles of IPM mean in the context of Norwegian grain farming. Furthermore, by including non-academic stakeholders, we follow suggestions of Lamichhane et al. (2016) for strengthening the wider network of IPM development. While Creissen et al. (2019) employed a more elaborate process for determining the weights than we did, an advantage of our index compared to theirs is exclusive survey questions for each principle rather than questions covering several principles. These two methods seem to be compatible and may be good starting points for further work towards a common IPM assessment metric that is widely applicable. However, depending on the situation and context, certain components of IPM are more important than others for achieving the overarching goals of IPM. The use of a similar method should, therefore, result in different index items and weights depending on the context.

The finding that pest prevention and suppression, monitoring and decision-making were the practices and principles of IPM deemed most important in the current context (Table 2), is in line with the recommendation by Barzman et al. (2015) to direct efforts towards the preventive and suppressive components of IPM. It is also in agreement with the main component of the general IPM principles as described in the Sustainable Use Directive. Furthermore, the ranking appears to follow the temporal dimension of the principles with significance being highest for practices undertaken early in the growing season — when prevention and suppression practices are most suitable — and decreasing through the season. This study shows that the principles deemed least important for IPM implementation in Norwegian grain farming were those generally practiced after the decision to intervene has been made, namely pesticide selection and evaluation. This suggests that the IPM experts in the current study are aligned with the focus in IPM first on prevention and then intervention on demand.

The index calculation method enabled an assessment of the extent to

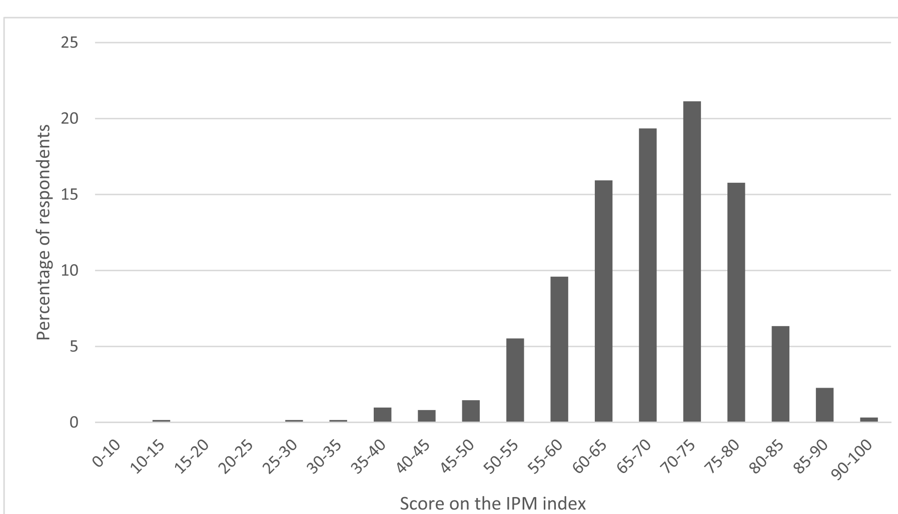

Fig. 1. Distribution of surveyed Norwegian grain farmers' scores on the IPM index (percentage of respondents obtaining scores in intervals on a scale from the lowest to the highest possible score; see the Methods section for further explanation).

which respondents are practicing IPM. Given the high average index scores among Norwegian grain farmers, it is more relevant to discuss varying levels of IPM use rather than how to increase adoption in general. While the adoption rates have not previously been documented in Norway, the findings are consistent with the country's decades-long history of an active policy for reducing risks from pesticides and its relatively low pesticide consumption compared to other European countries. Using a similar assessment method, Creissen et al. (2019) found very similar adoption rates among arable farmers in the UK and Ireland, which supports the reliability of our method. Furthermore, the validity of our results are supported by the relatively high response rate in our survey compared to other studies in similar regions (Sharma et al., 2010). Moreover, the fact that some farmers obtained low IPM scores strengthens the indication of a generally high adoption rate, as it shows that it is a realistic option to score low. Consequently, this study along with that of Creissen et al. (2019) provide counterfactual examples to concerns that adoption of IPM in arable and field crop systems remains marginal, thereby suggesting that measurement methods should be updated. However, the results of the index measurement should be used with certain reservations. In order to accommodate for the high response rate and in order to ask questions relevant to the respondents, the number of practices measured for each principle was low (except for principle I), which might affect the precision of the measurement. Nevertheless, it gives an indication of the rate of adoption, which can be used for further analyses and provide direction for application of the measurement tool.

Calculation of average index scores for each IPM principle shows that the farmers have extensively adopted principles such as monitoring, anti-resistance strategies and evaluation. Meanwhile, using non-chemical methods and reducing pesticide use stand out as the principles where there is most potential for improvement. These findings are in line with what Farrar et al. (2016b) found when reviewing adoption of IPM in western U.S., where monitoring and preventive measures were more readily adopted than measures related to pest intervention. They also agree with those of Puente et al. (2011), who documented that growers more readily adopt less complex components of IPM such as monitoring and evaluation compared to more complex, knowledge and resource-demanding principles such as non-chemical methods and reduced pesticide use. The adoption rates of anti-resistance strategies found in this study are higher than in comparable studies (Sharma et al., 2010), maybe because the regional extension services have emphasized such strategies in recent years. The relatively high adoption rates of other costly and time-consuming principles such as monitoring, pesticide selection, and evaluation may be due to the characteristics of Norwegian grain farming with small production units (making field observations manageable), a high rate of part-time farming (reducing dependence on profits from farming) and the close contact with a partly subsidized extension service (externalizing some of the costs). Despite the apparent need for increasing adoption of more complex components of IPM, as Ehler (2006) argued, it is important that reducing the use of pesticides does not become an end itself. In other words, implementing complex principles of IPM (e.g., reducing the use of pesticides) without adjusting other practices simultaneously is not beneficial nor recommended as it may lead to economic problems resulting from expensive alternative measures or decreased yields. However, with a declining range of available chemical pesticide options due to stringent risk assessment (Lamichhane et al., 2015), there is an increasing pressure on farmers and the surrounding communities in the EU and EEA to establish effective, holistic IPM strategies less reliant on chemical pesticides. Future research should therefore focus on investigating the reasons why farmers may be struggling to find adequate alternatives to chemical pest intervention and to develop such alternatives. Additionally, updating what increased use of IPM entails with novel measures (e.g., field robots, drones, and sensors) might further improve the sustainability of IPM.

5. Conclusions

In this paper, we have documented the construction and application of a novel IPM index measuring the general principles of IPM as put forward by the Sustainable Use Directive. Through a mini-Delphi process including IPM experts, the principles deemed the most significant ones in assessing the use of IPM among Norwegian grain farmers were prevention and suppression, monitoring, and decision-making. The least significant ones were pesticide selection and evaluation. The IPM index was applied to survey-responses from grain farmers in southeastern Norway, who largely represent the entire population of Norwegian grain farmers. Most of the farmers obtained IPM scores between 60 and 80 on a 100-point scale, which strongly suggests that IPM is practiced extensively by most farmers. Evaluation and anti-resistance strategies were the principles that the farmers, on average, have adopted the most. Conversely, using non-chemical methods and reduced use of pesticides are the principles where the farmers have the highest potential for increased use of IPM. Arguably, the latter principles are complex, and in order to assist farmers in increasing the use of practices related to these principles, further research should investigate the barriers to and drivers for their increased use. Furthermore, the method for measuring IPM adoption documented in this paper can, with appropriate context-specific adjustments, be used to assess the adoption of IPM both in other sectors of Norwegian agriculture and in comparable countries.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Åsmund Lægreid Steiro: Conceptualization, Formal analysis, Data curation, Investigation, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Valborg Kvakkestad:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing - review & editing. **Tor Arvid Breland:** Conceptualization, Supervision, Writing - review & editing. **Arild Vatn:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cropro.2020.105201.

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