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Fostering Sustainable Potato Production: A Collaborative European Approach

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Abstract: Potato production faces increasingly severe agronomic problems, including intensive production and pedoclimatic changes. Increasing pest/disease incidence is contributing to inadequate application of pesticides and external fertilizers. This study aims to identify critical agri-environmental challenges currently faced by potato growers in Europe, assessing the needs and priorities of end-users to determine the feasibility of integrating more sustainable farming practices into potato cultivation. Additionally, we identified sustainable strategies to reduce reliance on external inputs. A total of 203 potato stakeholders from six European pedoclimatic areas completed a survey in 2020 to identify agronomic and environmental problems, priorities for action, and best-suited sustainable farming practices. Statistical and multicriteria decision analysis was then performed. Subsequently, focus group meetings with stakeholders were organized to present and discuss results and validate and complement them. Stakeholders perceived that more sustainable potato production involved reducing tillage intensity, using organic nutrient sources, increasing soil organic matter and, especially, diversifying crop rotations. Barriers to adopting new sustainable practices included farmers' lack of knowledge regarding novel farming practices and the need for expert technical advice. Some practices are complex, but also economic impediments. Therefore, thorough research, clear demonstrations, and tailored advice are crucial to farmers to lead agriculture toward profitable, sustainable systems.

Keywords: potato production; agricultural practices; sustainable farming; stakeholders' perception; multicriteria decision method (MCDM); soil conservation

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1. Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important crop produced in the world, with China being the main producer (64.2% of worldwide production) [1]. The European Union (EU) is a significant producer of potatoes, cultivating 1.5 million hectares of land in

2020 to yield 53 million tons. This represents around 1.5% of the EU's total arable land [2]. Potatoes are consumed by more than a billion people worldwide and are a major source of employment and income in rural areas [3]. Their availability, accessibility, and quality are, therefore, essential for ensuring food security worldwide [4].

Potatoes, with their shallow root system, are particularly sensitive to many threats, including global climate change, extreme climatic events and water scarcity. This is especially true during critical growth stages like stolonization, tuber initiation, and yield formation; changing climatic conditions can raise the incidence of pests and diseases [5,6]. The main environmental threats to potato production sustainability in Europe are related to soil degradation (wind and water erosion, declining soil carbon levels, compaction, contamination, salinization and soil biodiversity loss) [7]. That degradation is primarily caused by conventional intensive tillage practices, limited crop diversification (even continuous cropping in some areas), especially in Southern Europe [8], a lack of soil vegetation covers after the main crop is harvested, and inadequate soil conservation practices [9]. Additionally, potato production requires large amounts of fertilizers [10], which may cause soil-water pollution [11] and greenhouse gas (GHG) emissions, as well as multiple severe impacts on ecosystems and human health [12].

Furthermore, potatoes are especially vulnerable to numerous pests and diseases that negatively affect crop yield and quality. Therefore, sustainable agricultural practices (SAP) that include innovations are essential for the development of potato varieties with reduced water needs, increased pest and disease resistance, and improved resilience to climate change [13]. The most common diseases affecting potato production are Late and Early Blight (*Phytophthora infestans* and *Alternaria*), bacterial wilt (*Ralstonia solanacearum*), and potato blackleg (*Pectobacterium* and *Dickeya*). The most common pests are the Colorado potato beetle (*Leptinotarsa decemlineata*), the potato tuber moth (*Phthorimaea operculella*), the leaf miner fly (*Liriomyza huidobrensis*) and cyst nematodes (*Globodera*), which are commonly controlled through the application of pesticides [5]. Around 2.4 million tons of pesticides are applied annually worldwide, 350,000 tons of which are used in the European Union [2]. Diffuse pollution caused by this excessive pesticide use persists in soil and water, severely impacting ecosystems and food webs and affecting soil functionality, biodiversity, food safety and human health [14,15].

SAP are needed in order to ensure the long-term viability of potato production whilst protecting the environment by enhancing soil biodiversity and fertility [16]. In this regard, a relevant demand is increasingly seen in a greater willingness to pay for agricultural products produced using sustainable practices [17]. SAP in the potato sector are focused on four objectives: (1) economic efficiency and food security by providing nutritional quality; (2) enhancement and sustainability by conserving natural resources and avoiding GHG emissions; (3) contributing to market needs by supporting farming enterprises; and (4) meeting cultural and social demands within society [13]. The most common sustainable agricultural practices for potato farming focus on soil management [12] (reducing soil erosion, adequate fertilizer dosing, restoring soil organic carbon, avoiding soil compaction and maintaining soil structure and biodiversity) [6], rotations and intercropping with villous vetch resulted in higher potato tuber yield [18] and water use efficiency (reducing evapotranspiration, minimizing drainage, preventing soil salinization, using irrigation schedules and maintaining permanent soil cover in winter) [4].

With this in mind, the European Commission has launched several policy initiatives in recent years, such as the EU Green Deal in 2020, the Farm to Fork Strategy in 2020, the EU Biodiversity Strategy for 2030 in 2020, the Chemicals Strategy for Sustainability in 2020, the New EU Strategy on Adaptation to Climate Change in 2021, the Organic Farming Action Plan in 2020, the Zero Pollution Action Plan for Air, the New Soil Strategy in 2023, the Fertilizing Product Regulation revision in 2022, the new Sustainable Pesticide Use Directive and the Fit for 55 Climate Package in 2021 [19]. For the period 2023-27, the common agricultural policy (CAP) in 2021 seeks the adoption of good and fair agricultural practices that prevent soil loss and promote land restoration in the EU, the reduction in the application of inorganic fertilizers and phytosanitary treatments, and the conservation of soil nutrients that are beneficial for soil protection [20]. The adoption of environmentally sustainable practices, linked to the "Farm to Fork" strategy [20], is an opportunity for farmers to save costs and time and increase the quality and production of crops, such as potatoes, while decreasing the environmental impacts and improving ecosystem preservation [5].

The challenge of addressing the above problems is a complex task that implies redefining farming practices to ensure more sustainable potato production. The different features of cropping systems and pedoclimatic conditions require specific assessments of the capacity of different farming practices to resolve each area's problems and adapt to the needs of farmers while meeting the demands of society. This involves relying on new scientific evidence as well as on local stakeholders' practical knowledge. We hypothesized that stakeholders face several barriers to adopting the most sustainable agricultural practices, primarily skepticism towards new alternatives and farmers' lack of knowledge regarding the effectiveness of such practices. The objectives of our study were to (1) identify the most effective farming practices to increase the sustainability of potato production in six representative European study areas, (2) assess the practical potential for their implementation in potato cropping systems, and (3) validate them in focus groups with stakeholders.

2. Materials and Methods

2.1. Pedoclimatic Regions and Study Areas

The study covers five European countries (Spain, Belgium, Germany, Estonia, and Finland) and six pedoclimatic regions, namely Mediterranean South (MDS), Lusitanean (LUS), Atlantic Central (ATC), Continental (CON), Nemoral (NEM), and Boreal (BOR) (Figure 1 and Tables 1 and 2). All case-study areas are large potato-producing sub-regions, which in all cases is also the most important root crop in terms of both area and production.

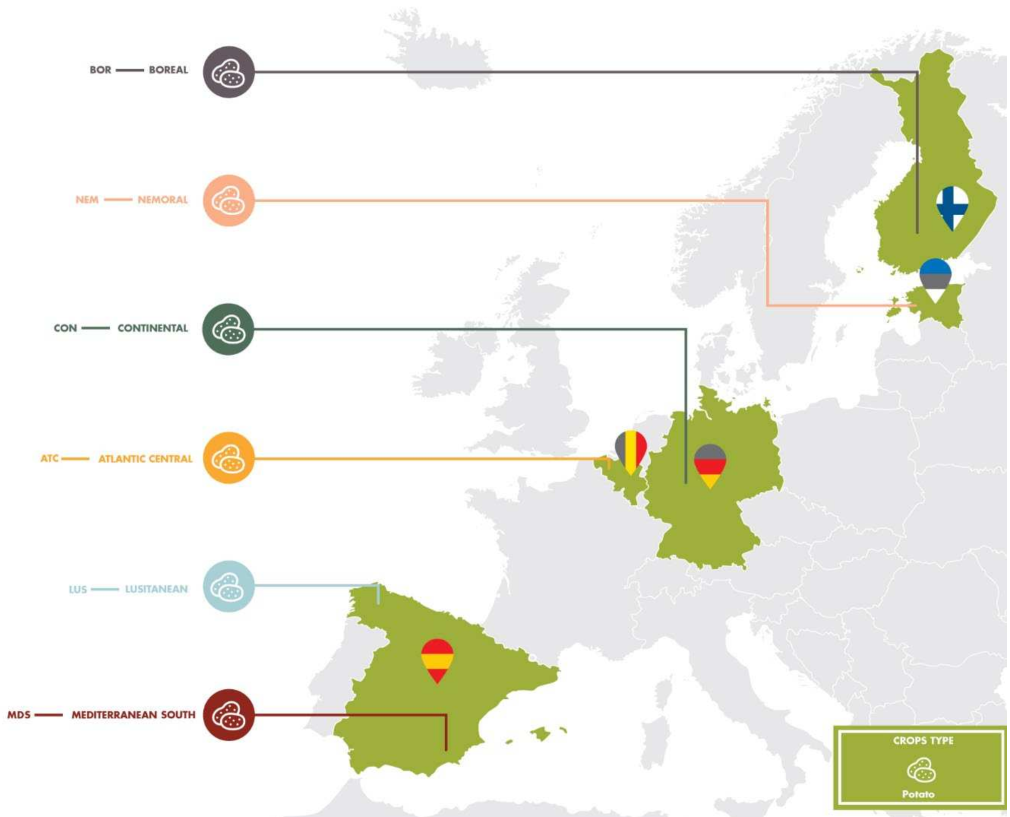

Figure 1. Location of case study areas and pedoclimatic regions.

Table 1. Partners overview common agricultural practices, the main problems in each region, and the use of pesticides in agriculture.

Bioregion/Country	Common Agricultural Practices	Main Problems	Pesticides in 2020 (kg/ha) *
Mediterranean South, Spain	- Water scarcity - High tillage - Low nutrient availability due to high pH	- High incidence of nematodes	4.6
Lusitanean, Spain	- High use of MO - High use of P input	- Spread of common scabies - Low P availability	
Atlantic Central, Belgium	- High tillage - High external input of organic matter	- Soil diseases - High soil erosion - Soil fertility - High P in soil	6.4
Continental, Germany	- High pesticide inputs - Intensive tillage	- Late blight disease	4.0
Nemoral, Estonia	- High pesticide inputs - High tillage intensity	- Fungal pests - Reduce functional soil biodiversity - Contaminated with mycotoxins by rotations with grains	1.1
Boreal, Finland	- Intensive systems - Deep ploughing - Irrigation and mineral fertilization	- Soil erosion risk - Loose soil organic carbon - Eutrophication risk	2.2

* Eurostat (2020) [2].

Table 2. Potato cultivation and climate conditions in the pedoclimatic regions of the case study areas.

Case Studies	Code	Potato Acreage in the Case Study Area (ha) (2020)	Production (Tons) (2020)	Efficiency Ratio (Tons/ha)	Average Temperature (°C)	Average Rainfall (mm/Year)
Mediterranean South, (Murcia) Spain	MDS [a]	4592	168,623	36.72	17 (1996–2020)	312 (1996–2020)
Lusitanean, (Galicia) Spain	LUS [b]	16,003	283,667	17.72	13.6 (1981–2010)	1299 (1981–2010)
Atlantic Central, Belgium	ATC [c]	38,833	1,584,753	40.80	11 (1991–2020)	837 (1991–2020)
Continental, Germany	CON [d]	100,700	3,973,800	39.46	9.3 (1991–2020)	791.4 (1991–2020)
Nemoral, Estonia	NEM [e]	3369	94,414	28.02	6.4 (1991–2020)	661 (1991–2020)
Boreal, Finland	BOR [f]	20,700	624,400	30.16	6.5 (1991–2020)	653 (1991–2020)

[a] Sistema de información agrario de Murcia. [b] Anuario de estadística (2020) Ministerio de Agricultura, pesca y alimentación. [c] Statbel. [d] Statistisches Bundesamt. [e] Statistics Estonia. [f] Natural Resources Institute Finland.

2.2. Potato Agronomical Situation: A Regional Overview

In order to design effective surveys for each region, we consult with the project partner regarding the main problems and strategies used. A detailed overview of this consultation is presented in Table 1, such as the use of pesticides in each pedoclimatic region.

Across Europe, potato growing practices vary significantly by region (as shown in Table 1), ranging from water scarcity in the Mediterranean area of Spain to high pesticide use in Germany and Estonia, for example. The main problems faced by potato growers are health problems, with erosion, carbon loss and eutrophication also of concern in Belgium and Finland and soil P content in the Lusitanean area of Spain and Belgium. The levels of pesticide use at the agricultural level in general are highest in Belgium (6.4 kg ha^{-1}), followed by Spain (4.6 kg ha^{-1}), and lowest in Estonia (1.1 kg ha^{-1}). On the other hand, we see in the literature that potato farmers use much lower amounts than the average of their countries, referred to 2018, being 4.9 kg ha^{-1}, 2.7 kg ha^{-1}, 2.5 kg ha^{-1} in Belgium, Germany and Spain, respectively and 0.6 kg ha^{-1}, for Finland and Estonia [5].

Referring to the productions of the different countries in 2020 (Table 2), we see that the highest productions occur in Germany, followed by Belgium and Finland, with Estonia being the country that produces the least with less than 100,000 t. We see, however, that the highest production efficiency per unit area occurs in Belgium (40.80 t ha^{-1}), followed by Germany and the Mediterranean area of Spain, coinciding with the highest values in pesticide use cited.

Some of the agronomic problems of potato production in the case-study areas identified prior to this study were related to the incidence of pests and diseases and to their control, especially with cyst nematodes in LUS and MDS and with fungi pests in Germany and Estonia. Alternative approaches are needed to avoid incurring substantial production costs associated with current practices to achieve optimal yields and effective pest control. In the case of MDS, LUS, Belgium, and Finland, the pedoclimatic characteristics, the use of intensive tillage and the prevalence of continuous cropping are linked to soil organic matter degradation, low plant nutrient content (with both nitrogen and phosphorus), and a low soil nutrient content which requires the application of large amounts of external fertilizers.

2.3. Survey to Stakeholders

Potato farmers and stakeholders were surveyed using a common structured questionnaire that was adapted to each case study by adjusting the lists of agronomic problems and farming practices to their particularities. The questionnaire was translated into each country's native language to reach all stakeholders in the study areas. The questionnaire was structured into the following five sections:

Section 1. A brief explanation of the project, the purpose of the survey, and the respondent's informed consent are required to be signed by each respondent before the questionnaire can be filled out.
Section 2. General respondent information (gender, age, type of stakeholder, etc.).
Section 3. Identification of the most relevant agronomic and environmental problems of potato production in the area (choice from a list of options) and qualitative assessment of their severity.
Section 4. Identification of end-users' needs through a qualitative assessment of the priority that should be given to different objectives related to the major agronomic and environmental problems of potato production in the area.
Section 5. Identification of the farming practices best suited to addressing the previously identified problems. Farming practices were grouped into tillage, fertilization, soil conservation, and pest/disease control practices. Each respondent could choose from a list of practices and add other practices not included in the list.

The samples for each country and the contact lists were formed with help from farmers' associations and agricultural cooperatives and companies. Surveys were conducted in 2020 using the SurveyMonkey® online surveying platform 2.0.50. version (https://surveymonkey.com, accessed on 20 November 2020), which allowed respondents to answer using a computer, tablet, or smartphone. Survey answers were reviewed to check for inconsistent answers, and incomplete questionnaires were eliminated.

2.4. Stakeholders Participating in the Survey

Three major types of stakeholders were targeted in the survey: (1) farmers growing potatoes in the case study area; (2) agricultural technical advisors with expertise in potato production (from cooperatives, public advisory/extension services, private advisors, input supply companies, etc.); and (3) other stakeholders such as researchers, public officers from agricultural administrations, environmental NGOs, etc., with experience in potato production. In total, data was collected from 203 respondents, thus reaching the minimum number required to be considered a decision group [21] since the respondents are considered experts who meet the requirements described for eligibility by [22] in terms of sufficient knowledge and experience, willingness to participate and good communication skills. Farmers' associations, agricultural cooperatives and agribusinesses helped to select and contact them in the areas of study so as to identify potential respondents with real expertise in potato cropping.

Table 3 shows the number of respondents per case study area and per stakeholder type. In some areas, difficulties arose in reaching a larger number of responses for several reasons: more difficulties in identifying suitable respondents to be contacted, less willingness from contacted stakeholders to participate in the survey, and a higher proportion of respondents leaving numerous questions unanswered, claiming that they lacked enough knowledge about the issues at stake and thus did not feel confident enough to answer certain questions. It must also be noted that some of the private technical advisors surveyed were also farmers but were considered technical advisors since that was their main occupation.

Table 3. Number, type, and age of survey respondents by case study (ND: not defined gender).

Case Studies	Female	Male	ND	Farmers	Advisory Services	Researcher/ Academic	NGO	Total Respondents	Average Respondent Age (Years)
MDS	5	18	0	15	5	3	0	23	41.3
LUS	14	49	0	48	10	4	1	63	45.7
ATC	5	17	0	9	5	8	0	22	45.3
CON	2	16	0	12	4	2	0	18	48.0
NEM	10	19	0	16	4	8	1	29	50.8
BOR	12	35	1	24	18	4	2	48	51.1

Mediterranean South, (Murcia) Spain (MDS); Lusitanean, (Galicia) Spain (LUS); Atlantic Central, Belgium (ATC); Continental, Germany (CON); Nemoral, Estonia (NEM); Boreal, Finland (BOR).

2.5. Analysis of Survey Results

Univariate statistical techniques and multicriteria methodology were used in order to analyze the questionnaire answers, as described in [18] and briefly explained as follows. Sections 3 and 4 of the questionnaire focused on assessing the severity of the main agronomic and environmental problems and the priority of the user's needs to seek sustainable and cost-effective production. Since those aspects are difficult to assess, ordinal linguistic labels were used. Many multi-criteria methods combine quantitative and qualitative labels in the same study. Here, the qualitative assessment was performed using linguistic labels that enabled the respondent to share their knowledge, even when unable to provide an exact value. The valuation scale chosen had six labels numbered: "Very low" (0), "Low" (1), "Medium-low" (2), "Medium-high" (3), "High" (4); and "Very high" (5), as well as the option "I don't know/I can't answer", following the recommendations of Sturgis, 2012 [23], to avoid an intermediate compromise answer when in doubt or due to a lack of knowledge. Each linguistic response was equated to its numerical value, and the weighted average value within that scale from 0 to 5 was used in the analysis.

Answers to the questions referring to the effectiveness of agricultural practices in each area (Section 5 of the questionnaire) were ranked using a Decision Support Methodology based on multicriteria methods (MCDM), which enabled the integration of the ranking of the specific problems addressed in each area (objectives) with the effectiveness of the farming practices.

In the Multicriteria methodology, the decision environments were defined based on five elements described as $\{D, C, r, I, \prec\}$:

- $D = \{D_1, \ldots, D_i, \ldots, D_n\}$ is the set of possible alternatives to adopt, which, in our case, were the different agricultural practices that would meet the proposed objectives to a different degree of efficiency.
- $C = \{C_1, \ldots, C_j, \ldots, C_m\}$ is the set of m criteria, in our case objectives, with which each agricultural practice (D) to be adopted was valued for effectiveness. In this case, D and C were finite sets, which allowed us to avoid convergence, integrability, and measurability problems.
- r: $D \times C \rightarrow r$ is a function where each decision (Di) and each criterion (Cj) corresponds to a real interval: (C_j): $(D_i, C_j) \rightarrow r\ (D_i, C_j) = r_{ij}$
- I is the set of linguistic labels used by decision makers to evaluate the priority of each alternative Di to meet each objective Cj and takes values between "Very low" (0) and "Very high" (5).
- $\prec$ are the evaluations of the decision makers regarding the different alternatives Di and their effectiveness in meeting the objectives Cj considered in the decision.

For this questionnaire, multicriteria were adapted to (D_i) for alternatives and (C_j) for priorities in the different study areas. Respondents were asked to assess the effectiveness of each agronomic practice (D_i) for the objective (C_j) through linguistic labels (I) and preference values ($\prec$), giving a representation of the perception of the effectiveness (r_{ij} values) on a decision matrix.

Based on the characteristics of the resulting decision matrix, the TOPSIS method was chosen (Technique for Order of Preference by Similarity to Ideal Solution) [24–26]. The method has been widely used in choice processes for decision-making problems about sustainable agricultural practices [27–29]. The TOPSIS analysis is based on the ranking of all the alternatives that have the shortest distance to the positive ideal solution and the farthest from the negative ideal solution. A final rating was obtained by means of the proximity index that ranks between 0 and 1. The result of the TOPSIS method was an ordered list of all the alternatives (agricultural practices), where those with the highest ratings were the most effective ones.

2.6. Focus Groups

Following the survey, focus groups with stakeholders were organized for each case-study region to discuss, validate, and complement the survey results. The aim was to involve as many different types of stakeholders as possible (farmers, technical advisors, public officers, researchers, input suppliers, value-chain stakeholders, NGO representatives, etc.). Focus groups took place in a face-to-face or online format, with the results from the survey to stakeholders being used as a basis to initiate discussion, asking participants about their agreement with the survey results, the reasons for their possible disagreement, as well as other issues that should have been considered. The presentation and discussion of the results were carried out separately for each group of farming practices. The discussion focused on the major agronomic problems of the cropping system in the particular area, the potential effectiveness of different farming practices to address the identified problems, their practical feasibility, and potential barriers to their implementation.

3. Results

3.1. Assessment of the Most Relevant Agro-Environmental Problems in Each Study Area

The survey respondents' qualitative assessments of the severity of the agronomic and environmental problems affecting potato production in their area of study are reported in Table 4. The stakeholders surveyed did not perceive most problems as being of high or very high severity. The most severe problems were perceived, on average, as being of medium-high severity and differed significantly from one case study to another. However, the stakeholders' expressed perception of the severity of the problems was consistent with the specific nature of the agricultural systems analyzed. For example, rainfall scarcity during the growing period was identified as one of the most severe problems in Belgium, Germany, Estonia and Finland, where most potato production is rainfed, and the survey followed a relatively dry season. The high incidence of pests was also among the most severe problems in most of the study areas (LUS, Belgium, and Germany) in addition to Estonia for fungal disease problems. To a lesser extent, the high use of plant protection products was also among the most severe problems in LUS and Belgium, medium in MDS, Germany, and Estonia, while in Finland, they were barely perceived as relevant. High weed pressure was also identified as a major problem in MDS, LUS, and Germany. More related to soil management, the loss of soil organic matter (SOM) content was among the most severe problems in MDS, Belgium, and Finland, as well as soil compaction in all areas except Germany. There was also concern about soil waterlogging in LUS. Low soil biodiversity was among the most severe problems identified, but only in MDS, whereas it was among the least severe problems in Belgium and Germany. Overall, the least severe problems for stakeholders were water pollution by leaching or run-off of nutrients, soil acidification, development of resistance to plant protection products, and soil erosion, which was only perceived as having some severity in MDS and Belgium.

Table 4. Stakeholders' qualitative assessment of the severity of different agronomic and environmental problems in their area (mean scores; scale "Very low" (0); "Low" (1); "Medium-low" (2); "Medium-high" (3); "High" (4); and "Very high" (5); n.r.: item not considered as relevant for this study area and not included in the questionnaire).

Problems	MDS	LUS	ATC	CON	NEM	BOR
Low and/or variable yields	2.45	3.21	2.40	3.18	2.93	2.50
Low soil fertility	2.41	2.89	1.95	2.22	2.63	2.40
Rainfall scarcity in growing period	2.91	2.75	3.71	3.56	2.96	2.93
Irrigation water scarcity	2.52	3.02	3.00	n.r.	n.r.	n.r.
High incidence of pests	2.68	3.41	3.00	3.17	2.21	1.47
High incidence of fungal diseases	2.77	3.33	3.47	3.11	2.75	2.44
High use of phytosanitary products	2.55	3.24	3.41	2.28	2.25	1.59
Development of resistance to phytosanitary products	2.41	3.05	2.88	1.44	2.35	1.68
Low presence of beneficial invertebrates/insects in the soil	2.86	2.57	2.20	2.47	1.91	2.26
Low soil microbial biodiversity	3.17	2.62	2.27	1.88	2.60	2.34
Waterlogged soils/inadequate drainage	n.r.	3.37	1.83	n.r.	2.48	2.42
Excessive use of machinery	2.64	2.79	2.65	2.17	2.61	2.12
Soil compaction	3.14	2.77	2.95	2.41	2.78	2.74
Water pollution by leaching or run-off of nutrients	2.73	2.80	2.86	1.41	1.74	1.40
Soil erosion	2.74	2.33	2.67	1.89	1.58	2.10
SOM loss	3.48	2.39	2.75	2.39	2.58	2.79
Soil acidification	n.r.	2.42	2.06	1.65	n.r.	n.r.
High incidence of bacterial diseases	2.64	2.57	2.41	n.r.	n.r.	n.r.
High weed pressure	3.04	2.98	2.42	3.35	n.r.	n.r.
Low number of earthworms in soil	3.05	2.47	2.24	1.53	2.57	2.50
Excess rainfall	n.r.	2.58	n.r.	2.72	2.30	1.93

Mediterranean South, (Murcia) Spain (MDS); Lusitanean, (Galicia) Spain (LUS); Atlantic Central, Belgium (ATC); Continental, Germany (CON); Nemoral, Estonia (NEM); Boreal, Finland (BOR).

3.2. Prioritization of Objectives (End-Users' Needs)

The stakeholders' views regarding the priority that should be given to different objectives for action in potato production in their area are reported in Table 5. Their answers were consistent with the previous identification of relevant problems.

Table 5. Stakeholders' qualitative assessment of the priority of different objectives in their area (mean scores; scale 0 = Very low/null . . . 5 = Very high; n.r.: item not included in the questionnaire for this study area).

Objectives	**MDS**	**LUS**	**ATC**	**CON**	**NEM**	**BOR**
Increase soil fertility	3.96	3.11	3.71	3.47	3.61	3.80
Mobilize soil nutrients during plant growth	3.73	3.22	3.53	3.69	3.63	3.45
Reduce the incidence of pests and diseases	3.57	3.51	3.65	3.65	3.67	3.30
Increase soil OM content	4.00	2.92	4.00	3.24	3.70	3.88
Improve soil structure to improve aeration, water retention and rooting	4.00	3.11	3.86	3.13	3.78	4.09
Increase soil biodiversity	3.65	3.00	3.58	3.06	3.46	3.68
Reduce soil erosion	3.26	2.48	2.85	2.71	2.64	3.30
Reduce soil pollution	3.45	2.77	2.32	1.94	2.52	2.15
Reduce soil salinization	3.61	2.13	n.r.	n.r.	n.r.	n.r.
Reduce soil acidification	n.r.	2.49	2.67	2.13	n.r.	n.r.
Improve water infiltration/drainage systems	3.36	2.82	n.r.	2.6	3.46	3.52
Improve water quality	n.r.	2.75	3.35	n.r.	n.r.	2.77
Reduce weed incidence	n.r.	2.81	n.r.	3.71	3.52	2.79

Mediterranean South, (Murcia) Spain (MDS); Lusitanean, (Galicia) Spain (LUS); Atlantic Central, Belgium (ATC); Continental, Germany (CON); Nemoral, Estonia (NEM); Boreal, Finland (BOR).

The table shows that, in general, the respondents in each area gave the highest priority to actions targeted towards increasing SOM content and improving soil structure to increase aeration, water retention and favor plant rooting, which were deemed the most urgent needs in MDS, Belgium, Estonia and Finland. Similar priority was given to reducing the incidence of pests and diseases and to weed control, which were the most urgent needs in LUS and Germany. The next priorities for stakeholders were mobilizing soil nutrients during the plant growth stage, increasing soil fertility in some regions and, to a lesser extent, increasing soil biodiversity.

3.3. Identification of the Most Effective Farming Practices to Address Agronomic and Environmental Problems

The order of preferences for each group of farming practices resulting from the multi-criteria analysis is shown in Table 6. A higher ranking means that practice was considered to be more effective in achieving the identified priorities for action (objectives) by the stakeholders surveyed. Stakeholders' answers regarding the factors that may hinder the implementation of more sustainable farming practices in each study area are given in Table 6. The following sections summarize the results for each group of farming practices.

Table 6. Stakeholders' assessment of the effectiveness of farming practices to address the agronomic and environmental problems in the crops and areas of study (ranking of preferences from the multicriteria assessment, min: 0, max: 1; n.r.: item not included in the questionnaire for this study area).

	Case Studies	MDS	LUS	ATC	CON	NEM	BOR
Tillage	Conventional tillage	0.194	0.797	0.396	0.501	0.713	0.434
	Tillage according to level curves	0.240	0.024	0.301	0.000	0.156	0.038
	Shallow tillage	0.427	0.392	0.287	0.240	0.178	0.335
	Minimum tillage	0.820	0.316	0.589	0.516	0.433	0.502
	No tillage with herbicides	0.135	0.164	0.000	0.360	0.237	0.125
	No tillage without herbicides (mechanical weed control)	0.531	0.197	0.298	0.193	0.200	0.419
	None of these are effective	0.394	0.554	0.526	0.357	0.382	0.690
Fertilization	Incorporating crop residues to soil	0.343	0.245	0.093	0.323	0.181	0.196
	Addition of solid OM/manures	0.441	0.462	0.696	0.462	0.427	0.664
	Use of green manure	0.457	0.117	0.548	0.61	0.710	0.627
	Combination of manure and mineral fertilizers	0.290	0.263	0.140	0.258	0.230	0.226
	Precision agriculture to optimize fertilization	0.250	0.431	0.163	0.203	0.313	0.303
	Use of biostimulants. etc.	0.547	0.254	0.256	0.345	0.309	0.060
	Addition of slurries	0.000	0.000	0.000	n.r.	0.000	0.000
	None of these are effective	0.293	0.667	0.305	0.226	0.436	0.283
Soil conservation	Mulching (with crushed offcuts from pruning. etc.)	0.338	0.122	0.426	0.290	n.r.	n.r.
	Maintain vegetation cover (natural or cover crops)	0.296	0.236	0.394	0.636	n.r.	n.r.
	Maintain strips of vegetation between lines	0.234	0.055	0.194	0.113	n.r.	n.r.
	Hedges or natural vegetation on edges of the plots	0.09	0.059	0.290	0.000	n.r.	n.r.
	Erosion barriers or margins with vegetation	0.300	0.077	0.172	n.r.	n.r.	n.r.
	Addition of OM	0.563	0.367	n.r.	n.r.	0.397	0.428
	Crop diversification	0.666	0.706	n.r.	0.635	0.797	0.832
	Use of catch crops to reduce N/P leaching	0.181	0.222	0.619	0.333	n.r.	n.r.
	Avoiding plant protection products	n.r.	0.262	0.389	0.185	0.222	0.130
	None of these are effective	0.342	0.547	0.286	0.339	0.072	0.100
Pest and disease control	Pest alerts	0.171	0.187	0.327	0	0.196	0.031
	Crop diversification	0.925	0.788	n.r.	0.646	0.787	1.000
	Trap crops	0.169	0.066	0.079	0.223	n.r.	n.r.
	Increase soil invertebrate biodiversity	0.378	0.249	n.r.	0.391	n.r.	n.r.
	Use of biostimulants and mycorrhizas	0.321	0.238	n.r.	0.359	n.r.	n.r.
	Pesticide use	0.206	0.325	0.216	0.371	0.300	0.150
	Ploughing	n.r.	0.286	n.r.	n.r.	0.158	0.149
	Allelopathic crops	0	n.r.	0.401	0.121	n.r.	n.r.
	None of these are effective	0.306	0.495	0.754	0.221	0.139	0.135

Mediterranean South, (Murcia) Spain (MDS); Lusitanean, (Galicia) Spain (LUS); Atlantic Central, Belgium (ATC); Continental, Germany (CON); Nemoral, Estonia (NEM); Boreal, Finland (BOR).

3.3.1. Tillage Practices

Alternative conservation tillage practices include reducing tillage frequency and depth through shallow tillage; minimum tillage (the minimum amount of tillage required for seedbed preparation and plant establishment); no tillage (with or without herbicides), which involves no seedbed preparation other than chemical preparation and soil-opening for seed placement.

Stakeholders chose different tillage practices that are adequate to fulfill the end-users' needs/objectives. The results from the multicriteria assessment (Table 5) showed differences among areas and highlighted the ongoing debate between conventional intensive tillage and the different conservation tillage alternatives. However, in most case studies, stakeholders gave the highest-ranking score to either conventional tillage or minimum tillage. More sustainable tillage practices, such as shallow tillage or no tillage, were the second preferred alternative in some case studies yet received very low-ranking scores in others.

Conventional tillage was by far the most preferred tillage alternative in LUS and Estonia, whilst minimum tillage, closely followed by conventional tillage, was the most preferred alternative in Belgium and Germany (Table 6). Stakeholders in MDS and Finland gave lower ranking scores to conventional tillage, selecting minimum and shallow tillage, respectively, as the preferred alternative, with no tillage using mechanical weed control being the second most preferred alternative in both cases. However, it should be noted that the option "None of these tillage practices is effective in facing the problems in the area" received the highest-ranking score in Finland and the second-highest-ranking alternative in LUS and Belgium.

Stakeholders were asked about the factors that can hinder the implementation of more sustainable tillage practices in the crop and study area (Table 7). Although responses differed significantly from one case study to another, most stakeholders pointed to the farmers' lack of knowledge regarding their effectiveness and, to a lesser extent, the lack of tradition of conservation tillage practices as being the most relevant barriers. Another frequently indicated barrier was the complexity of implementing more sustainable tillage practices without adequate technical advice being available. Another relevant perceived barrier in LUS and Finland was their incompatibility with other farming practices and existing farm machinery. On the other hand, most stakeholders did not perceive these tillage practices as being difficult to implement with adequate technical advice and did not perceive them as not being profitable.

Table 7. Stakeholders' identification of barriers that can make the implementation of more sustainable practices difficult (percentage of answers).

Tillage	**MDS**	**LUS**	**ATC**	**CON**	**NEM**	**BOR**
Lack of knowledge among farmers about the effectiveness of farming practices	66.67%	59.68%	62.50%	50.00%	23.08%	34.15%
Lack of tradition in the region	42.86%	46.77%	50.00%	18.75%	19.23%	31.71%
Complex/difficult to carry out without technical advice	23.81%	53.22%	31.25%	31.25%	15.38%	2.44%
Complex/difficult to carry out even with technical advice	14.29%	3.23%	0.00%	31.25%	11.54%	4.88%
Lack of adequate farm machinery	19.05%	4.84%	37.50%	18.75%	23.08%	19.51%
Inadequate/insufficient governmental support on technical issues	14.29%	16.13%	12.50%	0.00%	19.23%	2.44%
Lack of enabling legislation/regulations	4.76%	4.84%	12.50%	18.75%	0.00%	2.44%
The costs are too high	33.33%	12.90%	18.75%	18.75%	26.92%	14.63%
The benefits do not outweigh the costs	23.81%	4.84%	18.75%	31.25%	23.08%	24.39%
Incompatibility with other farming practices	23.81%	6.45%	18.75%	0.00%	26.92%	26.83%
Fertilization						
Lack of knowledge among farmers about the effectiveness of farming practices	57.89%	56.45%	50.00%	46.67%	36.00%	46.34%

Table 7. *Cont.*

Fertilization	**MDS**	**LUS**	**ATC**	**CON**	**NEM**	**BOR**
Lack of tradition in the region	47.37%	37.10%	28.57%	26.67%	40.00%	34.15%
Complex/difficult to carry out without technical advice	31.58%	62.90%	14.29%	13.33%	16.00%	14.63%
Complex/difficult to carry out even with technical advice	15.79%	3.23%	7.14%	33.33%	0.00%	12.20%
Lack of adequate farm machinery	5.26%	0.00%	21.43%	20.00%	12.00%	21.95%
Inadequate/insufficient governmental support on technical issues	15.79%	12.90%	14.29%	0.00%	16.00%	9.76%
Lack of enabling legislation/regulation	0.00%	6.45%	28.57%	26.67%	4.00%	4.88%
The costs are too high	31.58%	8.06%	7.14%	13.33%	28.00%	24.39%
The benefits do not outweigh the costs	31.58%	1.61%	0.00%	13.33%	16.00%	29.27%
Incompatibility with other farming practices	15.79%	3.23%	28.57%	13.33%	24.00%	14.63%
Soil conservation						
Lack of knowledge among farmers about the effectiveness of farming practices	66.67%	61.29%	50.00%	33.33%	52.00%	48.78%
Lack of tradition in the region	44.44%	45.16%	50.00%	20.00%	20.00%	31.71%
Complex/difficult to carry out without technical advice	38.89%	54.84%	21.43%	26.67%	12.00%	14.63%
Complex/difficult to carry out even with technical advice	5.56%	1.61%	7.14%	26.67%	4.00%	4.88%
Lack of adequate farm machinery	5.56%	3.23%	0.00%	13.33%	16.00%	21.95%
Inadequate/insufficient governmental support on technical issues	16.67%	14.52%	42.86%	6.67%	24.00%	14.63%
Lack of enabling legislation/regulations	11.11%	4.84%	42.86%	6.67%	4.00%	7.32%
The costs are too high	27.78%	3.23%	28.57%	6.67%	20.00%	21.95%
The benefits do not outweigh the costs	16.67%	0.00%	0.00%	20.00%	12.00%	21.95%
Incompatibility with other farming practices	22.22%	3.23%	7.14%	6.67%	16.00%	7.32%
Pest and disease control						
Lack of knowledge among farmers about the effectiveness of farming practices	44.44%	48.39%	42.86%	28.57%	44.00%	41.46%
Lack of tradition in the region	22.22%	33.87%	14.29%	14.29%	16.00%	39.02%
Complex/difficult to carry out without technical advice	38.89%	62.90%	14.29%	21.43%	12.00%	14.63%
Complex/difficult to carry out even with technical advice	5.56%	4.84%	7.14%	35.71%	12.00%	4.88%
Lack of adequate farm machinery	0.00%	1.61%	0.00%	14.29%	12.00%	12.20%
Inadequate/insufficient governmental support on technical issues	16.67%	14.52%	7.14%	7.14%	12.00%	12.20%
Lack of enabling legislation/regulations	27.78%	6.45%	28.57%	21.43%	12.00%	7.32%
The costs are too high	38.89%	11.29%	7.14%	14.29%	28.00%	21.95%
The benefits do not outweigh the costs	16.67%	1.61%	0.00%	7.14%	20.00%	21.95%
Incompatibility with other farming practices	16.67%	3.22%	0.00%	0.00%	4.00%	12.20%

Mediterranean South, (Murcia) Spain (MDS); Lusitanean, (Galicia) Spain (LUS); Atlantic Central, Belgium (ATC); Continental, Germany (CON); Nemoral, Estonia (NEM); Boreal, Finland (BOR).

3.3.2. Fertilization Practices

The participants chose the fertilization practices they considered to be most adequate to fulfill their respective end-users' needs (the previously assessed objectives). The results from the multicriteria assessment (Table 5) showed some differences among areas, albeit with greater consensus than with the tillage practices.

The addition of soil OM/manures and the use of green manure were the two preferred fertilization alternatives in all case studies, except in MDS, where they were the second and third alternatives, respectively, behind the use of biostimulants, biofertilizers, mycorrhizas, and new generation fertilizers. The third highest ranking scores corresponded to the use of precision agriculture techniques in LUS, Estonia, and Finland and to the use of biostimulants, biofertilizers, mycorrhizas and new-generation fertilizers in Germany. The use of biostimulants, biofertilizers, mycorrhizas and new-generation fertilizers did not receive very high-ranking scores, except in MDS, where they are widely used and were the preferred fertilization alternative, and in Germany, where it was the third highest-scored option. It should also be highlighted that "None of these practices are effective for the problems in the study area" received the highest-ranking score in LUS and was the third preferred option in Estonia.

A major perceived barrier to the adoption of more sustainable fertilization practices was the farmers' lack of knowledge regarding their effectiveness (Table 6). A significant number of stakeholders also pointed to the complexity of implementing such practices without the help of technical advisory services (MDS and LUS) and to their lower profitability (MDS and Finland). Stakeholders in Belgium and Germany also highlighted the lack of enabling regulations or legislative reforms in these sub-regions. Lastly, stakeholders in Belgium and Estonia also pointed out incompatibility with other farming practices. On the other hand, only a minority of stakeholders perceived those fertilization practices as being difficult to implement with the support of adequate technical advice. Except for MDS and Finland, few stakeholders considered the lack of profitability to be a barrier to the implementation of more sustainable fertilization practices.

3.3.3. Soil Conservation Practices

Stakeholders chose the soil conservation practices they considered to be the most adequate to fulfill their respective end-users' needs (the previously assessed objectives). Differences were again found among areas. For stakeholders in MDS, LUS, Estonia, and Finland, the highest-ranking score for the preferred soil conservation practices was for crop diversification, followed by the addition of OM, with the latter also being selected as one of the preferred fertilization practices in most case studies (Table 6). In Germany, crop diversification and vegetation cover (natural or cultivated) were the most preferred alternatives, whilst in Belgium, catch crops received the highest-ranking score, followed by mulching and maintaining natural vegetation covers and cover crops. In general, the third highest ranking score was given to soil cover alternatives, such as mulching, natural vegetation covers and cover crops, although some case studies found that avoiding plant protection products or the use of catch crops is more effective. However, a significant number of stakeholders in MDS and LUS also pointed out the complexity of the implementation of more sustainable soil conservation practices without the help of technical advisory services. This lack of technical support from the government and the lack of enabling regulations was also highlighted by stakeholders in Belgium. On the other hand, only a minority of stakeholders perceived soil conservation practices as unprofitable or difficult to implement with the support of adequate technical advice. In general, most stakeholders point to the farmers' lack of knowledge as being the most relevant barrier to the adoption of more sustainable soil conservation practices (Table 7).

3.3.4. Pest and Disease Control Practices

In most case studies, stakeholders awarded the highest-ranking score to crop diversification as an alternative for pest and disease control, whilst others opted for the use of pest alerts; in both cases with significant differences in the ranking scores given to these practices and to those with the second highest ranking scores (Table 6). The second preferred alternative was the use of pesticides, albeit with significantly lower ranking scores than the preferred alternative.

Crop diversification was the most effective pest and disease control practice in MDS, Germany, LUS, Estonia, and Finland, followed by the increase in soil invertebrate biodiversity in the first two cases and the use of pesticides in the latter three (Table 6). Crop diversification could be the most effective alternative for pest and disease control for most of the study areas. In Belgium, most stakeholders chose the "none of these practices are effective", which was the highest-ranked alternative, more than doubling the ranking score given to Allelopathic crops and pests.

In relation to the barriers that stakeholders perceived could hinder the adoption of more sustainable pest and disease control practices in the crop and study area (Table 7), most stakeholders pointed out the farmers' lack of knowledge regarding their effectiveness, the need to have adequate technical advice due to their complexity, and their higher costs as being the most relevant barriers. The lack of enabling legislation/regulations was also highlighted by stakeholders in Belgium.

3.3.5. Summary of the Proposed Farming Practices

The farming practices with the highest scores in each case study are showed in Table 6, whilst Table 8 summarizes the most effective practice per type based on the results from Table 6, illustrating the perception of the surveyed stakeholders regarding how each potato cropping area could be oriented towards more sustainable production.

Table 8. Most effective farming practices according to the stakeholders' qualitative assessment (ranking of preferences from the multicriteria analysis in brackets, max: 1; min: 0).

Case Studies	Tillage Practices	Fertilization Practices	Soil Conservation Practices	Pest and Disease Control Practices
MDS	Minimum tillage (0.82); No tillage without herbicides (0.53)	Use of biostimulants, biofertilizers... (0.55); Green manure (0.46); Addition of solid OM/manures (0.44)	Crop diversification (0.67); Addition of solid OM/manures (0.56)	Crop diversification (0.93); Increase soil invertebrates biodiversity (0.38)
LUS	Conventional tillage (0.80); Shallow tillage (0.39)	Addition of solid OM/manures (0.46); Precision agriculture (0.43)	Crop diversification (0.71); Addition of solid OM/manures (0.37)	Crop diversification (0.79); Use of pesticides (0.32)
ATC	Minimum tillage (0.59); Conventional tillage (0.40)	Addition of solid OM/manures (0.70); Use of green manure (0.55)	Catch crops to reduce N/P leaching (0.62); Mulching/Vegetation covers (0.43)	Allelopathic crops (0.40); Pest alerts (0.33)
CON	Minimum tillage (0.52); Conventional tillage (0.50)	Use of green manure (0.61); Addition of solid OM/manures (0.46)	Vegetation covers (0.64); Crop diversification (0.64)	Crop diversification (0.66); Increase soil invertebrates biodiversity (0.39)
NEM	Conventional tillage (0.71); Minimum tillage (0.43)	Use of green manure (0.71); Addition of solid OM/manures (0.43)	Crop diversification (0.80); Addition of OM (0.40)	Crop diversification (0.79); Use of pesticides (0.30)
BOR	Minimum tillage (0.50); Conventional tillage (0.43); No tillage without herbicide (0.42)	Addition of solid OM/manures (0.66); Use of green manure (0.63)	Crop diversification (0.83); Addition of OM (0.43)	Crop diversification (1.00)

Mediterranean South, (Murcia) Spain (MDS); Lusitanean, (Galicia) Spain (LUS); Atlantic Central, Belgium (ATC); Continental, Germany (CON); Nemoral, Estonia (NEM); Boreal, Finland (BOR).

3.4. Results from Focus Groups

In general, the participants in all the focus groups confirmed the validity of the survey results. The different focus groups concurred on the major agronomic problems and end-users' needs identified in the survey across case-study areas. Participants emphasized the need to reduce tillage intensity, to increase soil organic matter and, of the highest priority for those attending focus groups, to diversify crop rotations in order to avoid continuous potato cropping and its associated pests and diseases, such as cyst nematodes. Additionally, participants in some focus groups highlighted the importance of economic issues (marketing, production costs, and profitability issues) that had not been addressed in the survey, which had focused purely on agronomic problems. The focus groups also confirmed the general suitability of the preferred farming practices selected to cope with the major agro-environmental problems in each case study area. However, the participants pointed out certain problems with the selected practices, such as the need to use local manure to avoid importing plagues or the increased incidence of weeds when using minimum tillage.

The most fruitful discussion was related to the barriers to the adoption of sustainable farming practices, where a consensus existed in the survey results, with the farmers' lack of knowledge on the real effectiveness of more sustainable soil management practices and the need for expert technical advice being the issues that raised most concern in all the focus groups. Learning about and training in new farming practices was considered to be the biggest challenge to driving the adoption by potato farmers of farming practices that support soil biodiversity and increase the fertility of agricultural soils. However, despite such a consensus, the participants also pointed out additional issues. Participants in the MDS, LUS, and Finland focus groups identified the small size of plots and/or farms in their areas as representing a particularly relevant barrier to crop diversification. The reason for that is that crop rotations require larger plots and/or areas to take advantage of economies of scale and produce the large volumes required by agricultural intermediaries. Other relevant barriers to diversifying crops were the need to contract harvesting machinery for rotation crops in potato farms and the resulting increase in production costs (Finland), and that potato farmers did not know which diversification crops were the most suitable for their areas as well as the lack of marketing channels for those diversified crops (LUS). Additionally, the lack of government support (LUS), the fact that many technical advisors worked for input suppliers (Belgium), and the inadequate legislation concerning manure use (Belgium) were pointed out as other relevant barriers to the adoption of sustainable farming practices.

4. Discussion

This study investigated how potato production could be oriented towards more sustainable farming practices based on the views of stakeholders in six different pedoclimatic areas across Europe. The study provides, using a multicriteria decision-making framework, a ranking of the effectiveness of alternative farming practices based on an assessment of the severity and priority of agri-environmental problems in potato production and an evaluation of how those practices can contribute to addressing those problems. It also identifies barriers to more widespread adoption of sustainable agricultural practices in potato production in the areas of study.

The stakeholders agreed on the need to move towards a change in the agriculture production system through an improvement in soil quality and soil biodiversity [17]. In this sense, the future of agriculture requires increased use of sustainable land management practices, restoring degraded soils, and promoting a "sustainable production intensification" through adapting biological resources, increasing soil fertility, efficient water use, ensuring sustainable use of inputs and the recycling of agricultural by-products [30]. There is global agreement regarding the urgent need to halt land degradation and soil nutrient depletion, establish frameworks for sustainable soil management, and ensure the conservation of ecosystems and biodiversity as a means of promoting the goals of sustainable development (GSD) proposed by the United Nations. However, soil tillage was the most controversial topic for the stakeholders interviewed. Although there was debate on the use of conventional tillage and less intensive tillage options, with conventional tillage still being the preferred tillage alternative in some case studies, most stakeholders did nevertheless consider that it was necessary to shift towards less intensive tillage alternatives, such as minimum or shallow tillage to address soil degradation in their corresponding study area. Related to this, the preferred soil conservation practices seem to be more oriented towards improving soil conditions than to avoiding soil loss. More specifically, crop diversification and the addition of solid OM, such as mulching, were perceived as the most effective alternatives in many case studies [12,30,31].

These results suggest that skepticism persists regarding the benefits of conservation tillage and other soil conservation practices that are at odds with the empirical evidence of their advantages despite their benefits having been shown in the scientific literature. Reducing tillage avoids soil disturbance and improves the soil structure, thus enabling infiltration, aeration, and root penetration [32] and promoting functional soil biodiversity [33]. Reducing tillage in potato production minimizes waterlogging and nutrient leaching and supplies sufficient depth for tuber formation and root growth [34]. Alternatives to conventional tillage in potato rotations reduce energy inputs and the incidence and severity of disease without changes in tuber yield [35]. The use of mulching decreases erosion in the first weeks of the crop, whilst cover crops help to dry out the potato beds, providing good quality tubers regulating the optimum temperature for tuber formation (15–18 °C) and diminishing damage in harvest [36].

Regarding the preferred fertilization practices, the stakeholders' perceptions are coherent with empirical evidence, and they identify problems related to the OM content and an increase in soil fertility. Alternatives to conventional fertilization practices aim for more efficient fertilization and the use of organic sources of nutrients such as manure, incorporating crop residues into the soil, green manure, precision agriculture techniques to optimize the fertilizer dose, or biostimulants, could all be adopted with a high potential for improving crop yield and product quality whilst reducing the environmental impacts on agro-ecosystems [3]. The potato crop has high nutrient needs and can, therefore, benefit from the application of organic manure and the incorporation of crop residues or mulching, which also prevent soil erosion and enhance the soil structure and the soil OM, thus enhancing soil fertility. Appropriate fertilizer use improves crop yield, water use efficiency, the resilience of crop production to aridity, and the conservation of the environment and biodiversity, contributing to climate change mitigation [37–39]. In this sense, adequate management of potassium (K) fertilization is also crucial for the uptake, transport, and efficiency of water use by plants [40].

The issue of the perceived impact of more sustainable fertilization practices on farm profitability was one of the barriers pointed out by stakeholders. Several studies have shown that changing towards more sustainable agriculture through a reduction in the use of inorganic inputs, as proposed by the European Commission, would have some negative impact on the income of designed farming systems [41,42]. However, the additional co-benefits for society in terms of reduced GHG emissions and reduced pressures on ecosystems would clearly be significant [43]. Nevertheless, we must not forget that agricultural intensification has been commonly driven by the price of agricultural products, which is an important factor influencing the actions of farmers [44] and can affect the adoption of sustainable agriculture techniques as well as generational change.

Another highly relevant issue in potato production is the incidence of pests and diseases, which commonly require the application of pesticides or fungicides to prevent yield losses [45–47] or a high level of integrated pest management based on preventive measures [48]. Despite all these benefits, some skepticism remains regarding alternative pest control practices among stakeholders in Belgium, LUS, Estonia, and Finland. In fact, pesticide use was key to stakeholders from Belgium and LUS areas. Most farmers use pesticides and fungicides in a preventive and uncontrolled manner, i.e., repeated or unnecessary applications. The inefficient use of phytosanitary products in an incorrect way favors the development of pest and disease resistances [49,50], reduces the efficacy of existing active matters and forces an increase in their application, thereby increasing the associated pollution. The current emphasis on sustainable crop production has rendered it necessary to regulate plant protection products for disease management. The EU "Farm to Fork" Strategy (European Commission, 2020), part of the European Green Deal, sets a 50% reduction in the overall use of chemical pesticides in the European Union by 2030.

Moreover, most of the methods developed as an alternative to chemical control of pests and diseases, such as allelopathic crops or the use of biostimulants and mycorrhizas, received relatively low rankings with respect to crop diversification (always ranking below 0.40 after multicriteria analysis), and with significant differences among study areas. Diversification strategies (crop rotations, intercropping, strip cropping, cover crops, etc.) significantly contribute to maintaining and regenerating soil biodiversity with respect to continuous cropping systems [51–53]. Despite being a highly recommended non-chemical approach for controlling pests and diseases in potato production, trap crops received lower rankings in this study compared to other alternatives [54,55]. Trap cropping allows for the reduction of input use (fuel, labor, time, and insecticides) and increases crop profit while protecting pollinators and other beneficial insects [56]. The views that farmers have on environmental protection and the negative consequences associated with the use of pesticides differ depending on the sources of knowledge that they consult [57]. In this sense, farm advisors, input suppliers, and external consulting companies play key roles in passing knowledge on to farmers. Technical advice should aim to educate farmers about sustainability by proposing alternatives to conventional systems in pest and disease control [3,46,58,59].

In general, the barriers identified by stakeholders are coherent with the existing literature. Although a large number of studies have analyzed those factors that favor or inhibit the adoption of more sustainable farming practices, few universal explanatory factors exist, and in practice, they tend to be quite specific to each farming practice and agricultural system [60–62]. Several factors related to how farmers perceive new technologies are often cited as reasons for adoption or resistance. These factors include the perceived complexity of implementation, the relative advantages compared to existing methods, compatibility with current practices and machinery, farmers' confidence in their ability to use the technology, and the level of uncertainty associated with its effectiveness [60,63], and in certain cases may be barriers due to the farmer's age [64]. These findings underscore the need to conduct on-farm demonstrations of promising agricultural practices across all European regions, like the demonstrations conducted in projects like FarmDemo, Nefertiti and IPMWORKS, to foster knowledge exchange among different actors and efficient adoption of innovation.

5. Conclusions

By asking the views of stakeholders, this study has achieved the objective of identifying the most promising farming practices for more sustainable potato cultivation in selected European countries. It has also illustrated stakeholders' perceptions of how alternative practices can be integrated into different cropping systems to address key priorities, such as enhancing soil quality and improving the control of pests, diseases and weeds. In this sense, reducing tillage intensity, shifting towards organic fertilization and diversifying crops were broadly viewed as essential for improving soil health, crops' nutrition and pest control, although perceptions varied across regions and cropping systems.

Despite empirical scientific evidence supporting sustainable farming practices, uptake by farmers is still relatively low. Consulted stakeholders highlighted barriers to adoption, consistently pointing to the lack of local farmers' knowledge regarding the real implications of practices yet to be extensively used in their region, the need for adequate technical advice due to the complexity of their implementation, and insufficient governmental support on technical issues.

From our findings, we can conclude that increasing the sustainability in potato production is a complex task that, despite most stakeholders being aware of the problems and the solutions, still requires robust technical advice and policy support. There is a need for real-life trials and on-farm demonstrations of the agronomic, economic, and ecological benefits and risks of new practices. Major challenges include the development of robust and accessible technical support systems and targeted legislative reforms that fill regulatory gaps, promote sustainable farming practices and encourage sustainable transitions in diverse European farming contexts.

In terms of future research, effective policy intervention requires a more in-depth analysis of the perceptions and barriers associated with some specific farming practices, especially with promising but barely-adopted alternatives, such as biostimulants and mycorrhizas or pest alerts, and with those ones, such as the tillage strategy, that have raised less consensus among stakeholders.

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