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A multi-attribute decision analysis of pest management strategies for Norwegian crop farmers

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Abstract

This study provides a multi-attribute approach to support decisions by Norwegian crop farmers considering adopting innovative crop protection measures. In modelling choice among pest management strategies, we have accounted for both economic risks, risks to human health and risks to the environment. We used the Simple Multi-Attribute Rating Technique (SMART) to evaluate the results of a field trial comparing four different pest management strategies. In the trial, various pre-crops in year one were followed by two consecutive years of winter wheat. Two treatments had different levels of integrated pest management (IPM). IPM1 was the most innovative treatment and used less pesticides (i.e. herbicides, insecticides and fungicides) than IPM2. The third treatment ('Worst Case', WC) used pesticides routinely. The fourth treatment ('No Plant Protection', NPP) used no plant protection measures except one reduced dose of herbicide per year on winter wheat. Two main attributes were included in the SMART analysis, an economic indicator and a pesticide load indicator, each of which comprised a number of attributes at a subsidiary level. The results showed that the IPM1 and NPP strategies performed better than IPM2 and the WC strategies. However, the ranking of the pest management practices depended on the weighting of the two main attributes. Although the SMART analysis gave ordinal utility values, permitting only ranking of the alternatives, we were able to transform the results to measure financial differences between the alternatives.

Key words: Integrated Pest Management, Multi-Attribute Utility Theory, Pesticides, Simple Multi-Attribute Rating Technique, Winter wheat, Plant diseases.

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1. Introduction

There is widespread increasing emphasis on the goal of sustainable resource use in general, and in agriculture in particular. Where pesticides are concerned, farm managers need to consider both the long-term profitability of their farm businesses as well as effects on human health and on the environment. An important goal for agriculture is to reduce the use of harmful pesticides. Yet weeds, plant diseases and pest insects are major constraints on cereal production, influencing both yields and quality (Oerke, 2006). The use of pesticides, such as herbicides, fungicides and insecticides, has made it possible to increase yields, but has raised concern about adverse effects on human and animal health, environmental pollution, and adverse effects on beneficial organisms (Meissle et al., 2010). Furthermore, strong reliance on pesticides has resulted in some pest species becoming resistant to pesticides (Barzman et al., 2015). The concept of integrated pest management (IPM) has been introduced and promoted in many countries as the new standard pest management practice. IPM entails a careful choice of pest control measures among those available, including adoption of follow-up measures that limit the pest populations. The aim is to keep pesticides and other interventions to levels that minimise risks to human and environmental health, with a focus on natural pest control mechanisms, so that farmers can grow healthy and profitable crops with the least possible disruption to agro-ecosystems (FAO, 2018). In several countries, governments have sought to encourage farmers to widen the adoption of IPM by various measures, including advices and restrictions on pesticide use. For example, since 2009, the EU Directive on the Sustainable Use of Pesticides (EU, 2009) urged all member states to promote the general principles of IPM. Although Norway is not an EU member, it has followed this EU Directive. Since June 2015, Norwegian farmers have been obliged to follow the eight general principles of IPM (LOVDATA, 2015): prevention and suppression; monitoring;

decision making; non-chemical methods; pesticide selection; reduced pesticide use; anti-resistance strategies; and evaluation (Barzman et al., 2015).

Before 2015, the uptake of IPM in Norway was mixed. Among greenhouse growers, the uptake was high; in 2012, 86% of tomato producers and 99% of cucumber growers used IPM practices (SSB, 2012). Among other crop producers, however, adoption was much lower. A survey in 2008 revealed that only 30% of Norwegian farmers thought they had good knowledge of IPM, while 38% stated that they intended to use IPM in the future. Only 29% answered that they had used IPM during the period 2003-2008 (Bioforsk, 2010). Because of the obligation to use IPM imposed in 2015, the adoption of IPM principles is probably larger nowadays. Results from a recent survey showed that Norwegian grain producers use several types of pest management measures (Kvakkestad and Prestvik, 2015). In addition to need-based spraying, grain farmers regularly use preventive measures such as crop rotation and disease resistant varieties. Harrowing for weed control and targeted spraying are less common. The evidence suggests Norwegian farmers lack either knowledge of IPM or motivation to implement it.

While IPM principles are primarily designed to reduce the risk of damage to the environment and human health, there are concerns that these methods may reduce the profitability of farming. Several studies have examined the effect of IPM-based farming systems on farm profitability (e.g., Mouron et al., 2012; Pimentel and Burgess, 2014). Pelzer et al. (2012) argued that the profitability of IPM-based winter wheat cropping was slightly lower than that of high-input conventional cropping because of the higher labour cost for extra tillage and more frequent crop monitoring. On the other hand, Vasileiadis et al. (2011) found that an innovative IPM-based maize system improved profitability owing to lower production costs and higher yields.

Notwithstanding possible concerns about profitability, there is evidence that farmers' attitudes to risks to human health and to the environment can be key factors in the adoption of IPM (Cuyno et al., 2001). Thus, for decision support it is necessary to use a multi-attribute approach where the attributes denote the quality characteristics of interest – possible damage to human health, possible harm to the environment, and farm profitability.

Eltun et al. (2002) evaluated cropping systems in Norway based on their economic and environmental effects. However, they evaluated those effects separately, making it difficult to compare the total effects among different farming systems. In other European studies, multi-criteria analysis has been preferred for evaluating innovative projects with conflicting objects, especially when quantitative data were available (Sadok et al., 2009; Lipušček et al., 2010; Pavlovic et al., 2011). Vasileiadis et al. (2017) used hierarchical and entirely qualitative multi-criteria decision-aid modelling of European wheat- and maize-based cropping systems to compare innovative cropping systems with current systems.

The objective of this study is to evaluate the relative performance of four on-farm pest management strategies quantitatively in terms of profitability, effect on human health and environmental impact, using data from a Norwegian field trial of four strategies for pest management. We aim to offer decision support to crop farmers in the study area about which pest management strategy to adopt. We also aim to demonstrate a method for comparing IPM strategies that might be applied in other socio-economic and agricultural systems.

There are three main steps in our study. First, we illustrate a whole-farm decision support framework for farmers' choices of IPM strategies; second, using data from a Norwegian cropping trial, we evaluate and rank the relative performance of four pest management strategies, thereby providing decision support for farmers whose circumstances are similar to those in the trial; and third, we demonstrate an extension of the multi-attribute approach to transform the ordinal utilities into cardinal equal-utility attribute scores that allow us to quantify the differences between the alternative pest management strategies.

2. Data

2.1 Main data source and the description of four pest management strategies

Our main data were collected from a three-year experimental field trial of the SMARTCROP project[1], conducted from 2015 to 2017. The goal of the project was to develop innovative tools, approaches and policy instruments to increase adoption of IPM for sustainable and financially viable food production.

The pest management practices designed and tested were chosen to span the range of possible IPM use, from minimal use to (current) best practice. Several models in VIPS[2], a free web-based system or app to support Norwegian farmers in their decisions on direct control of pest insects ($VIPS_{insects}$), plant diseases ($VIPS_{diseases}$) and weeds ($VIPS_{weeds}$), were used to variable degrees in the four pest management strategies tested in the field experiments (Table 1). The widely-used pesticide risk indicator Environmental Impact Quotient (EIQ) (Kovach et al., 1992) was used to decide which types of fungicides and insecticides to apply to the main crops. Crop rotation affects the incidence and severity of plant diseases caused by plant pathogens. Consequently, the different pre-crops grown for the different pest management strategies were expected to affect the main crop, i.e. winter wheat

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[1] SMARTCROP is the research project ‘Innovative approaches and technologies for IPM to increase sustainable food production; http://www.smartcrop.no’ financed by the Research Council of Norway.

[2] VIPS is an on-line decision support tool developed by NIBIO (see https://www.vips-landbruk.no/). It provides advice on whether or not pesticides should be applied, which types of pesticides to use according to circumstances, the right time to apply pesticides, the appropriate amount of a pesticide to apply, etc.

(*Triticum aestivum*, cv. Ellvis) differentially: good disease suppression from peas, moderate from spring barley and least from spring wheat. The four pest management treatments designed to represent different IPM strategies were:

i) IPM1: This treatment was designed to represent the best IPM strategy in terms of crop yield, pest control, and environmental and health risks of pesticides. VIPS was generally used for all pest groups (Table 1). Several innovative IPM tools targeting pest insects were implemented, i.e., a flower strip, overwintering boxes and an odour dispenser, all facilitating natural enemies of pest insects. A non-cereal pre-crop, peas (*Pisum sativum*, cv. Tinker), was chosen to reduce yield losses of the main crop (wheat) due to plant diseases. No pesticides were used in the pre-crop and weeds were controlled by flex-tine weed harrowing.

ii) IPM2: This treatment was designed to represent the second best IPM strategy. A non-wheat pre-crop, spring barley (*Hordeum vulgare*, cv. Helium), was used. $VIPS_{weeds}$ was used to optimise herbicide applications in the pre-crop (one application) and in the main crop (two applications per year). $VIPS_{insects}$ was used to decide whether insecticide application was necessary.

iii) WC (Worst Case): This treatment was designed to represent a worst case scenario in which all pest groups were generally controlled with pesticides routinely. No VIPS models were used. The pre-crop was spring wheat (*Triticum aestivum* cv. Bjarne).

iv) NPP (No Plant Protection): This treatment provided a reference for what happens when pest management is omitted. However, during the pre-crop in the first year of the trial there was strong weed infestation, so it was decided to perform one herbicide treatment per year based on $VIPS_{weeds}$. Otherwise, weeds would have represented a natural flower strip, which was one of the innovative tools in IPM1. No fungicides or insecticides were applied in this treatment.

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Table 1. Characteristics of the four pest management treatments tested in a three-year field trial in SE Norway.

The first year (2015) with spring sown pre-crops was followed by two years with winter wheat (2015/2016 and 2016/2017). IPM = Integrated Pest Management. Ploughing; seedbed preparation; sowing and harvesting were common to all crops.

	IPM1	**IPM2**	**'Worst case'**	**'No plant protection'**
Pre-crop (2015)	Peas	Spring barley	Spring wheat	Spring wheat
Fertilizing	Yes (but not in pre-crop)	Yes	Yes	Yes
Weed management in pre-crop	Weed harrowing once	Spraying herbicide once according to VIPS$_{weeds}$	Spraying herbicides (once), insecticides (once) and fungicides (once), according to a fixed spraying calendar	No measures
Pest insect management in pre-crop	Flower strip to support biological control. Traps for monitoring pest insects (pea moths)	No measures needed according to VIPS$_{insects}$		
Plant disease management in pre-crop	No measures	No measures		
Weed management in winter wheat	Herbicide once per year according to VIPS$_{weeds}$	Herbicide twice per harvest according to VIPS$_{weeds}$	Spraying herbicides (twice per harvest), insecticides (twice per harvest) and fungicides (twice per harvest), according to a fixed spraying calendar	Herbicide once per year according to VIPS$_{weeds}$
Pest insect management in winter wheat	Flower strip, overwintering boxes and odour dispensers to support biological control. Traps for monitoring pest insects. No further measures needed according to VIPS$_{insects}$	No direct control measures needed according to VIPS$_{insects}$		No direct measures
Plant disease management in winter wheat	Spraying fungicides with lowest EIQ according to VIPS$_{diseases}$ twice per harvest	Spraying fungicides with medium EIQ according to VIPS$_{diseases}$ twice per harvest		

The field trial was conducted from spring 2015 (April) to autumn 2017 (August). The four pest management treatments were repeated on the same plots through the experimental period. Plot size was 10 m by 9 m. The IPM1 plots were located about 250 m away from the other fields to avoid the effect of innovative odour-based measures against pest insects in this treatment from affecting the other treatments. Except for IPM1, treatments were randomized within each of the four replicate blocks. Table 1 shows pre-crops, main machine operations and plant protection measures applied in the four treatments. The experiment was located at Akershus in SE Norway (59°39′23″N, 10°45′23″E). Over 81% of Norwegian grain production is in the eastern part of Norway (SSB, 2016a), meaning that the trial results can be considered representative of Norwegian cereal farms in the general area of Akershus, as well as indicative for cropping farms in other parts of SE Norway.

2.2 Other data sources

In addition to the trial data, some data were obtained from a survey that was conducted in 2014 by NILF (Norwegian Agricultural Economics Research Institute) to investigate farmers' attitudes to IPM. We also obtained some information from a focus group meeting. The focus group comprised farmer representatives, farmer advisers from NRL (Norwegian Agricultural Advisory Service) and researchers from NIBIO (Norwegian Institute of Bioeconomy Research). These two additional data sources were used for weighting of the attributes, as described in the section 3.3, steps 3 and 4.

3. Methods

3.1 Multi-attribute decision making

Determining the best farming strategy for crop farmers while accounting for multiple goals is a case for multi-attribute decision making, where the attributes relate to the properties of each alternative. In our case profitability, human health and environmental health are attributes that should be considered as part of an overall assessment. For such assessments, multi-attribute utility theory

(MAUT) is a commonly advocated method (Velasquez and Hester, 2013). In MAUT analyses, alternatives are evaluated based on assessed utility values of the decision maker (or adviser) for the levels of each of the set of attributes, then the importance of each attribute range is assessed by the decision maker assigning weights to the range of each attribute. The result is a weighted utility value for each alternative that provides a basis for ranking the alternatives. The utility functions for individual attributes may be linear or non-linear, as elicited from the decision maker, and the way the weights on attribute ranges are assessed means that the derived weights may or may not sum to 1.0. If the sum of the weights is not 1.0, the aggregation of the attribute utilities is multiplicative, otherwise it is additive (Keeney, 1974; Keeney and Raiffa, 1976; Hardaker et al., 2015, ch. 10).[3]

Despite the theoretical merits of MAUT, full implementation of the method confronts difficulties in eliciting the required judgements from decision makers. Consequently, various simplifications of MAUT have been proposed. One such, called Simple Multi-Attribute Rating Technique (SMART), was originally developed by Edwards (1977). It differs from full MAUT in that ratings of attribute levels are typically assigned in terms of natural scales, such as monetary units or physical quantities, that are then 'normalized' from zero for the worst value and 1.0 for the best, then these normalized values are treated as utilities. Weights on the attribute ranges are derived to sum to 1.0, so that the value of each choice alternative can be calculated using a linear additive model:

$$u_i = \sum_{j=1}^{m} w_j u_{ij}\left(a_{ij}\right), i = 1,2 \ldots n \tag{1}$$

where:

[3] Multiplicative weights may be indicated if a zero level of any attribute is unacceptable.

u_i is the overall utility value for strategy i;

w_j is the weight of relative importance assigned to the range of attribute j, numbered from 1 to m, with $\sum_{j=1}^{m} w_j = 1$;

a_{ij} is the value or level of attribute j for strategy i;

$u_{ij}(a_{ij})$ is the normalized utility score for the level of attribute j for strategy i, in the range 0 (worst) to 1.0 (best); and

n is the number of attributes.

SMART, like full MAUT, is built on an assumption of preferential independence, meaning that the utility assigned to any attribute can properly be assigned without reference to the utility values of other attributes (Hardaker et al., 2015, ch. 10). While it is hard to assess whether the assumption of preferential independence is satisfied, we consider that any failure in this regard in our study is unlikely to have substantially affected the results since the main attributes relate to distinctly different aspects.

When the level of some of the attributes is uncertain, it is possible in MAUT to account for risk aversion of the decision maker via non-linear utility functions. That is not possible using SMART because the utility functions for attributes are treated as linear via the normalization step, meaning that concerns about uncertainty in attribute levels can only be handled by sensitivity analysis. On the other hand, SMART, like MAUT, does account for both the levels of the attributes and for the relative weights to be assigned to reflect the assessed importance of each attribute. Both methods can be applied to quantitative and qualitative data.

3.2 Attributes used

To implement the SMART analysis, we first set up a value tree to describe the attributes of the pest management strategies - see Fig. 1. We chose two levels of attributes. The two first-level attributes are an economic indicator and an indicator of pesticide load. The overall utility values of the first-level attributes are the utility values of the subsidiary-level attributes, aggregated using their weights of importance. The subsidiary level attributes used to measure the economic indicator are: 1) profitability for the farmer and 2) labour use for IPM on-farm implementation. The subsidiary-level attributes used to measure pesticide load are: 1) human health (a measure of the load to which the operator is exposed when handling and applying pesticides); 2) environmental behaviour (a measure of how fast the pesticides degrade in the soil, the risk of accumulation in the food chain and the risk of leaching to groundwater); and 3) environmental toxicity (a measure of the pesticide's toxicity for animals and plants in the field and the surrounding environment) (Kudsk et al., 2018).

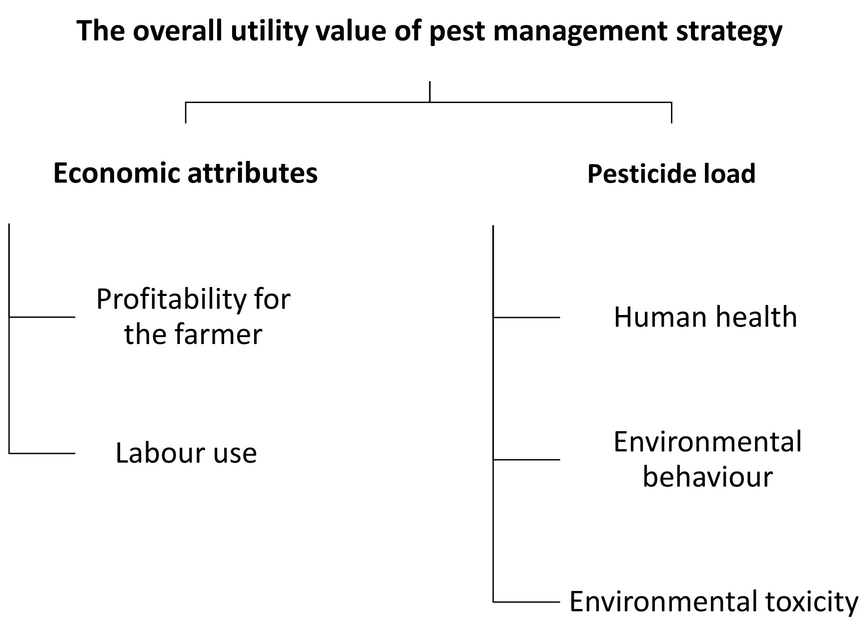

Fig. 1. Hierarchy tree of SMART analysis for the four pest management strategies tested.

3.3. Implementing SMART

The main steps followed in our implementation of SMART can be summarised as in Fig. 2:

Step 1: Obtain parameter values for each attribute

↓

Step 2: Normalise utility values for the second-level attributes

↓

Step 3: Derive proportional weights for the each of the second-level attributes

↓

Step 4: Obtain weights for the two first-level attributes

↓

Step 5: Calculate the total utility values for all alternatives, as the basis for ranking

↓

Step 6: Pick the strategy with highest utility as benchmark, and pick an attribute that is measured as a scalable cardinal value

↓

Step 7: Vary the level of this attribute to get the same utility as the benchmark

↓

Step 8: These equal-utility attibute scores are cardinal, and can be used for comparison and statistical testing

Fig. 2. Main steps in our implementation of SMART

These steps are described in turn below:

1. Using data briefly described above (and more in detail reported in the results section), we obtained the parameter values of alternative i under attribute j, i.e., a value for each a_{ij} in equation (1). We derived parameters for the five following second-level attributes: profitability for the farmers, labour use, human health, environmental behaviour, and environmental toxicity.
2. We obtained the normalized utility value $u_{ij}(a_{ij})$ for each of the five second-level attributes by applying the formula: $u_{ij}(a_{ij}) = \frac{a_{ij}-a_{minj}}{a_{maxj}-a_{minj}}$ where a_{ij} is the parameter value of

alternative i under attribute j, a_{maxj} is the maximum parameter value of attribute j, and a_{minj} is the minimum parameter value of attribute j. If a higher raw performance score indicates worse overall performance, then the utility value score is calculated as $u_{ij}(a_{ij}) = \frac{a_{maxj}-a_{ij}}{a_{maxj}-a_{minj}}$.

3. We derived proportional weights for each of the second-level attributes as follows:

    a. Under the economic indicator:

    To weight the second-level attributes under the economic indicator, we used data from a survey that was conducted by NILF in 2014 to investigate farmers' attitudes towards IPM (NIBIO, 2015). The survey was sent to 1000 randomly chosen cereal farms with a response rate of 42%. In the survey, farmers were asked to rate the importance of each of the economic attributes (gross margin/ha (GM/ha) and labour needed) on Likert scales from 1 to 7, where score 1 stands for 'not important' and score 7 means 'very important'. (The range from 1 to 7 is widely used.) Because some of the observations from the survey had incomplete information, those observations were omitted, and we end up with 164 observations. We averaged the 164 observations of survey scores for each of the two attributes, then divided the average scores by the sum of the average scores, yielding normalised weights of 0.601 for GM/ha, and 0.399 for labour use.

    b. Under pesticide load:

    For the second-level attributes under the first-level attribute of pesticide load, we gave equal weights to human health, environmental behaviour, and environmental toxicity, i.e. weights of value (i.e. 1/3 for each), as suggested by Kudsk et al. (2018).

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4. First-level attribute weights. We had no firm basis to obtain weights for the two first-level attributes, and we expected that different decision makers would favour different relative weights. Hence, we used sensitivity analysis, applying different weight-ratio scenarios, as reported in the results section of the paper.

   As mentioned earlier in section 2.2, a focus group comprised of farmer representatives, farmer advisers and researches was involved in the SMARTCROP project. In the focus group meeting farmer representatives were asked to rate the first-level attributes. The average weight ratio of the economic indicator relative to the pesticide load indicator from the focus group was 6:4. This weight ratio was used as a starting point to investigate the overall utilities of the four strategies.

5. Next, we used equation (1) to calculate the total utility values for all alternatives as the sums of the corresponding weighted utility values of the attributes, providing a basis for ranking the choice alternatives.

In order to obtain cardinal measures of the differences between alternatives, as described above, we applied the following procedures:

6. Starting with the strategy with the highest utility as a benchmark (from step 5 above), we picked an attribute that is measured as a scalable cardinal value - here we picked gross margin per hectare (GM/ha).
7. We then varied the level of this chosen attribute to get the same utility as the benchmark. The required attribute level can be found in Excel by varying the level of GM/ha to minimise the difference between the two utility values.

8. This score is cardinal, so difference comparisons between strategies and statistical testing are possible and meaningful.

4. Results

In this section, we first report the results from experimental field trials, which provided data for the subsidiary-level attributes in the SMART analysis. Then, we present the utility scores and equal-utility scores of the four pest management strategies.

4.1. Economic attributes

4.1.1. Profitability for the farmer

We chose GM/ha of winter wheat as the measure of profitability. We calculated GM/ha in the standard way as (wheat yield in kg per ha * price per kg) – variable costs per ha.

Wheat yields

Fig. 3 shows the annual yields of the four strategies from the experiment.

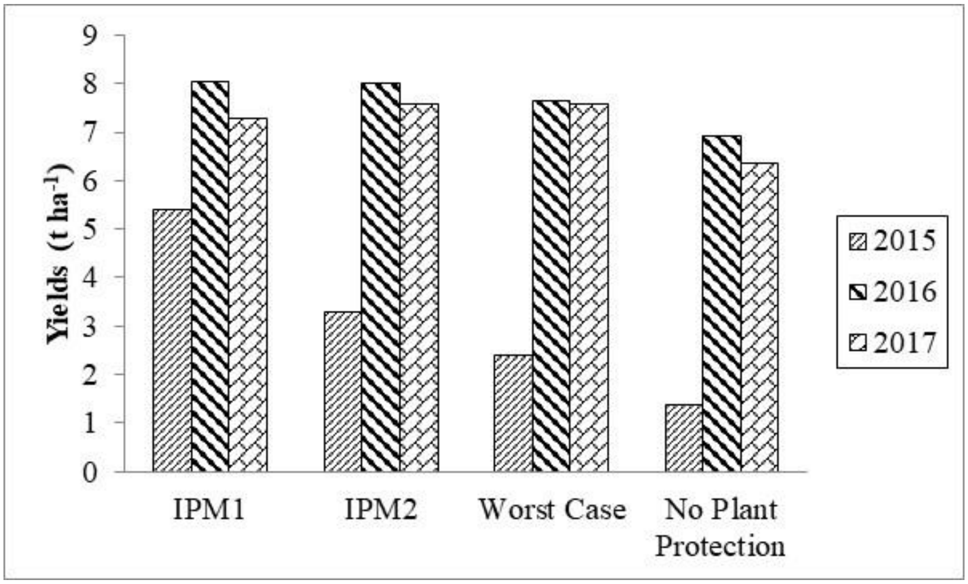

Fig. 3. Yields in tonnes/ha (t ha^{-1}) from 2015 to 2017. Various pre-crops were grown in 2015 for IPM1 (peas), IPM2 (spring barley), 'Worst Case' and 'No plant protection' (spring wheat). Winter wheat was grown the two last years (2016 and 2017).

Yields in 2015 were low for all strategies because this was the year the experiment was established and not all procedures were fully in place. Moreover, the growing season that year was short. In 2016, both IPM1 and IPM2 strategies had the equal highest yields. However, in 2017, IPM2 and WC showed the equal highest yields.

In the SMART analysis, the average yields from the experiment were used. The three-year average yield for IPM1 was 6.91 t ha^{-1}, which is the highest among all strategies. IPM2 had a three-year average of 6.29 t ha^{-1}. The three-year average yield for the WC strategy was 5.88 t ha^{-1} and 4.89 t ha^{-1} for NPP.

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Price of winter wheat

In order to protect and support the farmers, Norway has established a target price system for most agricultural products, under which the prices are controlled and are independent of price changes in the world market. For cereals, a target price system, implemented via import tariffs and quotas, has been in place since 2000 (Knutsen, 2006). The Norwegian Agricultural Purchasing and Marketing Co-operation (Felleskjøpet) is responsible for market regulation. The target price is negotiated between the two farmers' unions and the government annually (NIBIO, 2017).

Cereal prices for farmers are influenced by both the basic price and the quality of the grain, the latter being determined by the seed quality, protein and hectolitre-weight (HL-weight). The price used in our analysis for the four strategies was the average weekly target price published by Felleskjøpet (2017), plus or minus the additional amount determined by the wheat quality, as measured in the trial.

The prices of winter wheat for IPM1 and 'Worst Case' (WC) varied from 2015 to 2017 because of quality differences, with a three-year average of 3.22 Norwegian kroner[4] (NOK)/kg for IPM1 and 3.05 NOK/kg for WC. The price for IPM2 and 'No Plant Protection' (NPP) were comparably stable. The three-year averages were 2.81 NOK/kg for IPM2 and 2.84 NOK/kg for NPP.

Variable costs

The fixed costs were similar among the four strategies, and because of that ignored in the analysis. Machine and labour costs represented the largest share of variable costs for all four strategies (Fig. 4). The prices of pesticides, fertilizers and seeds were collected from Felleskjøpet.

[4] 1 USD = 9.10 NOK, 1 EUR = 10.16 NOK per 22 October 2019.

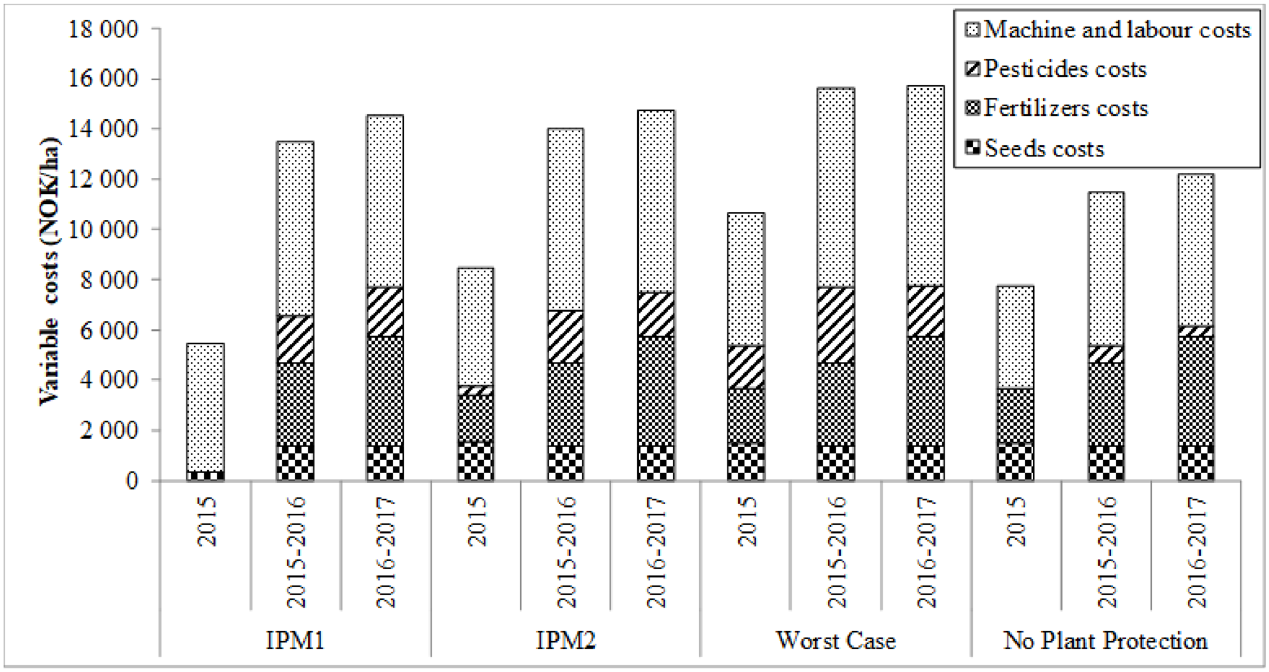

Fig. 4. Variable costs in NOK/ha from 2015 to 2017.

The three-year average variable costs were 11 350 NOK/ha for IPM1 and 12 639 NOK/ha for IPM2. The NPP strategy had the lowest variable cost of 10 691 NOK/ha. The WC strategy had the highest variable cost of 14 275 NOK/ha.

4.1.2 Labour use for IPM on-farm implementation

IPM strategies that involve the implementation of non-chemical pest controls are more time-consuming than traditional pest management since they require monitoring of pests and the application of decision support systems (Williams et al., 2005). Less than 9% of Norwegian cereal farm operators had more than half of their total net income from cereal production in 2015 (SSB, 2016b). Consequently, most farmers have at least a second occupation, other than farming. The high level of wages in Norway means that the opportunity cost of working on one's own farm is high. Therefore, labour use related to the implementation of pest management strategies is an important attribute for the measurement of the economic indicator.

Because of the small size of plots and the need for intensive management, labour used in the experimental trial may be quite different from that needed on commercial farms. Therefore, we could not use the experimental data on labour use in our analysis. Moreover, we had no access to reliable data on the time required on farms for the strategies, particularly those requiring monitoring of pests and the application of decision support systems. We therefore held a focus group meeting with farmers' representatives, researchers and farmers' advisers. Labour use data from the experimental trials were presented to the group as a starting point for the group to consider when estimating time requirements on commercial farms. Using feedback from the group, we ranked the labour use of each the four strategies on the qualitative scale 'very low', 'low', 'medium' or 'high', quantified as 1, 2, 3, and 4, respectively in SMART.

4.2. Health and environmental attributes

Various risk indicators have been developed across Europe to assess environmental and health risks of pesticide use, such as SYNOPS in Germany (Gutsche and Strassemeyer, 2007) and EYP in the Netherlands (Reus and Leendertse, 2000). Pesticide Load (PL) is a risk indicator developed in Denmark to monitor pesticide load and for setting quantitative targets for pesticide use (Kudsk et al., 2018). We chose PL as the risk indicator for environmental and human health impact because Norway and Denmark share the Scandinavian climate conditions and have similar standards in pesticide application and regulation. PL consists of three sub-indicators: human health, environmental behaviour, environmental toxicity.

Under PL, the assessment of the risk to human health is focused primarily on operator exposures to toxic chemicals, and is based on the risk classification on the label of the product, giving a value of zero or a positive number.

The PL for environmental behaviour is determined by the values from the pesticide property database (PPDB) of half maximal lethal/effect concentration (LC_{50}/EC_{50}) (describing acute toxicity), half lethal oral dosages (LD_{50}) (data for bee toxicity), and no effect concentration ($NOEC$) (used to describe chronic toxicity). Combing these components gives a value of zero or a positive number for the second-level attribute 'environmental behaviour' in the hierarchy tree of SMART.

The PL for environmental toxicity is made up of the half-life in soil (the period until 50% or less of the applied chemicals can be detected in the soil), the bioaccumulation factor (the accumulation of the pesticides in a chosen organism, such as a rat) and the SCI-GROW index (a measure of the mobility of the active ingredient and major metabolites, indicating the risk of leaching to the groundwater). These three measures were combined to give a value of zero or a positive number.

Detailed information on the calculation of PL can be found at Kudsk et al. (2018).

The annual PL values for the four strategies from 2015 to 2017 were calculated consistently with the above methods, based on the data and information registered in the field trial. The results are shown in Fig. 5.

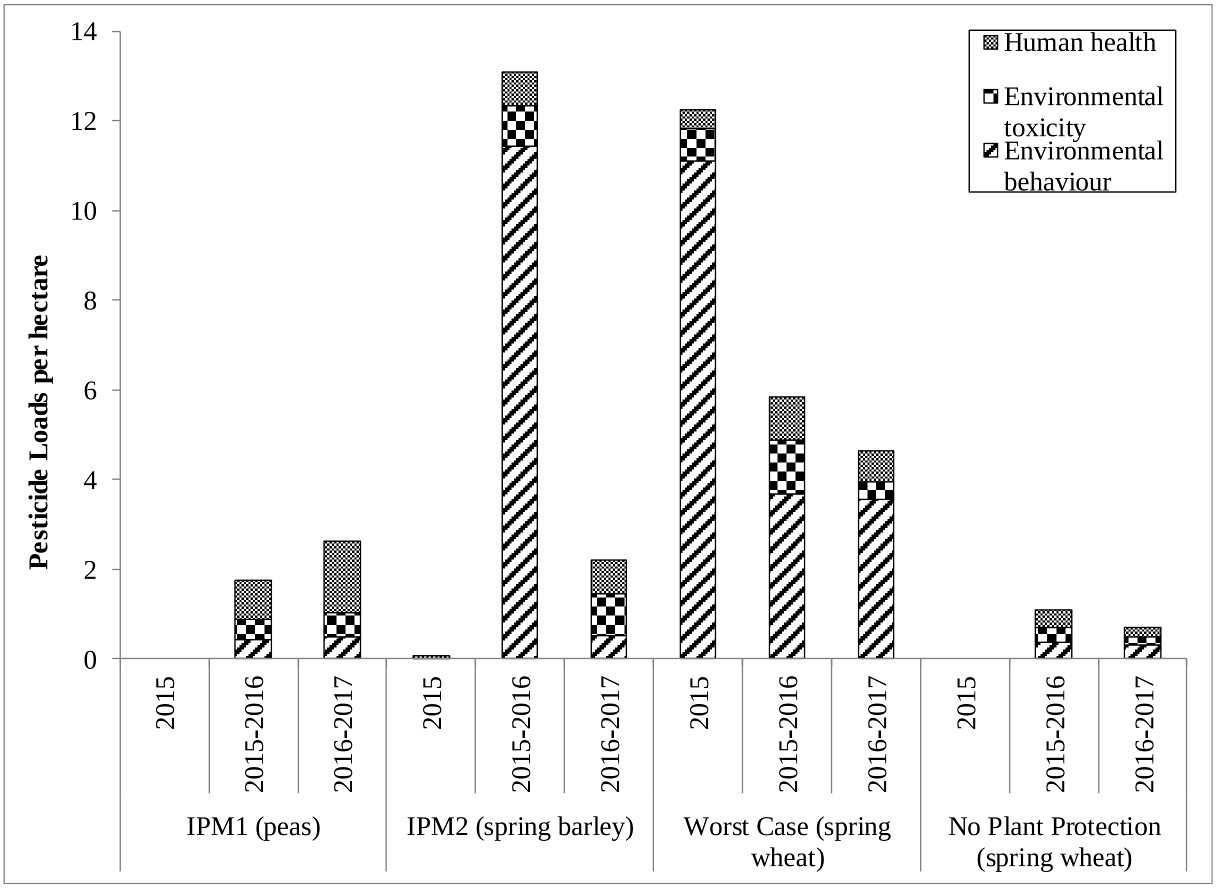

Fig. 5. Pesticide load per pest management strategy and year. Various pre-crops were grown in 2015 for IPM1 (peas), IPM2 (spring barley), 'Worst Case' and 'No plant protection' (spring wheat). Winter wheat was grown the two last years (2015/2016 and 2016/2017).

As expected, the WC strategy had the highest average PL in all three sub-indicators from 2015 to 2017. The NPP strategy had the lowest PL because very few pesticides were applied during the three-year period. IPM1 strategy, with most of the PL in human health, had lower total PL than IPM2 and WC. For the IPM2 and WC strategies, toxicity took up the largest part of the total PL.

4.3. Parameters of the attribute values

Applying the methodology described in section 3.3 and the data illustrated in sections 4.1 and 4.2, we obtained parameter values for attributes for each of the pest management alternatives, as reported in Table 2.

Table 2 shows that IPM1 had average highest gross margin per hectare and NPP the lowest. However, NPP was ranked first for labour use (require least labour input) and had the lowest PL for all three sub-indicators. WC had highest average PL for the indicators of environmental behaviour and environmental toxicity, and IPM1 had highest average PL for indicator human health.

Table 2. Summary of attribute values. Three-year averages from 2015 to 2017.

Pest management strategy	Economic indicator		Pesticide load		
	Gross Margin (NOK/ha)	Labour use (ranked)	Environmental behaviour	Environmental toxicity	Human health
IPM1	10883	3	0.324	0.308	0.824
IPM2	5046	4	0.615	3.985	0.517
Worst Case	3663	2	0.781	6.114	0.690
No Plant Protection	3190	1	0.167	0.230	0.198

The normalised values of the data in Table 2, obtained through step 2 described in section 3.3, are shown in Table 3. These values, all in the range 0 to 1.0, are treated as utilities in subsequent steps.

Table 3. Summary of utility values for attribute levels displayed in Table 2.

Pest management strategy	Economic indicator		Pesticide load		
	GM	Labour use	Environmental behaviour	Environmental toxicity	Human health
IPM1	1.000	0.333	0.744	0.987	0.000
IPM2	0.241	0.000	0.270	0.362	0.490
Worst Case	0.061	0.667	0.000	0.000	0.214
No Plant Protection	0.000	1.000	1.000	1.000	1.000

The weighting of the second-level attributes was reported in section 3.3: for the economic indicator, 0.601 for GM and 0.399 for labour use. For pesticide load, we used equal weights of 0.333, for the second-level attributes of environmental behaviour, environmental toxicity, and human health.

4.4. Utility and equal-utility attribute values

Using the weight ratio 6:4 for the economic indicator vs the pesticide load indicator, the preferred ratio of the focus group, yielded the results in the third column in Table 4. With this ratio, the results show that IPM1 had the highest utility and is ranked first, with the NPP strategy ranked second, and the IPM2 strategy ranked third, leaving WC last.

Since different decision makers may assign different weights between the two main attributes, we investigated four scenarios where the weight ratio between economic and pesticide load indicators ranged from 8:2 to 2:8 (Table 4).

Table 4. Total utility and ranking for different weight ratios.

	Weight-ratio between economic and pesticide load indicators							
	8:2		6:4		4:6		2:8	
Strategy	Utility	Rank	Utility	Rank	Utility	Rank	Utility	Rank
IPM1	0.703	1	0.671	1	0.640	2	0.608	2
IPM2	0.191	4	0.236	3	0.282	3	0.328	3
WC	0.257	3	0.210	4	0.164	4	0.118	4
NPP	0.519	2	0.639	2	0.760	1	0.880	1

With a weight ratio 8:2 IPM1 is still ranked first and NPP second. In the cases with higher weight on the pesticide load indicator, 4:6 and 2:8, NPP is ranked first, followed by IPM1 second, and IPM2 third. A further evaluation of the sensitivity of the overall utility, using a range of weight-ratios between the economic and pesticide load indicators, is presented in Fig. 6. The figure shows that, for any weight-ratio case, IPM1 and NPP are ranked above IPM2 and WC. With a weight ratio of (5.6):(4.4) (i.e. 56% weight on the economic indicator and 44% weight on the pesticide load indicator) IPM1 and NPP have the same utility (0.665), so are ranked equally.

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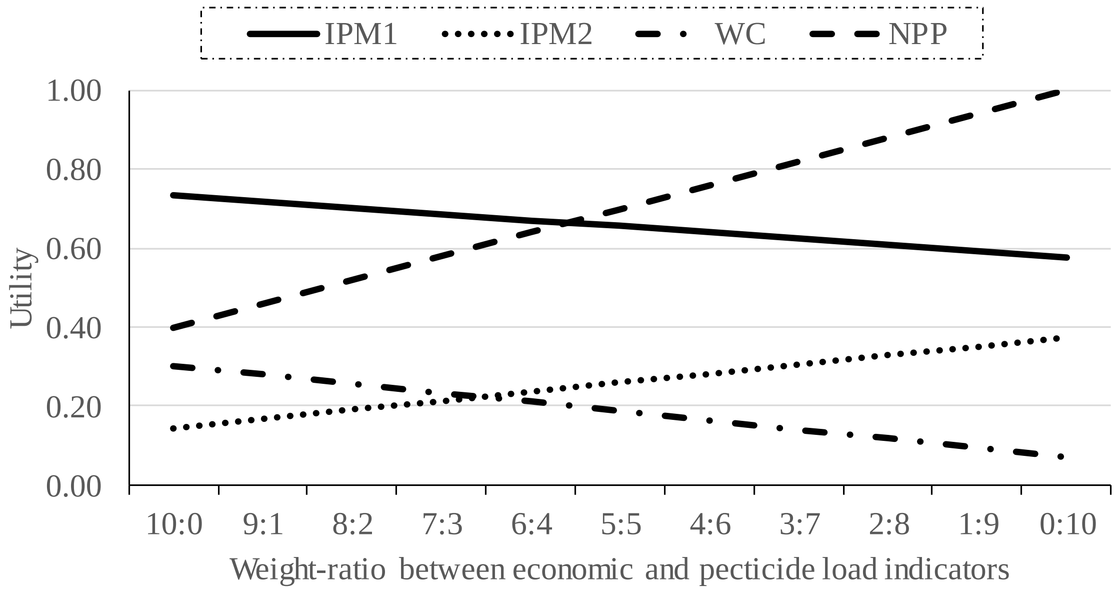

Fig. 6. The overall utility of the four different pest management strategies with different weight-ratios of economic benefits versus pesticide load. A weight-ratio 10:0 means 100 percent weight to the economic indicators and 0 percent weight to the pesticide load indicators, and vice versa.

Applying steps 6 and 7 in section 3.3, to convert the utilities to equal-utility attribute values in terms of gross margins per ha, we obtained the results shown in Table 5. This table shows GM/ha values with the same utility as the benchmark (the strategy with the highest utility for each of the weight ratios). These GM values can be used as measures of the differences between the available strategies.

Table 5. Summary of equal-utility attributes score and differences in equal-utility attributes score in GM/ha for different weight ratios. The numbers in bold are the benchmarks - the strategies with the highest utility for each of the weight ratios. The rankings are necessarily the same as those in Table 4.

		Weight-ratio between economic and pesticide load indicators			
Strategy	Basis GM/ha	8:2	6:4	4:6	2:8
GM/ha					
IPM1	10 883	**10 883**	**10 883**	14 718	28 258
IPM2	5 046	13 235	14 319	20 322	40 364
WC	3 663	10 798	13 494	22 721	52 436
NPP	3 190	6 124	3 868	**3 190**	**3 190**
The increase in GM/ha required to give the same utility as the ’best practice’ (NOK)					
IPM1		0	0	3 835	17 375
IPM2		8 190	9 274	15 277	35 319
WC		7 135	9 831	19 059	48 774
NPP		2 934	678	0	0

For a weight ratio of 6:4, IPM1 is better than NPP by NOK 678/ha and is superior to the other two strategies by more than NOK 9000/ha. With a weight ratio of 8:2, IPM1 out-performs all the other three strategies by about NOK 3000/ha or more. When the economic indicator is given less weight relative to pesticide load, with a weight ratio of 4:6 or 2:8, NPP outperform the other three strategies, and substantially so with a weight ratio 2:8, with differences ranging from NOK 17 375/ha to NOK 48 744/ha. The large values in equal-utility attribute scores at the 2:8 ratio indicate a substantial gulf between the attitudes and values of those who are anxious about the adverse effects of pesticides on human health and the environment, and others. The ’others’ here may include those farmers who see the need for at least some careful use of pesticides to remain profitable.

The results in Table 4 can be used to indicate the financial incentvies Government might need to offer for the farmers to change their current practices to more sustainable options. The results in Table 5 give an indication of the sizes of subsidies that would be required. For example, with a weight-ratio of 6:4, as preferred by the focus group of farmers, the difference between NPP and the ‘best’ strategy IPM1 is NOK 678/ha, showing that a farmer who accepts the weight-ratio of 6:4, would require an incentivey of this amount to be willing to change from IPM1 to the more environmentally friendly and safe to health strategy NPP.

5. Discussions and conclusions

The eight general principles of IPM have become compulsory for Norwegian cereal farmers. The aim of this study was to provide support to decision makers considering adopting IPM strategies in Norwegian cereal production. In pursuit of this aim, we were able to draw on relevant experimental trial data from the SMARTCROP project.

Our results show that the IPM1 and NPP strategies have the highest and the second highest overall utility among the four strategies, although the ranking of the two strategies shifts as the weight-ratio changes. The IPM1 out-performs the NPP and the other two strategies if the economic attribute is given high weight (8:2 and 6:4). On the other hand, if the weights shift to emphasize the importance of risks to health and the environment (4:6 and 2:8), the utility scores for NPP becomes greater than that for IPM1 and for the other two strategies.

The equal-utility values, provide quantitative measures of the differences between pairs of strategies. A large GM/ha difference in the lower panel of Table 5 means we can be confident about the ranking of the strategies, whereas, if the GM/ha difference between strategies is low, the rankings would be less convincing. These results also provide a basis for judging what subsidies might be needed to encourage non-adopters of IPM to change their choice of strategy.

Our findings show, as expected, the importance of choice of weights on economic considerations versus pesticide load. Different priorities for these main attributes will indicate different choices among pest management strategies.

Earlier studies (e.g., Bergevoet et al., 2004; Gasson et al., 1988) have reported that farmers have several goals and see farming as more than a way to make money. In a study of Norwegian dairy and crop farmers' goals, Lien et al. (2006) found that sustainable and environmentally sound farming was ranked highly, tending to support our focus group results that gave weight to both the economic indicator and the pesticide load indicator. Hence, we expect that many crop farmers have adopted, or will in future adopt, pest management strategies similar to the IPM1, which, compared to the three other strategies, gives higher yields and better-quality yields (Vasileiadis et al., 2011; Pimentel and Burgess, 2014), thus earning higher returns. However, compared to NPP, IPM1 has higher costs in pesticides and fertilizers, as well as more labour use, and is more of a threat to human health and the environment. Our results indicate that farmers who set these considerations above profit maximization might still prefer IPM1; only if they place relative weights strongly in favour of minimizing pesticide load (4:6 and 2:8) do our results indicate a shift to NPP.

Given the policy objective of promoting the uptake of IPM, these findings indicate a need to consider measures which might shift farmers' perceptions of the relative importance of economic vs other attributes. Farmers' choices can be influenced by public policies through regulatory instruments, information dissemination measures and incentive-based instruments (Lefebvre et al., 2015). To increase the proportion of farmers who will use improved IPM-based practices, information dissemination measures such as improved advisory services are important.

Lowering the risk to health and the environment is expensive for farmers, even though they may thereby also reduce risks to the sustainability of their farms and to the surrounding environment. Some (neo-liberal) economists argue that interference in markets can only be justified if there is market failure, for example, the existence of externalities. Public health costs and environmental damage are externalities from pesticide use, implying that market intervention may be justified. Subsidies are currently paid to Norwegian farmers who use flex-tine weed harrowing instead of herbicides to control annual weeds (Fylkesmannen, 2016), and there is discussion about increasing the number and kinds of available public instruments to accelerate the adoption of IPM strategies in such forms as targeted subsidies and improved advisory services. Our results form a contribution to those discussions.

For future research, our analysis could be improved if we had better measures of labour use under farm conditions. Validation of attribute levels and weights will increase the reliability of the findings. Other multi-attribute analysis methods or approaches can also be considered for comparison. Moreover, including risk and risk-aversion is an important aspect for further research. It may be helpful to consider farmers' perceptions of the risk inherent in the adoption of IPM, part of which may stem from the lack of knowledge of the available strategies and their performance. It would be useful to know whether our assessments of the utilities and weights differ from what particular farmers believe. Perhaps those who have adopted IPM will have different views than how non-adopters perceive IPM.

The results of this study could also be further tested by investigating the long-term performance of the four strategies, implying the need to gather panel data. Our model can be updated as new information comes available or it can be adapted, if the data permit, to match circumstances in other areas of Norway or in other countries.

Our main findings can be summarized as follows. The weights on the two main attributes, economic and pesticide load indicators, matter, and affect which farming strategy is indicated as the best. For plausible weights, the IPM1 strategy is ranked first, the NPP second, the IPM2 third, and finally WC, the routine use of pesticides, is ranked as the worst strategy. IPM1 represented the most innovative integrated pest management strategy and used less pesticides than IPM2. If higher emphasis is placed on the pesticide load, the NPP strategy, meaning no plant protection measures at all beyond one reduced dose of herbicide per year in the winter wheat years, is clearly better than others. Because some of the benefits of moving to lower pesticide load are externalities for farmers, there is a case for the government to consider expanding the current instruments used to promote IPM uptake.

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