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Pesticide Policies and Farm Behavior: The Introduction of Regulations for Integrated Pest Management

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Abstract: Integrated pest management (IPM) was introduced in the 1960s as a response to increasing pesticide use and has since evolved from being understood mainly as an economic issue to also including environmental and human health considerations. The EU has made IPM mandatory for all farmers through the Sustainable Use of Pesticides Directive (SUD). Using a mixed-methods approach, this paper examines how Norwegian cereal farmers have responded to this requirement. The qualitative results show that most farmers have an understanding of IPM that goes beyond economic considerations only. The quantitative results display that farmers' intrinsic motivation for IPM changed after introduction of the SUD. There is increased emphasis on using methods other than spraying, producing grain without traces of pesticides, and preventing pesticide resistance. Farmers' self-reported knowledge of IPM increased, and 41% of farmers stated that they use IPM to a greater extent than before the SUD was introduced. These results demonstrate that mandatory IPM requirements have been a successful strategy for increasing farmers use of IPM in Norway. Clearer IPM provisions and increased intrinsic motivation for IPM among farmers will, however, be important to reduce the risks from pesticides further.

Keywords: integrated pest management policies; regulation; farmer behavior

Citation: Kvakkestad, V.; Steiro, Å.L.; Vatn, A. Pesticide Policies and Farm Behavior: The Introduction of Regulations for Integrated Pest Management. *Agriculture* **2021**, *11*, 828. https://doi.org/10.3390/agriculture11090828

Academic Editor: Sanzidur Rahman

Received: 10 July 2021
Accepted: 26 August 2021
Published: 30 August 2021

1. Introduction

Pesticide policies are an important part of agricultural policy as it influences the profitability of farming, the environment and human health [1–4]. Policies for integrated pest management (IPM) could be an important strategy for ensuring that agriculture produces enough food for a growing population while keeping negative environmental impacts at an acceptable level [5,6]. IPM was developed in the 1960s in the United States in response to the increasing use of pesticides and their effects on farm productivity [7–10]. During the first 50 years of IPM development, the most common IPM measures were pest monitoring and economic thresholds for whether to spray or not [11,12]. When a FAO expert panel defined integrated control in 1967, economic considerations played a crucial role. This group defined integrated control as "a pest-management system that [. . .] utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury" [13] (p. 4). The current definition of IPM by FAO, however, includes increased emphasis on environmental considerations. They define IPM as "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment" [14] (p. 6).

A possible response to the need for increased adoption of IPM is to introduce legal provisions for IPM. In the EU, the Sustainable Use of Pesticides Directive (SUD) made IPM mandatory for all professional growers since 2014. The definition of IPM in this directive is largely inspired by the current FAO definition [15] and states that IPM implies keeping "the use of plant-protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimize risks to human health and the environment" [16] (Art. 3, p. 6). We observe that these IPM obligations imply that farmers should balance economic, environmental, and health aspects. However, the directive does not explicitly address how to handle trade-offs among these considerations.

Although many studies have examined farmers' adoption of IPM [17–21] as well as effects from environmental pesticide taxes on pesticide use [22–24], very few studies have examined how regulatory requirements for IPM influence farmers' pest management. The contribution of this paper is therefore to examine farmer responses to IPM regulations and how farmers perceive the importance of economic and ecologic considerations in IPM. The context for our study is Norwegian grain farming. As a member of the European Economic Area (EEA), Norway approved the SUD in 2015, triggering the enforcement of a new set of bylaws on pesticides [25]. We ask the following research questions:

(1) How do farmers understand the concept of IPM?
(2) Have farmers changed their pest-management goals, IPM knowledge, and behavior after IPM became mandatory? If so, what changes have been made?
(3) To what extent do farmers embrace IPM even if it reduces profits and what explains the variation in farmers' willingness to embrace IPM if it reduces profits?

2. Theory and Context

2.1. Farm Behavior

Since Gasson's [26] study of farmers' goals and their lifestyle appreciation, it is acknowledged that farmers' motivations go beyond profit maximization. Results from more recent studies of farmers' behavior generally support that farmers' adoption of more sustainable production methods deviates from pure profit maximization and that agri-environmental policy instruments designed within a pure neoclassical economics paradigm may be insufficient in reducing negative environmental externalities from farming [27]. Farmers' personality [28], farming objectives and intrinsic motivations [29–32], as well as norms and behavior within the farming community and the wider society [33,34] are found to influence farmers' decisions to adopt more sustainable practices.

Although IPM, in its early phase, focused mainly on economic thresholds, the current concept of IPM requires that farmers act differently from the rationality that is assumed in neoclassical economics. The current concept assumes that farmers will consider the environment and human health in their pest-management decisions. Empirical results on the importance of non-economic considerations for the adoption of IPM are somewhat ambiguous, however. Several studies report that the adoption of IPM practices has generally been below official policy goals (especially for arable and field crops) and that farmers rarely do more than adopting cost-effective and need-based pesticide spraying [10,12,35–37]. Farmers perceive lack of time and competing goals as potential barriers for adopting IPM [38–40]. A few studies have found some divergence from economic rationality. Social concerns (e.g., displaying environmental commitment) can drive IPM adoption [41] and some farmers adopt IPM mainly to reduce costs, while others were also motivated by environmental and health reasons [42]. Other studies document that farmers trained within an ecology-based IPM paradigm are more likely to reduce their pesticide use than are farmers trained within an economic threshold IPM paradigm [43] and that choices of EU farmers regarding natural pest control correlate with farm income, implying that farmers with higher income are more financially flexible and can adopt more costly and more environmentally sound pest-control methods [19]. Furthermore, some farmers find that maximizing yield is most important and pay less attention to maximizing net income in their pesticide decision-making [44]. This type of motivation could actually increase the use of pesticides beyond what is economically optimal.

2.2. The Norwegian Context

Norwegian grain production is characterized by relatively small units producing mostly cereal grains for the domestic market. The main grain types produced are barley, oats, and wheat. 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 [45]. The country has had an active policy for reducing risks from pesticides since the 1990s, and its pesticide consumption is low compared to other European countries. In 1999, an environmental tax on pesticides was introduced that taxes pesticides according to health and environmental risks [46]. Certification has been compulsory for professional users of pesticides since 1997, implying that farmers who want to use pesticides must have a valid certificate of authorization.

The first action plan for reducing risks from pesticides was introduced in 1990, and the action plan for 2010–2014 stated that by 2014 50% of farmers in Norway should use IPM [47]. In this action plan, IPM was defined as a "plant-protection strategy that combines various methods to combat pests while minimizing negative environmental impacts" [47] (p. 2, authors' translation). Other important information sources for farmers defined IPM somewhat differently; the National Quality System in Agriculture [48], the Norwegian Agricultural Extension Service [49], and the IPM site of a research institute under the Ministry for Agriculture and Food [50] instead defined it as applying "all techniques and methods that can be combined to keep the amount of pests below the level that causes financial damage" (authors' translation), placing more weight on economic thresholds.

When Norway adopted the SUD in 2015, IPM became mandatory for professional plant growers. The directive mandates that all professional users of pesticides must implement eight general principles of integrated pest management. These principles [16] are summarized as follows:

- P1: Using preventive measures such as crop rotation, certified seed and planting material, and pest-tolerant varieties;
- P2: Monitoring harmful organisms;
- P3: Using economic threshold values to decide whether or when to apply plant-protection measures;
- P4: Choosing non-chemical plant-protection products if they provide satisfactory pest control;
- P5: Choosing pesticides that have the fewest side effects for the environment and human health;
- P6: Keeping use of pesticides as low as possible, such as through reduced application frequency and reduced dosage;
- P7: Applying anti-resistance strategies;
- P8: Checking the success of applied plant-protection measures.

Principles 2, 3, and 6 concern need-based spraying, which implies not using more pesticides than necessary based on monitoring, using economic thresholds and using the lowest possible dosage. Principle 4 includes considering whether non-chemical alternatives provide satisfactory pest control. Principles 1 and 5 do not, however, include any formulations about economic considerations or considering what is necessary.

Random inspections of IPM are carried out by IPM checklists and the control of compulsory records of pesticide use. In these records, the farmers are to document which assessments they have made, any principles they applied, and a justification for their pest-management decisions [25]. Specific IPM guidelines for the most common crops have been developed. Economic policy instruments for IPM include support for weed harrowing and flaming of weeds.

The introduction of the SUD in Norway implied an increased emphasis on limiting the pesticide use to what is economically and ecologically justified. A guidance on the new regulation by the Norwegian Food Safety Authority state that "If there is an alternative method that is as effective as chemical pesticides, then the price difference should be disproportionately large between the two methods to justify pesticide use" and that "If, for example, mechanical control . . . will entail a disproportionate investment cost, then this may suggest that you can use chemical control" [51] (p. 30, authors' translation). Hence, farmers are required to accept a moderate economic loss if pesticide spraying could be reduced.

3. Materials and Methods

3.1. Research Strategy

We used a mixed method design to achieve validated and well-substantiated conclusions [52] regarding how Norwegian grain farmers perceive IPM and how they have reacted to new legal provisions for IPM. Combining quantitative and qualitative methods makes representativity possible as well as ensuring a deeper understanding of the involved motivations [53]. The purpose for this design is therefore to obtain different, but complementary data on the same topic to best understand the research problem. Qualitative data were collected before and after the collection of quantitative data to facilitate development of a more useful quantitative survey and provide a more thorough understanding of the survey results. This mixed methods approach is inspired by several other studies of farmers' behavior and adoption of sustainable farming practices that have followed a similar approach [54–58].

3.2. Description of Methods for Data Collection

The data collection included the following four elements (in chronological order):

A. In 2014 (before the SUD implementation), an internet-based survey was sent to a representative sample of 775 grain farmers in the six (including the former counties of Vestfold, Østfold, Hedmark, Oppland, Buskerud, and Akershus) largest grain-producing counties in Norway (from here, designated as the Prior-survey), with 335 completed responses. The survey was tested on several grain farmers before the final version was distributed.
B. Four focus groups were carried out after the implementation of the SUD in Norway. One focus group study was conducted in the fall of 2015 and the rest during 2016 and the winter of 2017. The dual purpose of the focus groups was to explore how farmers described or felt about IPM and to develop a more useful quantitative survey. The focus groups were conducted in four municipalities located in four (Østfold, Akershus, Hedmark, and Oppland) of the six counties. There were 7–9 farmers in each group. Farmers from these municipalities were recruited from the area subsidy register for grain farming, which includes all active grain farmers. Farmers were randomly selected and contacted by phone. About 80% of those answering agreed to participate. The reason for not participating were other obligations on that specific date or that they had a very limited grain area. The meetings lasted on average 3 h including a break. The farmers first discussed experiences with their own plant-protection strategies and then their views on IPM and the SUD. We combined open debates with rounds where each participant had to respond individually.
C. In November 2017, a survey (designated as Post-survey) was sent to a representative sample of 1250 grain farmers in the same six counties as for the Prior-survey. Because the responses to the Prior-survey had been anonymized, we could not aim for a panel data set. The internet-based Post-survey had 617 completed responses. This survey was tested on several grain farmers before the final version was distributed.
D. In the spring of 2018, qualitative interviews were conducted with a subsample of 24 farmers selected among those completing the Post-survey—four farmers from each of the six counties. The interviews were performed, after the Post-survey was completed, to provide a more thorough understanding of the Post-survey results.

The participants in both surveys were randomly selected from the area subsidy register for grain farming, which includes all active grain farmers within the six counties. The six counties constitute 79% of the country's grain area [59]. Only farmers with at least 10 ha were included in the samples to ensure that grain production was economically important for the farmer. Due to the focus on IPM and pesticides, only conventional farmers or farmers with both organic and conventional grain production were included.

3.3. Methods Used for Analysis

For the first research question (how farmers understand the concept of IPM), we used elements B, C, and D. The focus groups and the qualitative interviews provided knowledge about how IPM is understood among Norwegian farmers, and the Post-survey included questions about what increased use of IPM on their farm would mean for them. The dialogues of the focus groups and the interviews were first transcribed, and qualitative content analysis was used to locate descriptions of how the farmers understood the concept of IPM. The survey results were analyzed by calculating means and standard deviations (SD). We used SAS software for all statistical analyses in this paper.

For the second research question (whether farmers had changed their pest-management goals, IPM knowledge, or behavior after IPM became mandatory), we used all data sources. The Prior- and the Post-survey included identical survey questions about farmers' pest-management goals and IPM knowledge. The survey results were compared using *t*-tests and chi-square tests. Comparing relative changes between the two surveys are likely to yield a more accurate picture of possible changes than asking the respondent whether their IPM knowledge have increased or whether their pest management goals have become more in line with IPM. The Post-survey included a survey question about whether respondents had changed their use of IPM during the last five years and which changes they had undertaken. We chose to ask for changes during the last five years instead of asking for changes since SUD implementation to avoid making respondents feel obliged to report changes. The respondents were also asked to specify which changes they had made to increase the accuracy of their answers. The focus groups and the qualitative interviews included discussions about whether the respondents had increased their use of IPM in recent years, whether and how the SUD affected their pest management, and the effect of the requirement to record their pest-management decisions.

For the third research question (whether farmers embrace IPM even if it reduces profits and what explains the variation in farmer response to this issue), we analyzed variation in the responses to the survey item "I am positive about IPM even though it can entail reduced profits" in the Post-survey (element C). We used ordinary least squares (OLS) regression to analyze what could explain the variation. The survey included questions about farmers' pest-management goals, general farming goals, sources of advice about pest management, involvement with other farmers, as well as sociodemographic and farm characteristics. These variables were used as explanatory variables. The inclusion of explanatory variables was based on previous adoption studies [18,19,60] and results from the focus groups. We used an exploratory principal component analysis (PCA) with orthogonal varimax rotation [61] to reduce the number of survey items regarding farmers' pest-management goals and general farming goals to a smaller number of principal components. We assessed solutions with different numbers of components, and the components that were most representative were chosen. Items with loadings below 0.50, items with significant loading of more than one component, or communalities below 0.50 were deleted [61]. We developed summated scales by combining all items loading significantly on a component into a single composite measure, where the individual survey items were averaged. Since we used different Likert scales for the survey items, we used linear interpolation between the scales. The five points scale was converted to seven points before we developed the summated scales. We then checked for reliability. Item-to-total correlations above 0.50, inter-item correlations exceeding 0.30, and Cronbach's alpha above 0.60 are deemed acceptable in exploratory research [61]. We used the summated scales as measures in the regression.

The OLS regressions were checked for collinearity with variance inflation factors and condition indices.

4. Results

This section is divided into three subsections following the structure of research questions. In Section 4.1, we analyze how farmers understood the concept of IPM. In Section 4.2, we analyze whether farmers changed their pest-management goals, IPM knowledge, or behavior after IPM became mandatory, and in Section 4.3 we examine whether farmers embrace IPM even if it reduced profits, along with any variation among farmers concerning this issue.

4.1. How Do Farmers Understand the Concept of IPM?

The Post-survey, focus groups, and qualitative interviews provided information about how Norwegian grain farmers understand the IPM concept. The general picture from the focus groups and qualitative interviews is that most of the farmers have an understanding of IPM that corresponds well to most of the eight IPM principles in the new regulation. When asked what IPM is, many of the focus group farmers and those in the qualitative interviews mentioned considering several measures (including both non-chemical and chemical) and preventive measures. As one farmer said, "IPM is all measures you do before you touch your tractor sprayer". Another understanding among some of the farmers was that IPM is equivalent to good agronomy and that there is nothing new about the concept. A typical statement was that "they have introduced a new concept for things that I learned from my father and grandfather". Many farmers in the qualitative interviews and a few in the focus groups mentioned that IPM meant need-based spraying. A few of the farmers in the focus groups also mentioned measures such as seeking counselling, using anti-resistance strategies, and evaluating the measures.

Some of the farmers in the qualitative interviews mentioned weed harrowing when they were asked what IPM is, and they expressed distrust in the suitability of this technology for their farm. Some of these farmers reported that IPM is to "do weed harrowing and stop spraying" and that "reduced dosage is not IPM". One of the farmers in the qualitative interviews emphasized that IPM is to "not use pesticides". These understandings go beyond the aim of the SUD.

In the Post-survey, the farmers were asked what would happen if they increase the use of IPM in their grain farming and what such an increase would require. Table 1 shows that the farmers perceived that increased use of IPM foremost would require increased knowledge and more time. More than half of the farmers also perceived that increased use of IPM would increase yield risks. About half of the respondents disagreed that increased use of IPM would reduce yields and profits. This result indicates that only a minority of the farmers perceive IPM as entailing some sort of economic sacrifice. Most of the farmers in the focus groups were not explicit about whether practicing IPM meant some economic sacrifice or not. The farmers who emphasized that IPM is need-based spraying expressed that this practice in terms of economic thresholds is positive for farm profits. One farmer stated that IPM is "a moral principle that implies applying as little pesticides as possible", and several farmers expressed a similar sentiment without defining it as a moral principle. Two focus group members emphasized that IPM is holistic thinking to achieve good yield quality and high yields.

4.2. Pest-Management Goals, IPM Knowledge, and IPM Behavior before and after IPM Regulation

To generate knowledge about whether farmers changed their pest-management goals and knowledge about IPM after it became mandatory, we compared responses regarding these factors on the Post- and Prior- surveys. As shown in Table 2, the responses changed significantly for some of the pest-management goals. The most significant change was that using means other than spraying has become more important. This feature is a crucial part of IPM and could indicate that introduction of the SUD influenced pest-management goals. Two other important parts of IPM—preventing pesticide resistance and producing grain without traces of pesticides—have also become significantly more important for the farmers. Highest possible yields have become significantly less important and low workload significantly more important. Less emphasize on maximizing yields might ease the adoption of IPM, while more emphasize on low workload might reduce the adoption.

Table 1. Respondent perceptions about what increased use of IPM would imply for their farming (N = 617, Post-survey).

Increased Use of IPM in My Grain Farming Will [1]:	**Farmers' Response [1]**					**Mean**	**SD**
	1	**2**	**3**	**4**	**5**		
- Require that I acquire more knowledge	3.9%	7.8%	24.6%	37.3%	26.4%	3.75	1.05
- Require that I use more time on grain farming	4.9%	8.3%	30.5%	33.1%	23.3%	3.62	1.08
- Increase the yield risk	14.1%	18.5%	39.4%	19.8%	8.3%	2.90	1.13
- Reduce yields	25.0%	25.8%	35.5%	9.9%	3.9%	2.42	1.08
- Reduce profitability	26.7%	24.2%	38.3%	7.5%	3.4%	2.37	1.06

[1] Measured on a Likert scale (1 = fully disagree, 5 = fully agree).

Table 2. Differences in farmers' goals and knowledge prior to and after IPM became mandatory.

	2014	**2017 (N = 617)**		***p*, *t*-Test**
	Mean (SD)	**N**	**Mean (SD)**	
Which goals are important when you manage weeds and fungal pests? [1]				
- Producing grain without traces of pesticides	6.24 (1.44)	314	6.54 (0.90)	<0.001 **
- Preventing pesticide resistance	6.15 (1.19)	307	6.52 (0.75)	<0.001 **
- Highest possible crop quality	6.52 (0.84)	317	6.45 (0.80)	0.207
- Highest possible yields	6.40 (1.00)	313	6.21 (0.97)	0.033 *
- Highest possible profit	6.10 (1.20)	314	6.06 (1.03)	0.334
- Protecting the environment	5.85 (1.32)	313	5.85 (1.14)	0.982
- That fungal pests are entirely eradicated	5.30 (1.60)	313	5.35 (1.56)	0.589
- That weeds are entirely eradicated	5.10 (1.60)	313	4.92 (1.57)	0.193
- Low workload	4.10 (1.70)	312	4.64 (1.52)	<0.001 **
- Using other means than spraying	3.55 (1.81)	311	4.63 (1.44)	<0.001 **
Respondents' Self-Reported Knowledge of IPM	**N and % Share**	**N = 317**	**N and % Share**	***p*, χ^2-Test**
No knowledge of IPM	55 (18%)		38 (6%)	
Some knowledge of IPM	189 (61%)		272 (44%)	<0.001 **
Good knowledge of IPM	67 (22%)		307 (50%)	

[1] Measured on a Likert scale (1 = not important, 7 = very important,* $p \leq 0.05$, ** $p \leq 0.01$.

Although we observe significant changes in the farmers' goals in Table 2, we observe that pest-management goals such as producing grain without traces of pesticides, preventing pesticide resistance, and highest possible crop quality and yields were the four most important goals both before and after introduction of the SUD. Using means other than spraying, low workload, and complete eradication of weeds were the least important goals in both periods.

The results in Table 2 also show that the farmers' self-reported knowledge of IPM had increased significantly from 2014 to 2017, indicating that introduction of SUD had this effect. The fact that several of the farmers in the qualitative interviews and focus groups reported that IPM is nothing new could, however, indicate that they have increased knowledge of the term "IPM", but not so much about the practices captured by the term.

For example, farmers certainly knew about crop rotation prior to the introduction of the SUD, but they did not call it "IPM".

To examine whether farmers changed their behavior after IPM became mandatory, the respondents in the Post-survey were asked whether they had changed their use of IPM during the last five years. The results in Table 3 indicate that more than 40% of the farmers began using IPM to a greater extent whereas most reported using IPM to the same extent as before. Less than 5% reported using IPM to a lesser extent. For more concrete responses from farmers who reported increased use of IPM, we asked them to specify which IPM measures they had adopted. The measures most frequently adopted represent different aspects of IPM, including need-based spraying (e.g., monitoring, reduced dosage), preventive measures (e.g., crop rotation, tolerant crop, and soil tillage), and preventing pesticide resistance.

Table 3. Farmers' self-reported change in the use of IPM during the last 5 years [1] and the most frequent measures adapted (N = 617, Post-survey).

Change in Use of IPM	N	Share (%)
Use IPM to a lesser extent	22	4
Use IPM to the same extent	342	55
Use IPM to a greater extent	253	42
Most frequent measures adopted (by the farmers that use IPM to a greater extent)		
Monitoring	98	39
Crop rotation	75	30
Reduced dosage	57	23
Use varieties that are tolerant to fungal pests and cover for weeds	45	18
Increased soil tillage	44	17
Need-based spraying in general	42	17
Preventing pesticide resistance	41	16
Choose pesticides that are specific and environmentally friendly	23	9
Prefer measures at the optimal time	22	9
Less spraying	21	8
Weed harrowing	20	8
Spot spraying	13	5
Use of economic thresholds	12	5
Use of VIPS (a web-based forecasting system for agricultural pests and diseases)	10	4

[1] Farmers were asked, "Compared to what was normal about 5 years ago, do you use IPM to a greater extent now?"

To gain more in-depth knowledge about how the SUD has influenced farmers' crop-management practices, the focus groups and the qualitative interviews included questions about these issues. Farmers who had increased their use of IPM stated that they had become more conscious about treatment deadlines, dosage, weather conditions, time of spraying, and using preventive measures such as cover crops and increased soil tillage (e.g., plowing, harrowing). The farmers who had not increased their use of IPM the last 5 years reported that they have been practicing IPM for several years. An interesting finding from these interviews is that several of the farmers reported that their greatest change in pest management was the adoption of need-based spraying and that this change happened 10–15 years ago. According to them, this change was triggered by information from the Norwegian Extension Service and environmental pesticide taxes. One of the farmers said, "In the 1990s, pesticides were cheaper, so then we sprayed to be certain. We bought pesticides before we had observed the crop".

The farmers in the focus groups and qualitative interviews reported that the most concrete change following the SUD was the obligation to record the assessments made and any principles applied and to offer a justification for their choices if pesticides were used. The farmers were divided, however, regarding whether the record obligation influenced their pest management. Those who felt that the obligation to record influenced their pest management reported that it made them more conscious and made them think twice. As one of the farmers said, "I think it sharpened us a bit! We need to think about it because we have to write some words about it". The farmers who expressed that the record requirements had not affected their pest management felt that it had no practical consequences and was about post-rationalization and adjusting the pesticide record to their spraying practices and not vice versa. One of the farmers said, "What I write in the pesticide record, I adjust to the spraying. It should have been put up in a way that forced me to think a bit differently". Several of the farmers in the focus groups and the qualitative interviews also expressed some frustration concerning the pesticide record obligation. They felt that it resulted in more paperwork, along with being humiliating by forcing them to justify their choices, and that doing good work in their field should be more important than writing good sentences. One of the farmers asked, "Why should I document something that I always have been doing?" Some of the farmers were also uncertain about the practical implications of the pesticide record obligation. They were uncertain whether "the authorities are going to judge the decisions". They felt unsure about whether their farm subsidies could be reduced based on what they write in the record and whether they could, e.g., write year after year that they did not have access to a weed harrow.

4.3. Do Farmers Embrace IPM Even If It Reduces Profits?

In the Post-survey, the farmers were asked whether they felt positive about IPM even though it could entail reduced profits. The results in Table 4 show that the farmers were quite divided on this issue.

Table 4. Respondent attitudes to IPM if it implies reduced profits (N = 617, Post-survey).

	Farmers' Response [1]						
	1	**2**	**3**	**4**	**5**	**Mean**	**SD**
I am positive about IPM even though it can entail reduced profits [1]	8.1%	18.5%	36.3%	24.0%	13.1%	3.16	1.12

[1] Measured on a Likert scale (1 = fully disagree, 5 = fully agree).

An important question that can offer suggestions about how to ensure farmers' adoption of IPM measures that can entail moderate economic losses such as preventive measures, is how different variables correlate with farmers' willingness to adopt IPM practices even though doing so can reduce profits. To answer this question, we ran an OLS regression model with the survey item, "I am positive about IPM even though it can entail reduced profits", as the dependent variable. Table 5 presents the mean response to the independent variables that were included in the OLS regression model.

To reduce the number of items regarding goals and attitudes (A and B in Table 5), we used PCA to detect the links among the 18 items regarding what was important for the farmers in general and when they manage weeds and fungal diseases (A and B). We removed three items associated with low communality and/or cross-loading from the final PCA model, as presented in Table 6. Four components were extracted. One item was removed from the second component because of reliability problems. The Kaiser–Meyer–Olkin overall measure of sampling adequacy for the final model was 0.85.

Table 5. Independent variables as based on questions from the Post-survey (N = 616 [1]).

		Mean	SD
A.	How important are the following aspects to you as a farmer? [2]		
-	Contribute to food production in Norway	4.67	0.61
-	Being up to date in terms of knowledge	4.59	0.61
-	Being a skillful grain farmer	4.54	0.68
-	Limiting losses of soil nutrients	4.47	0.67
-	Satisfactory income	4.46	0.75
-	Protecting biodiversity	4.27	0.80
-	Highest possible income	4.23	0.79
-	Limiting the use of chemical pesticides	3.96	0.95
B.	Which aspects are important when you manage weeds and fungal pests? [3]		
-	Producing grain without traces of pesticides	6.54	0.90
-	Preventing pesticide resistance	6.52	0.75
-	Highest possible crop quality	6.45	0.80
-	Highest possible yields	6.21	0.97
-	Highest possible profit	6.06	1.03
-	Protecting the environment	5.85	1.14
-	That fungal pests are entirely eradicated	5.35	1.56
-	That weeds are entirely eradicated	4.92	1.57
-	Using other means than spraying	4.63	1.44
-	Low workload	4.64	1.52
C.	Where do you get advice and knowledge about pest management?		
-	Certification course for the use of pesticides [D] (1 = yes)	0.68	
-	The Norwegian agricultural extension service [D] (1 = yes)	0.66	
-	Professional growers' journals [D] (1 = yes)	0.56	
D.	Communicating with other farmers about pest management [D] (1 = weekly or more often)	0.62	
E.	Sociodemographic farmer variables and farm characteristics		
-	Age (year of birth)	1964	10.9
-	Sex [D] (1 = male)	0.93	
-	Higher education (university or similar) [D] (1 = yes)	0.35	
-	Agricultural education [D] (1 = no)	0.37	
-	Working position outside the farm [D] (1 = yes)	0.66	
-	Not disclosed any information on income from agriculture [D] 1 = (yes)	0.08	
-	Low income from agriculture [D] (1 = yes)	0.23	
-	High income from agriculture [D] (1 = yes)	0.25	
-	Size of grain area (hectare)	367	303

[1] One of the 617 completed answers had to be removed because of missing response. [2] Measured on a Likert scale (1 = not important, 5 = very important). [3] Measured on a Likert scale (1 = not important, 7 = very important). [D] means dummy variable, 0 = otherwise.

Table 6. Results from PCA of respondent evaluations of (1) which conditions are important for them as farmers and (2) what is important for them when they manage weeds and fungal diseases (Post-survey, N = 616).

	Varimax Rotated Loadings [1]				
	1. Economy	**2. Environment**	**3. Quality & Resistance**	**4. Clean Fields**	**Communality**
Highest possible income. [2]	**0.82**	0.06	0.02	0.17	0.70
Satisfactory income. [2]	**0.77**	0.25	0.03	−0.01	0.65
Highest possible profit. [3]	**0.72**	−0.03	0.33	0.24	0.69
Highest possible yield. [3]	**0.67**	0.02	0.32	0.33	0.67
Being a skillful farmer. [2]	**0.63**	0.27	0.28	0.01	0.55
Protecting biodiversity. [2]	0.27	**0.83**	0.12	0.01	0.78
Limiting the use of chemical pesticides. [2]	−0.04	**0.76**	0.11	0.21	0.64
Limiting the loss of soil nutrients. [2]	0.35	**0.69**	0.20	0.03	0.64
Protecting the environment. [3]	−0.00	**0.68**	0.42	0.04	0.63
Preventing pesticide resistance. [3]	0.22	0.22	**0.76**	0.04	0.67
Highest possible crop quality. [3]	0.37	0.10	**0.70**	0.06	0.65
Producing grain without traces of pesticides. [3]	0.03	0.29	**0.66**	0.08	0.52
That weeds are entirely eradicated. [3]	0.20	0.05	0.02	**0.91**	0.86
That fungal diseases are entirely eradicated. [3]	0.15	0.18	0.13	**0.88**	0.85
					Total
Sum of squares (eigenvalue).	5.20	1.90	1.41	1.01	9.52
Percentage of variance.	0.37	0.14	0.10	0.07	0.68

[1] α = 0.84 for component 1. α = 0.81 for component 2. α = 0.68 for Component 3. α = 0.85 for Component 4. α is Cronbach's alpha reliability coefficients (standardized variables). Component loadings > |0.50| in bold. [2] Respondent evaluations of which conditions are important for them as a farmer. [3] Respondent evaluations of what is important for them when they manage weeds and fungal diseases.

The first component was termed Economy and covers economic considerations as well as yield and being a skillful grain farmer. The second component was termed Environment and covers different environmental considerations such as protecting biodiversity, low use of pesticides, loss of soil nutrients, and protecting the environment in general. The third component, 'Crop quality and resistance', is more heterogeneous than the others. Two of the items concern crop quality in general and grain without traces of pesticides. The third item concerns preventing pesticide resistance. The mean for these three items is higher than for the other items and the standard deviation is lower (see Table 2). The fourth component, 'Clean fields', concerns the importance of entirely eradicated weeds and diseases. This component represents the opposite of IPM.

The results from the OLS regression in Table 7 identify factors that make a farmer more likely to be positive about IPM even though it can entail reduced profits. These features include being environmentally engaged, female, and reporting having received advice and knowledge about pest management from the certificate course, all but one with significance levels $p \leq 0.01$. Of note, we found that the variable 'Economy' was highly significant, and as expected, with the opposite sign. We further observe that farmers communicating often with other farmers about pest management ($p < 0.05$) and farmers of younger age ($p < 0.01$) are more likely to be negative to IPM if it means reduced profits. There seems to be a tendency that farmers with high income from agriculture ($p < 0.1$) are more likely to be positive about IPM even though it can entail reduced profits. The opposite tendency exists for farmers not wanting to report income from agriculture ($p < 0.1$).

Table 7. Regression model for response to the item "I am positive about IPM even though it can entail reduced profits" [1] (Post-survey, N = 616). Prob > F < 0.0001.

	Coef.	Std. Err.	*p* > *t*
Intercept	29.97	8.11	<0.001 ***
Attitudes and goals (components presented in Table 6)			
- Component 'Economy'	−0.21	0.06	0.001 ***
- Component 'Environment'	0.32	0.05	<0.001 ***
- Component 'Crop quality and pesticide resistance'	0.04	0.09	0.633
- Component 'Clean fields'	−0.02	0.03	0.526
Advice and knowledge about pest management			
- Certification course for the use of pesticides D (1 = yes)	0.27	0.09	0.003 ***
- The Norwegian agricultural extension service D (1 = yes)	0.11	0.10	0.256
- Professional growers' journals D (1 = yes)	0.12	0.09	0.164
Communicating with other farmers about pest management D (1 = weekly or more often)	−0.19	0.09	0.033 **
Sociodemographic farmer variables and farm characteristics			
- Size of grain area (hectare)	−0.00	0.00	0.354
- Age (year of birth)	−0.01	0.00	<0.001 ***
- Gender D (1 = male)	−0.42	0.17	0.013 **
- Higher education (university or similar) D (1 = yes)	0.14	0.09	0.143
- Agricultural education D (1 = no)	0.05	0.09	0.613
- Working position outside the farm D (1 = yes)	0.11	0.10	0.271
- Not disclosed any information on income from agriculture D 1 = (yes)	−0.31	0.17	0.064 *
- Low income from agriculture D (1 = yes)	−0.05	0.11	0.631
- High income from agriculture D (1 = yes)	0.21	0.12	0.074 *
R^2	0.1511		
Prob > F			<0.0001 ***

[1] Measured on a Likert scale (1 = not important, 5 = very important). * $p \leq 0.10$,** $p \leq 0.05$, *** $p \leq 0.01$. D means dummy variable, 0 = otherwise.

5. Discussion

The contribution of this paper concerns the effects of introducing legal provisions for IPM, farmers understanding of IPM and their willingness to adopt IPM if it reduces profits. The IPM definition in the SUD included keeping the use of plant protection products to levels that are *economically and ecologically justified* and *reduce or minimize risks to human health and the environment.* It is, moreover, concretized by eight principles. Our qualitative results regarding research question one show that for most of the farmers, their understanding of IPM corresponds well with the eight IPM principles. This means that their understanding goes beyond economic thresholds and need-based spraying which were the core elements of IPM when it was introduced in the 1960s. Some of the farmers did, however, perceive IPM to imply not using pesticides. The quantitative results show that most farmers believed that increased use of IPM would require more knowledge and time, but they largely disagreed that it would reduce yields and profits. When interpreting the latter finding, one should note that important information sources for farmers (like the Norwegian Extension Service and the Norwegian Food Safety Authority) have given somewhat mixed signals to farmers, regarding economic and ecologic considerations (see Section 2.2).

Regarding research question two, our quantitative results indicate that the implementation of the SUD have been accompanied with a significant increased knowledge of IPM as well as a change in farmers' pest-management goals. These goals have become more in line with IPM. More than 40% of the farmers reported having increased their use of IPM during the last five years. This indicates that the implementation of the SUD has had an important impact on farmers use of IPM and their intrinsic motivation. A majority of the famers are, however, using IPM to the same extent as before. Several explanations are possible for this latter finding. First, many Norwegian grain farmers were to a large extent using IPM also before the SUD came into force [62]. Several of the interviewed farmers reported already having practiced IPM for many years and that this practice was triggered by pesticide taxes introduced in 1999 and the emphasize on need-based spraying by the national extension service. Second, the availability of new IPM tools is quite limited in Norway [63]. The qualitative data revealed that the farmers perceived weed harrowing as one of the few new measures that they could use, but most of them distrusted the suitability of this measure for their farm. Third, reducing dependence on pesticides is not only a matter of changes at the farm level but also depends greatly on market conditions. Several of the farmers in the focus groups reported that new quality requirements for wheat for human consumption implied increased use of fungicides.

Research question three concerned whether farmers embrace IPM even if it reduces profits. The qualitative results show that the farmers were quite split in their responses. Regression results show that the intrinsic motivation of the farmers as well as gender and the use of different information sources had a significant effect on their response to this issue and in the expected direction. More surprisingly, we observed that younger farmer and farmers communicating often with other farmers about pest management are more likely to be negative to IPM if it means reduced profits. A possible explanation is that younger farmers are more dependent on their farm income than older farmers and that farmers communicate with other farmers about pest management to achieve the best possible agronomic and economic management of their pests and thus are less likely to accept reduced profits.

An important question is how farmers' adoption of IPM could increase in the future. Our qualitative results document that some of the farmers were uncertain about what is required from them regarding IPM and what kind of penalties that could be implemented. IPM is a complex concept that includes several principles, decision-making procedures, and considerations (economic and environmental considerations) [64]. These factors make IPM difficult and costly to control [65] and farmers' uncertainty about what is required will be high. Hence, it might be necessary to develop clearer criteria for how farmers should apply the general principles of IPM and how it should be measured and controlled. The European Commission will in fact revise the SUD as a response to these shortcomings [66]. It would, however, be wise to combine clearer provisions with increased attention on building intrinsic motivation for IPM among farmers to increase adoption and reduce control costs. Our regression results for research question three show that the attitude components 'Environment' and 'Economy' had significant effects in the expected direction on the farmers' response to embracing IPM even though it could entail reduced profits. This is in line with results from other empirical studies that are quite unambiguous in showing that adopting sustainable agronomic practices is negatively correlated with economic objectives, and positively correlated with environmental objectives [27]. Hence, increased environmental engagement among farmers can ease the adoption of IPM. A holistic approach addressing different behavioral factors is, however, needed to change farmers intrinsic motivation [67] and this could be a painstaking and uncertain process. Our regression results from research question three indicate that certification course for the use of pesticides could be an important arena for building intrinsic motivation for IPM.

It is important to note that our results are based on survey answers and statements from farmers in focus groups and personal interviews and not on observations of what they do or what they think. Misunderstanding of questions and distorting answers to look good are examples of errors that could reduce the possibility to produce data that can be used to answer our three research questions [68]. We have, however, undertaken measures to reduce errors associated with answers. Both surveys were tested on farmers and survey questions were formulated to increase the farmers willingness to report accurately (see

Section 3.3). Our experience with the qualitative data is that the farmers were honest and consistent in their replies and that they saw it as an opportunity to express their opinion. We observed no major differences between the replies from the farmers in the focus groups and the personal interviews. For some of the focus groups, there was a tendency that some of the farmers gave similar responses as those who seemed to be highly experienced farmers in the group. We tried to avoid this by changing the directions of the rounds where each participant had to respond individually.

6. Conclusions

In this paper we analyzed the implications of introducing the EU Sustainable Use of Pesticides Directive (SUD), which made IPM mandatory for all professional users of pesticides, for grain farming in Norway. The first research question concerned how the Norwegian grain farmers understand the concept of IPM. Our results show that their understanding of IPM corresponds well with the eight IPM principles in the SUD and their understanding goes beyond economic thresholds and need-based spraying. Most farmers believed that increased use of IPM would require more knowledge and time, but they largely disagreed that it would reduce yields and profits. The second research question was whether farmers have changed their pest-management goals, IPM knowledge, and behavior after IPM became mandatory. We found that the directive has made farmers' pesticide goals more in line with IPM and that a substantial share of the farmers increased their knowledge and use of IPM. While 22% of the grain farmers reported good knowledge of IPM in 2014, the corresponding number was 50% in 2017 and 42% of the farmers reported that they use IPM to a greater extent than before. The third research question concerned to what extent farmers embrace IPM even if it reduces profits and what explains the variation in farmers' response to this issue. The results indicate that the farmers are quite split when it comes to being positive to IPM if it entails reduced profits. The regression results show that the attitude components 'Environment' and 'Economy' as well as gender and using advice on pest management from a mandatory certification course had significant effects in the expected direction. Younger farmers and farmers that communicate often with other farmers about pest management are more likely to be negative to IPM if it means reduced profits.

There is a need for similar research in other European countries that have implemented the SUD. The early introduction of pesticide taxes in Norway in the 1990s, the focus on need-based spraying in the last decades and the border protection of Norwegian grain production might imply that Norway is a 'special case'.

Author Contributions: Conceptualization, V.K., Å.L.S. and A.V.; methodology, V.K., Å.L.S. and A.V.; investigation, V.K. and Å.L.S.; formal analysis, V.K., A.V. and Å.L.S.; writing—original draft preparation, V.K.; supervision, Å.L.S. and A.V.; project administration, V.K.; funding acquisition, V.K. and A.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by The Research Council of Norway through the STRAPP project (project number 221394) and the SMARTCROP project (project number 244526). The funder had no influence on the design of the study.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: The processing of personal data was approved by the Norwegian center for research data and all participants were provided the information they need to make the decision to participate.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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