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Towards Sustainable Vegetable Farming: Exploring Agroecological Alternatives to Chemical Products in the Fez-Meknes Region of Morocco

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Abstract: The use of excessive chemicals in agriculture can cause harm to the environment and human health. Sustainable agriculture systems promote agroecological practices to reduce chemical use and promote environmental and human health. However, there is a lack of data on the status of chemical use and the adoption of agroecological practices in the Fez-Meknes region, which is a significant national vegetable production area. To address this gap, we conducted cross-sectional surveys with 603 farmers to analyze their practices, behaviors, and knowledge regarding chemical and bio-product use, as well as the risks to crops, health, and the environment. Additionally, we aimed to diagnose the diffusion of agroecological practices and identify the most relevant obstacles and motivations for adoption. Our results indicate that a majority of farmers (95%) use chemicals throughout the production process but lack a good understanding of their use and associated risks. However, farmers do have access to alternative practices such as crop rotation (99.67%), manure (96.35%), drip irrigation (74.46%), and intercropping (69%). The success of these practices among farmers was a significant motivation for their adoption (50%), whereas the difficulties of managing pests and diseases without pesticides (73.2%) and the lack of technical advice and support (70.8%) were the main barriers to adoption. In conclusion, our study highlights the need for training and financial encouragement from the state to promote healthy and eco-friendly farming practices. This research provides valuable insights into the current status of chemical use and the adoption of agroecological practices in the Fez-Meknes region, which can inform policy decisions and promote sustainable agriculture practices for the future.

Keywords: pesticides; agroecological practices; survey; vegetables crops

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1. Introduction

Vegetable crops play an essential role in the socio-economic plan while ensuring significant food autonomy for the population worldwide [1]. According to the latest statistics given by the Moroccan minister of agriculture, vegetable crops cover an annual area of about 40,000 ha, with a total production estimated at 2 million tons, of which 4% are processed, 8% exported, and 88% are destined for the local market [2]. The Fes-Meknes region has 50% of the national vegetable crop production in Morocco; the region is characterized by favorable rainfall, soil, and climatic conditions; rich soils with a high potential for crop production allow the mobilization of large areas for vegetable crops [3].

Despite all these advantages, vegetable crops are strongly affected by abiotic and biotic factors such as soil infertility, unfavorable climatic conditions [4], pests, diseases, and weeds [5]. Producers use large quantities of synthetic chemical pesticides to control the phytosanitary problems of vegetable crops [6,7]. According to a survey conducted in the area of Souss Massa (Morocco) in 2012 [8], eight pesticide residues were found in greenhouse tomato samples, including endosulfan, which is in excess of and exceeds the European MRL standards, and was classified as a persistent organic pollutant (POP) and banned by the Stockholm Convention in 2011 [9]. This causes many vegetables from Morocco to be withdrawn from the markets, especially in Europe in the last few years, and then causes huge losses for the Moroccan farmer [10]. In addition, according to the Agency for Agricultural Development, the use of industrial fertilizers increased to more than 1.6 million tons in 2020, and unfortunately, the majority of farmers empirically apply chemical fertilizers, rarely in line with the needs of the soil [11]. Additionally, unsafe farming practices such as excessive use, non-respect of registered concentrations, eating, drinking, or smoking during pesticide application, and the non-use of personal protective equipment [11,12] have a direct impact on consumers' and farmers' health [13,14]. To maintain and stabilize high productivity while minimizing negative environmental and human health impacts, it is essential to move away from chemical inputs and towards agroecological approaches, for better efficiency of soil resources and enhanced management of vegetable crop harms such as high pesticide residues.

In this regard, agroecology is a way of achieving sustainable agriculture without chemical inputs, with low water and energy consumption. More than that, it is a way of improving food security and nutrition [11,15]. The objective of agroecological practices is to provide an alternative to conventional agriculture and conserve biodiversity by using biological control, organic amendments, direct seeding, diversification, crop rotation, agroforestry systems, intercropping, allelopathic plants, irrigation by drip, mulching, and other eco practices as efficiently as possible [11,16]. Unfortunately, agroecology in Morocco is still poorly known; some farmers practice traditional agriculture without chemical inputs, unaware that many of their practices are agroecological, and others have no idea about the term [17]. The state of adaptation of agroecology by Moroccan farmers remains poorly known in the literature. Some research has shown that information on farmers' attitudes and knowledge about pesticide use and agroecological practices has not been sufficiently documented in Morocco [11]. However, to the best of our knowledge, no survey was conducted on the types of organic and chemical fertilizers used by farmers in the Fez-Meknes region. As well, no previous study has explored a diagnosis of agroecology diffusion in the region for the vegetable sector.

To gain a comprehensive understanding of the agricultural practices and their impact on the environment and biodiversity in the Fez-Meknes region, our study has set several objectives. Firstly, we aim to (i) investigate the primary active materials used by farmers on vegetable crops in the region. (ii) to analyze the behaviors, attitudes, and knowledge of farmers towards the use of chemical and organic products and identify the shortcomings in safety measures and awareness of pesticide risks to crops, human health, and the environment. (iii) to assess the diffusion of agroecological practices in the vegetable crop sector of the region. (iv) to raise awareness among farmers during our surveys about the importance of proper pesticide use practices and ecological alternatives. (v) to identify the most significant barriers and motivators to adopting agroecological practices, and (vi) to understand the farmers' intentions to convert their farms to agroecological agriculture and adopt sustainable practices in the future.

Addressing these objectives would generate valuable insights into the state of agriculture in the region and would serve as a critical source of information for state structures responsible for training farmers not only in the region but also in other areas of Morocco. With a well-characterized and significant population surveyed, the findings could be accurately expanded to assess the status of agroecology in Moroccan regions. In addition, gaps

and problems will be potentially identified to determine the types and contents of training required for this important farming society.

2. Materials and Methods

2.1. Study Areas and Sampling

We conducted cross-sectional surveys involving a total of 603 vegetable growers in the heart of northern Morocco, specifically the Fez-Meknes region, between June 2021 and February 2022. This region covers 40.07 km^2 and is home to 4,236,892 inhabitants, of whom 60.52% reside in urban areas. The Fez-Meknes region was chosen due to its significant contribution to agricultural production in the country, with an estimated utilized agricultural area of 1,335,639 hectares, accounting for 15% of the total useful agricultural area in Morocco [18]. Irrigated land covers 1,251,456 hectares in the region, representing 9% of all agricultural land. The Fez-Meknes region encompasses two prefectures, Fez and Meknes, and seven provinces: Sefrou, El Hajeb, Ifrane, Moulay Yaacoub, Taounate, Boulemane, and Taza, which are characterized by different bioclimatic stages [3]. Our study selected 55 rural communities, as shown in Figure 1, known for their significant agricultural activity in the region.

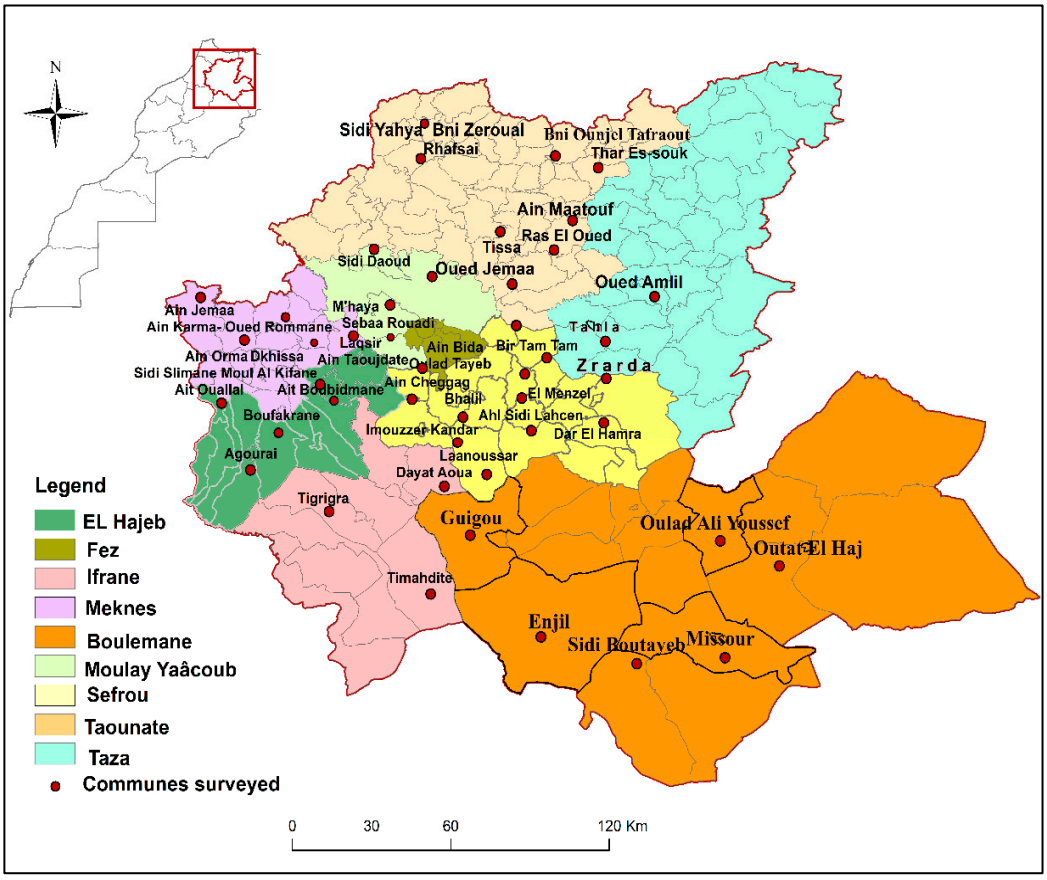

Figure 1. Location of the studied area in Fez-Meknes region, Morocco.

2.2. Sampling Method

We conducted a comprehensive study on the agricultural practices in the Fez-Meknes region of Morocco, involving 603 randomly selected vegetable growers between June 2021 and February 2022. The region, located in the heart of northern Morocco, covers 40.07 km^2 and is known for its significant contribution to the country's agricultural production, accounting for 15% of the total useful agricultural area in Morocco. Our survey was conducted with the utmost care, ensuring the anonymity of respondents, and participants were informed that participation was voluntary. The questionnaire was developed in

French and translated into the Moroccan dialect of Arabic to facilitate communication with the farmers. We also conducted visits to local vendors to learn about the pesticides most commonly used in the study area. To ensure the survey's quality, a pre-survey was conducted on a small sample of farmers, and direct observations were made during the survey to supplement the information provided during individual interviews. Our inclusion criterion was to include farmers who were 18 years of age or older, had more than five years of farming experience, and were either owners or employed. Our study aimed to cover a large diversity of vegetable crop production systems, and we reasoned the composition of the surveyed samples according to the diversity of production areas. Our study will provide valuable insights into the agricultural practices in the region and help identify gaps and problems, which will aid in the necessary types and contents of training required for this important segment of society.

The survey was conducted using a questionnaire divided into four parts:

The first part was devoted to sociodemographic questions (gender, age, education level, agricultural advisory services supervision (ACS), training in pesticide use and agroecological practices, and years of farming experience).

The second part dealt with the technical management of market gardening (crops, irrigation system, soil analysis, yield, destination of production, origin of seeds or seedlings, active materials used, organic and chemical fertilizers, etc.).

The third part focused on the practices, attitudes, and knowledge of market gardeners regarding alternative agroecological practices regarding diseases, pests, and weed management. Comparison between alternative and chemical methods in crop management; damage caused by fungicides, insecticides, and herbicides and their alternatives on crops; pesticide resistance; sanitary and environmental risks related to the use of phytosanitary products; protection measures taken by farmers during and after spraying the chemicals.

The last part is dedicated to the results related to the adoption of agroecological practices, the knowledge of their benefits and importance by farmers, major obstacles, the motivation of the respondents to adopt agroecological practices, and major problems encountered in the production of vegetable crops.

All these parts are structured in a questionnaire, including objective questions (yes/no or multiple choice) and subjective questions (explanations, viewpoint).

2.3. Data Collection and Processing

To ensure unbiased responses and obtain accurate agricultural practice data, farmers were not informed in advance about the survey. After data collection, incomplete responses and those not meeting the study criteria were removed. The responses were then double-checked for accuracy before being analyzed using SPSS 20 and Microsoft Excel 2013. Descriptive statistics, including frequencies, means, and percentages, were calculated, and chi-square tests were performed to determine the significance of categorical variables across different provinces. Multiple Component Analysis (MCA) was also conducted on the data collected. The study area and surveyed communities were plotted on a map using ArcGIS 10.3.1 software for visualization.

3. Results

3.1. Farmers' Descriptive Information

Table 1 presents an intriguing insight into the demographic makeup of farmers surveyed in the nine provinces of the study area. Out of the total participants, 96.4% (N = 581) were male, while only 3.6% (N = 22) were female. The majority of the farmers were aged between 35 and 55 years old with 60.7% of respondents falling into this age range. Additionally, 22% of respondents were under 35 years old. The education level of farmers varied, with 25.9% having no academic training, 16.6% having primary education, 8.9% having a college education, 34.5% having secondary education, and only 14.1% having a university degree. Geographical location was cited as a significant obstacle to accessing education. Regarding farming experience, most farmers had an experience between 5 and 10 and

15 and 20 years (32.7%). Surprisingly, a large portion of respondents (75.6%) had never benefited from agricultural advisory services; even more (81.3%) had not received any training on pesticide application; and a whopping 98.7% had no training on agroecological practices. Notably, there were significant differences in farmer age, education level, farming experience, and previous training/internship in pesticide use between provinces ($p < 0.05$), but no significant differences in gender or receipt of agricultural advisory services or previous training/internships on agroecological practices.

Table 1. Descriptive sociodemographic information of interviewers in Fez-Meknes region (N = 603).

Variable	Frequency	%	Tests
Gender			
Male	581	96.4	V = 0.166
Female	22	3.6	χ^2 = 0.166
Age (years)			
18–25	3	0.5	V = 0.268
25–35	127	21.1	χ^2 = 0.034
35–45	140	23.2	
45–55	226	37.5	
>55	107	17.7	
Education Levels			
Illiterate	156	25.9	V = 0.288
Primary	100	16.6	χ^2 = 0.00
College	54	8.9	
Secondary	208	34.5	
University	85	14.1	
Farming experience (years)			
5–10	197	32.7	V = 0.282
10–15	111	18.4	χ^2 = 0.00
15–20	197	32.7	
>20	98	16.2	
Benefit from agricultural advisory services (ACS)			
Yes	147	24.4	V = 0.364
No	456	75.6	χ^2 = 0.180
Previous training/Internship in pesticide use			
Yes	113	18.7	V = 0.194
No	490	81.3	χ^2 = 0.004
Previous training/Internship in agroecological practices			
Yes	8	1.3	V = 0.099
No	595	98.7	χ^2 = 0.660

Tests performed with Chi-square χ^2 and Cramer's V indicate the strength of the relationship between different provinces, significant at the 5% level.

3.2. Vegetable Crops and Agricultural Practices Adopted by Farmers

The results indicate that onions, potatoes, and garlic are the primary crops cultivated by farmers in the Fez-Meknes region. Additionally, certain crops, such as chicory, are concentrated in specific provinces (according to Table S1). Most farms in the region are small, with less than 2 hectares of land dedicated to vegetable cultivation. The most common sources of irrigation water are wells and rivers, and drip irrigation is the preferred method. Local seeds and seedlings are preferred over imported seeds, and the Chi-square test shows that all variables are significantly different between the studied provinces (Table S2) ($p < 0.05$).

These findings are consistent with previous research on agricultural practices in Morocco. For example, a study by [19] found that onions, potatoes, and tomatoes were the most commonly cultivated vegetables in the region. The preference for local seeds and seedlings over imported ones is also in line with previous research that has shown that farmers in Morocco often prioritize seed quality and adaptability to local conditions [20,21]. The concentration of certain crops in specific provinces could be due to variations in soil

type, climate, or market demand. For instance, Immouzzer in Sefrou province may have more favorable growing conditions for chicory than other areas in the region.

The predominance of small farms in the region is a common feature of agriculture in Morocco, where the majority of farmers operate on small plots of land [22]. The widespread use of drip irrigation is likely due to the region's water scarcity and the need to conserve water resources [23,24].

Overall, these results provide insight into the agricultural practices and preferences of farmers in the Fez-Meknes region and highlight the importance of considering local conditions and resources when designing agricultural policies and interventions.

3.3. Organic and Non-Organic Fertilizers Used by Farmers

The study highlights the poor fertilization practices among farmers in the Fez-Meknes region. The results indicate that most farmers (45%) randomly apply fertilizers without any consideration of the plant's needs, whereas only a small percentage of farmers (10%) base their fertilization on soil analysis results (Figure 2). The findings suggest that farmers lack knowledge about optimal fertilization practices, which can significantly impact crop yield. The study recommends that farmers adopt a more scientific approach to fertilization based on the soil's nutrient requirements and the plant's developmental stage.

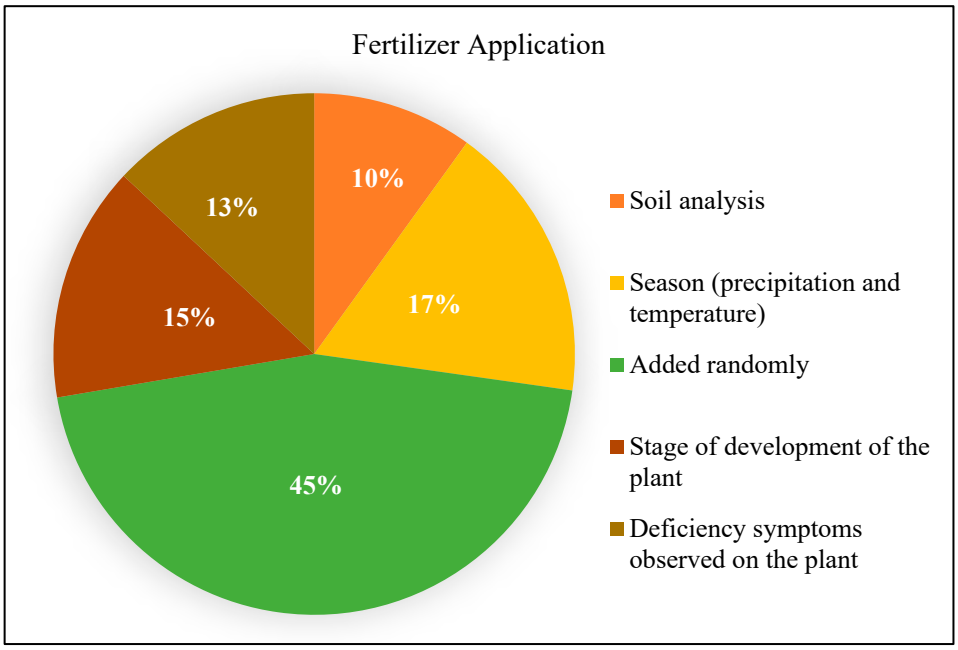

Figure 2. Fertilizer application patterns adopted by the farmers in Moroccan vegetable farming systems.

The study revealed that organic fertilizers, particularly manure from cows and sheep, are the most commonly used fertilizers among farmers in the region (96.35%) (Table 2). However, the use of industrial fertilizers such as NPK and ammonitrate 33.5 N, is also prevalent. Surprisingly, most farmers who use industrial fertilizers (95%) believe that they are necessary for good crop yields, despite the availability of organic fertilizers. The findings suggest that farmers need to be educated about the benefits of organic fertilizers, which can improve soil fertility and crop yield in the long run.

Table 2. Organic, mineral, and chemical fertilizers used by farmers with their frequency of use (N = 603).

Organic Fertilization	Always	Sometimes	Never
Manure	581 (96.35%)	1 (0.17%)	21 (3.48%)
Compost	164 (27.20%)	91 (15.09%)	348(57.71%)
Plant extracts	83 (13.76%)	122 (20.23%)	398 (66.00%)
Peat	28 4.64%)	42 (6.97%)	533 (74.14%)
Liquid Manure	99 (16.42%)	89 (14.76%)	415 (68.82%)
Green Manure crops	3 (0.50%)	18 (2.99%)	582 (96.52%)
Mulching	106 (17.58%)	142 (23.55%)	355 (58.87%)
Poultry droppings	96 (15.92%)	65 (10.78%)	442 (73.30%)
Respect for the quantities to be brought	12 (1.99%)	11 (1.82%)	580 (96.19%)
Mineral Fertilizers	**Always**	**Sometimes**	**Never**
Sulphur	155 (25.7%)	344 (57.05%)	104 (17.25%)
Potassium sulfate	203 (33.67%)	150 (24.88%)	250 (41.46%)
Natural phosphates	3 (0.50%)	7 (1.16%)	593 (98.34%)
Wood ash	23 (3.81%)	11 (1.82%)	569 (94.36%)
Lime and gypsum	0	7 (1.16%)	596 (98.84%)
Respect of the quantities to be brought	67 (11.11%)	123 (20.40%)	413 (68.49%)
Chemical Fertilization	**Always**	**Sometimes**	**Never**
NPK	241 (39.97%)	17 (2.82%)	345 (57.21%)
Ammonitrate 33.5 N	199 (33.00%)	93 (15.42%)	311 (51.58%)
Urea 46% N	40 (6.63%)	132 (21.89%)	431 (71.48%)
Ammonia sulfate 21% N	24 (3.98%)	30 (4.98%)	549 (91.04%)
Respect for the quantities to be brought	460 (76.29%)	136(22.55%)	7 (1.16%)

The study highlights that farmers often do not respect the quantities of fertilizers they use, particularly organic fertilizers, due to a lack of knowledge about their exact formulation and nutrient content. The study suggests that farmers need to be trained on how to measure the optimal quantities of fertilizers, particularly organic fertilizers, to avoid overuse, which can lead to soil degradation and environmental pollution.

The study found that the barriers preventing most farmers from using organic fertilizers are the odor (55.4%), slow effect (44.6%), and concerns about nutrient composition (22.7%). These findings are consistent with previous research that has shown that farmers often perceive organic fertilizers as less effective and less convenient than chemical fertilizers [25–27]. However, the study also indicates that most farmers find organic fertilizers cheaper than chemical fertilizers (95.19%) (Table 3), and they can recycle nutrients in the fields and solve the problem of organic waste. The findings suggest that farmers need to be educated about the benefits of organic fertilizers and how to mitigate the challenges associated with their use.

Table 3. Reasons for using each type of fertilizer by the farmers.

Why Chemical Fertilization?	N = 665	%	Why Organic Fertilization?	N = 573	%
Efficient	463	69.62	Action on the long term	19	3.15
Well-known formulation	92	13.83	Cheaper	574	95.19
Quick effect	110	16.54	Available	11	1.82

The study highlights that some farmers (12.6%) are fully committed to organic farming and never use chemical fertilizers, except for the mineral fertilizers that are permitted in organic agriculture. Surprisingly, these organic farmers reported having high yields at the end of their production (60.5%). This finding is consistent with previous research that has shown that organic farming practices can lead to high yields [28–30]. This finding suggests that organic farming practices can lead to high crop yields, and farmers need to be encouraged to adopt these practices. The study also found that most farmers (78.1%) combine the use of organic and chemical fertilizers but often inaccurately measure the quantities they apply. Among them, 88.9% use more organic inputs, leading to high yields, while only 11% use chemical inputs as the primary fertilizer (Table 4). The findings suggest

that farmers should be educated about the optimal ratios of organic and chemical fertilizers to achieve the best results.

Table 4. Types of fertilizers used (N = 603), the corresponding yield obtained, the highest input quantity in the case of a combination (N = 471), and the state of use of each fertilizer from year to year (N = 603).

Fertilizer		Yield				
	N (%)	Very High	High	Medium	Low	Very Low
Organics only	76 (12.6%)	0	46 (60.5%)	25 (33%)	5 (6.6%)	0
Chemical only	56 (9.3%)	9 (16.1%)	36 (64.3%)	11 (19.6%)	0	0
Combination of the two	471 (78.1%)	38 (8.1%)	261 (55.4%)	172 (36.5%)	0	0

The results suggest that farmers in the region are increasingly using chemical fertilizers and decreasing their use of organic fertilizers. This trend could have significant negative impacts on soil fertility, crop yield, and environmental pollution. Chemical fertilizers have been shown to degrade soil health over time, leading to reduced yields and increased use of these fertilizers, exacerbating the problem. Additionally, the overuse of chemical fertilizers can result in groundwater contamination and other environmental concerns.

The study recommends that farmers be educated about the benefits of organic fertilizers and the risks associated with the overuse of chemical fertilizers. This education should focus on the importance of maintaining soil health for long-term productivity and sustainability. Additionally, the government should encourage the use of organic fertilizers by offering subsidies, training programs, and awareness campaigns.

These recommendations align with the current understanding of the negative effects of chemical fertilizers on soil and the environment. Research has shown that organic fertilizers can improve soil health and productivity while reducing environmental impacts. Government initiatives to promote the use of organic fertilizers have been successful in some countries, such as India and China, where subsidies and training programs have been implemented [31–35].

In conclusion, the study highlights the poor fertilization practices among farmers in the Fez-Meknes region and recommends that farmers adopt a more scientific approach to fertilization based on the soil's nutrient requirements and the plant's developmental stage. The study also suggests that farmers need to be educated about the benefits of organic fertilizers and the risks associated with the overuse of chemical fertilizers. The findings have important implications for soil fertility and crop yield.

3.4. Pesticides Use and Sources of Agrochemical Information

The results of the study indicate that the use of pesticides in vegetable production is prevalent in the studied area, with 95% of farmers relying on these chemical substances to increase their crop yield and maximize economic benefits. Despite the availability of alternative organic farming methods, only a small percentage of farmers (3.6%) are certified organic or are in the certification process (1.33%). This heavy reliance on pesticides has led to crop diseases and harmful pests, which farmers try to combat by using a wide range of pesticides, with 54 active materials identified in the study.

Fungicides are the most commonly used type of pesticide (53.7%), followed by herbicides (29.6%), insecticides (16.7%), and molluscicides (2.79%) (Table S4). However, many farmers do not adhere to recommended dosage levels, which can result in increased risks to human health and the environment. The study also reveals that farmers primarily learn about agrochemicals and their potential negative health effects from other farmers (51.03%), with agrochemical sellers being the second most common source of information (24.61%) (Figure 3).

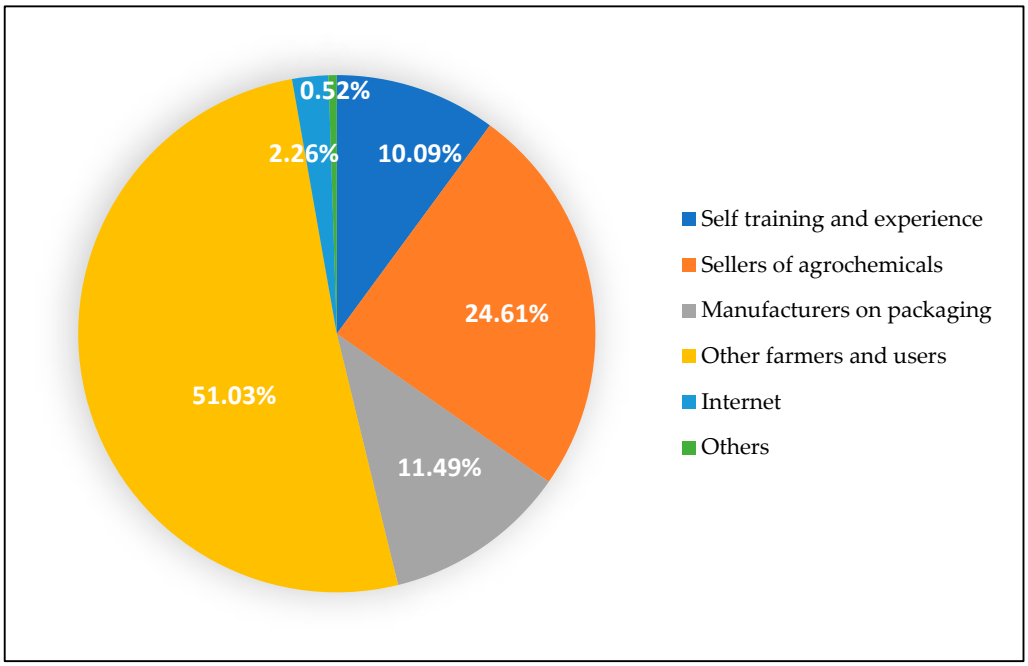

Figure 3. Sources of information about the agrochemicals adopted by the farmers in Moroccan vegetable farming systems.

These results demonstrate a concerning picture of the widespread use of pesticides in vegetable production in the studied area. The findings highlight the urgent need for education and support for sustainable, organic farming practices to reduce the risks associated with pesticide use and promote safer and healthier food production. Several studies have shown that organic farming practices are effective in reducing pesticide use and minimizing negative impacts on human health and the environment [36–39]. Governments, NGOs, and other stakeholders can help farmers transition to organic farming by providing technical assistance, training, financial incentives, and market support [36,37].

3.5. Rotation of Active Materials and Calendar of Treatments

The results of the study suggest that farmers in the studied area have a significant reliance on pesticides to maximize yield and economic benefits. However, this reliance comes with its own set of problems, including the issue of pest resistance to active materials, which is a major concern for over half of the farmers (56.55%), a worrying 43.45% of farmers are not aware of the risks of repeating the same active materials multiple times, even after their effectiveness has worn off. Despite the availability of alternative organic farming methods, only a small percentage of farmers are already certified organic, indicating a need for increased education and support for sustainable pest management practices.

The study also highlights the need for farmers to adhere to recommended dosage levels, establish a treatment calendar to manage pests, and seek out alternatives to avoid pesticide resistance over half of the farmers (54.39%) do not adhere to any treatment schedule. Instead, 59.34% of growers rely on their own experience and the severity of the pest problem to determine the dosage of pesticides to be used. These findings are in line with other studies that have shown the negative impact of excessive pesticide use on human health and the environment [40,41]. In addition, research has shown that sustainable pest management practices, such as crop rotation and biological control, can reduce pesticide use while maintaining crop yield [42,43].

To address these issues, there is a need for increased education and support for sustainable pest management practices, as well as the development and promotion of alternative pest control methods. This can be achieved through farmer training programs, public

awareness campaigns, and the provision of technical assistance and financial incentives to farmers who adopt sustainable practices [44].

3.6. Compliance with Pre-Harvest Interval and Postharvest Treatments with Fungicides

The Pre-Harvest Interval (PHI) is a critical aspect of pesticide use in agriculture that ensures the safety of consumers by allowing enough time for the chemical to break down before harvest. The fact that almost all farmers in the studied area (95.52%) are aware of and adhere to this important safety measure is positive news, as it indicates that farmers are taking consumer safety seriously. However, the fact that a significant number of farmers remain unaware of the importance of PHI is concerning, as it indicates a lack of education and awareness on the issue. Post-harvest treatments are also important for maintaining fruit quality and reducing post-harvest rot. Unfortunately, only a small percentage of farmers (7.63%) perform these treatments, while the majority (92.37%) prefer to apply no post-harvest treatment at all. This lack of post-harvest treatment could potentially lead to lower fruit quality and higher rates of spoilage, ultimately affecting the economic viability of the farming operation. Therefore, prioritizing both PHI and post-harvest treatments is crucial for ensuring the safety and health of consumers as well as promoting more sustainable and responsible agricultural practices [45–47].

3.7. Alternative Practices and Products to Pesticides Used by the Farmers

The results of this survey suggest that many farmers are implementing a range of cultural and chemical control methods for pest and disease management, which is in line with current recommendations for integrated pest management (IPM) strategies (Table 5). The use of cultural techniques, such as selecting resistant varieties and reducing plant density, is known to be an effective means of controlling fungal diseases without the use of fungicides [36,48]. Similarly, the use of manual weeding, plastic mulching, and permaculture for weed control aligns with IPM principles that aim to reduce reliance on herbicides [36]. The use of alternative pest management techniques, such as black soap and yellow adhesive plates for insect control, has also been found to be effective in reducing pesticide use [36].

Table 5. Fungicide, herbicide, insecticide, and molluscicide alternatives practices.

Insecticide Alternatives	**N**	**%**
Yellow adhesive plates	13	2.16
Wood ashes	23	3.81
Winter cover	58	9.62
Black soap	93	15.42
Less sensitive varieties	12	5.97
Alternatives for Molluscicides	**N**	**%**
Manual collection	74	12.27
Barriers and traps	58	9.62
Fungicide Alternatives Practices	**N**	**%**
Leaf stripping	29	4.81
Cow's milk	4	0.66
Vinegar	2	0.33
Lower density	22	3.65
Less sensitive varieties	36	5.97
Alternative to Herbicides	**N**	**%**
Wood mulch RCW	20	3.32
Plastic mulching	58	9.62
Mulching Wheat	16	2.65
Manual weeding	244	40.46
Permaculture	231	38.31
False seeding	18	2.99
Mechanical weeding	6	1

However, the relatively low usage of some cultural techniques for disease and pest control, such as stripping infected leaves and employing winter cover for insect management, suggests that there may be room for increased awareness and adoption of these practices. In addition, the reliance on manual weeding among smaller farms may indicate a need for better access to and adoption of more efficient mechanical weeding technologies, as well as training and education on the use of these tools [49].

Overall, the use of a combination of cultural and chemical control methods for pest and disease management, as well as the implementation of alternative pest management techniques, can contribute to more sustainable and responsible agricultural practices, with potential benefits for both the environment and human health.

3.8. Alternative and Chemical Methods Comparaison in Crop Management

The results indicate that a significant majority of farmers reported an increase in pesticide use year after year due to an increase in biotic constraints. This suggests that the farmers perceive pesticides as an effective method of pest, disease, and weed control. However, the use of alternative practices has decreased as farmers have observed higher efficiency rates with chemical methods (Table S3). This may be due to the perception that chemical methods are more effective and easier to use than alternative practices.

The effectiveness of chemical methods is supported by the high percentage of farmers who found chemicals to be "very effective" compared to alternative methods. This trend is also supported by Figure 4, which shows that chemical methods are highly effective at the field level. These results suggest that farmers are more likely to use chemical methods because they perceive them to be more effective and efficient.

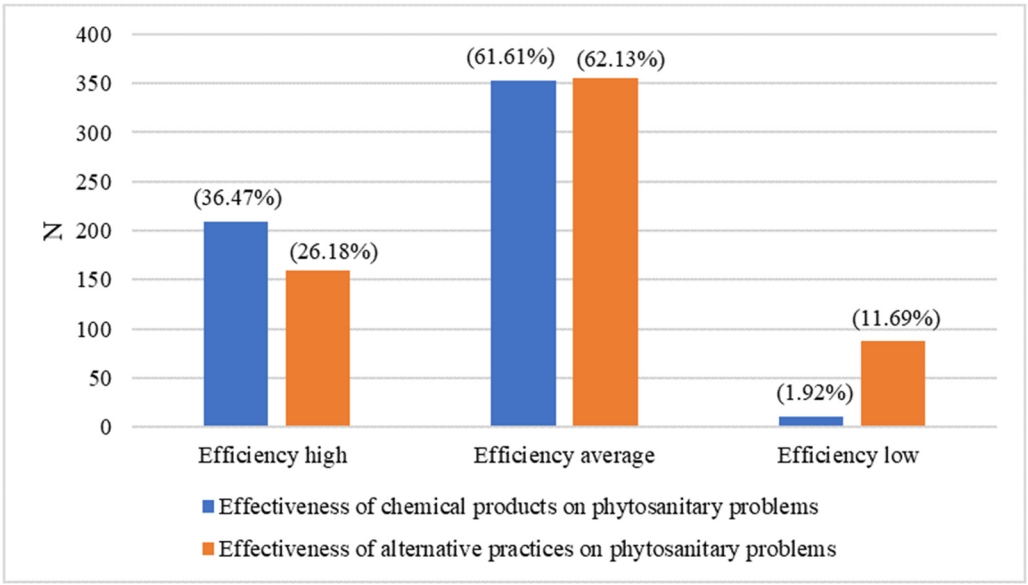

Figure 4. Rate of effectiveness of pesticides and alternative practices in the field (N = 573).

The findings are consistent with previous studies that have shown a preference for chemical methods among farmers due to their perceived effectiveness and ease of use [50–52]. However, this trend may have negative implications for the environment and human health, as the increased use of pesticides can lead to pesticide resistance and environmental contamination [52].

Therefore, it is important to promote and encourage the use of alternative practices that can reduce pesticide use and promote sustainable agriculture. These practices may include crop rotation, intercropping, biological control, and the use of resistant varieties [53]. By promoting sustainable agriculture practices, farmers can reduce their dependence on

pesticides and mitigate the negative impacts of pesticide use on the environment and human health.

3.9. Damage Caused by Fungicides, Insecticides, Herbicides, and Alternative Practices on Crops

The results suggest that despite the high awareness among farmers of the negative effects of excessive pesticide use on their crops, crop damage still occurs after pesticide application (Figure S1). This is indicated by the high percentage of farmers reporting crop damage from insecticides and fungicides. Additionally, more than 50% of farmers reported occasional damage to crops after pesticide use. These findings are consistent with previous studies that have highlighted the negative impacts of pesticide use on crop health [54,55].

In contrast, alternative practices were reported to rarely cause crop damage. This suggests that alternative practices may be a more sustainable and effective approach to pest management. These findings are consistent with previous studies that have shown the effectiveness of alternative practices such as integrated pest management, crop rotation, and intercropping in reducing pest damage [52,56]. It is important to note that the use of alternative practices may require additional resources and knowledge compared to the use of pesticides. However, the long-term benefits of sustainable practices may outweigh the short-term benefits of pesticide use [57]. Therefore, it is crucial to promote and encourage the use of alternative practices and provide farmers with the necessary resources and knowledge to adopt sustainable agricultural practices.

3.10. Farmers' Awareness of the Danger of Pesticides to Human Health and Environment

The results indicate that most farmers are aware of the negative health effects associated with excessive pesticide use, with 89.71% reporting experiencing symptoms related to pesticide exposure (Figure 5). The most commonly experienced symptoms were discomfort in the throat and visual disturbance, which are consistent with previous studies on the health effects of pesticide exposure [11–13,58,59]. However, the fact that all respondents answered negatively when asked about health risks for consumers suggests a lack of understanding among farmers about the potential risks to consumers.

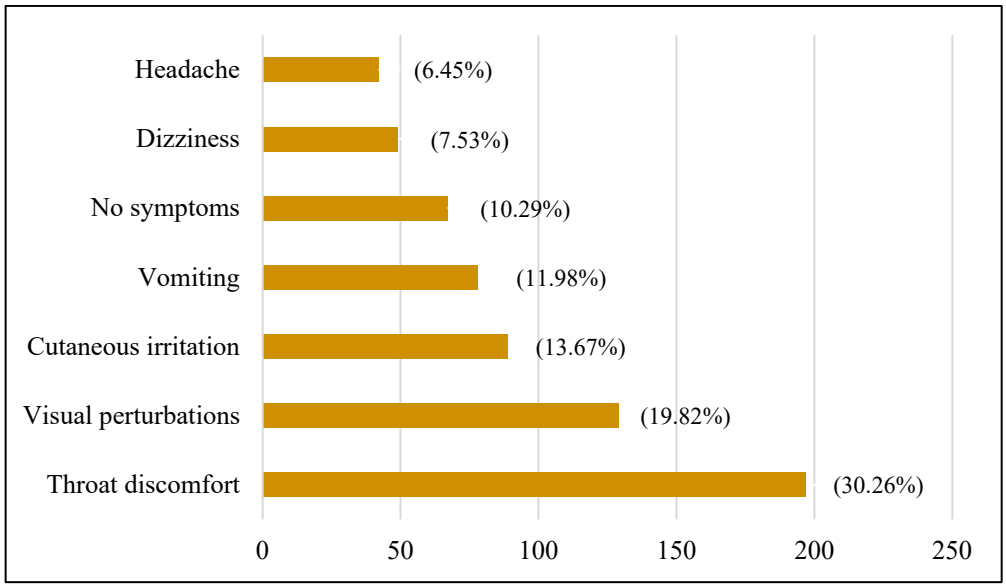

Figure 5. Sensations described by farmers after being in contact with pesticides (N = 651).

The study found that a large percentage of farmers (38.44%) were not aware of the harmful effects of pesticides on the environment, while 27.11% believed that pesticides had no impact on the environment. Only 38.45% of farmers had a high level of awareness, with 15.46% acknowledging that pesticides contribute to environmental pollution, 9.8% recognizing that pesticides cause soil sterility, and 9.19% stating that pesticides are linked

to biodiversity loss (Figure 6). This is a concerning finding given the well-documented environmental impacts of pesticide use, including water pollution, soil degradation, and biodiversity loss [60–62]. The results also suggest that there is a need for increased education and awareness-raising efforts among farmers regarding safe and environmentally friendly pesticide use.

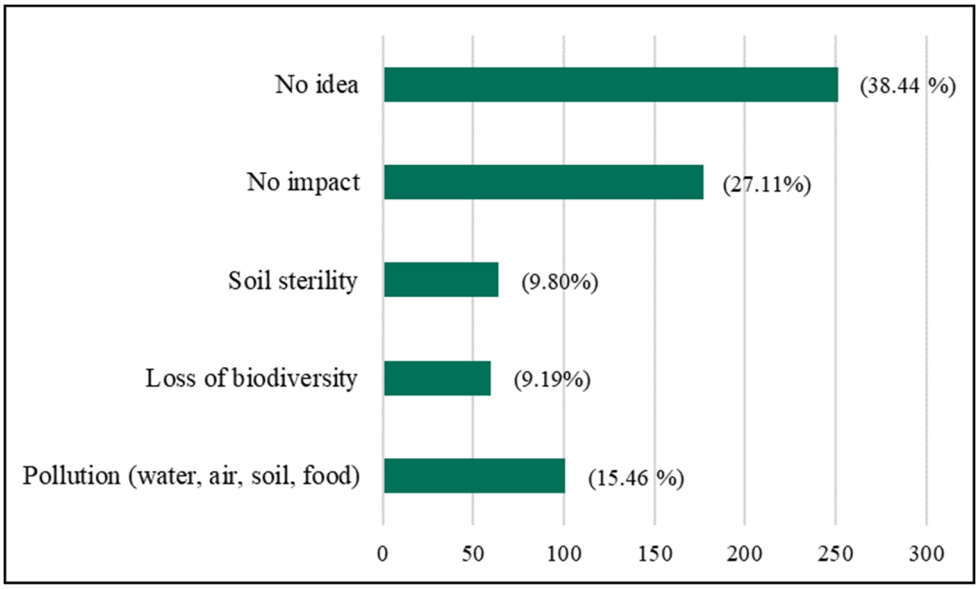

Figure 6. Farmers' perceptions of pesticide effects on the environment.

In terms of the disposal of phytosanitary product packaging, many farmers mentioned rejecting it in public landfills (37.41%). Cremation was the most preferred method of disposing of empty pesticide containers (31.80%), followed by burial (20.24%), and leaving the packaging on the site (10.54%).

The findings related to the disposal of phytosanitary product packaging are also note-worthy. The fact that a significant percentage of farmers dispose of empty pesticide containers in public landfills highlights the potential risks of contamination and pollution associated with improper disposal practices. Cremation and burial were the most preferred methods of disposing of empty containers, which suggests that farmers are aware of the need for safe and responsible disposal methods.

3.11. Safety Measures after and during Phytosanitary Treatments

The study found that, despite being aware of the negative effects of pesticide exposure on their health, a significant proportion of farmers (43.46%) did not take any precautionary measures during pesticide application. This result is alarming as it indicates that many farmers are not taking appropriate steps to protect themselves from pesticide exposure, which could have long-term health consequences. However, it is positive to note that the majority of farmers (56.54%) did take precautions, such as wearing gloves and goggles, depending on their availability (Table 6).

After pesticide application, more than 57% of farmers did not take any protective measures, which puts them at risk of exposure to pesticide residues. However, some farmers did take precautions such as washing their hands, changing clothes, showering, and washing equipment to protect themselves from pesticide residues. This highlights the need for more education and awareness-raising programs among farmers about the importance of taking protective measures before and after pesticide application.

According to a study conducted in Iran, inadequate protective measures taken by farmers during pesticide application are a significant risk factor for pesticide exposure [40,63]. The study emphasized the need for proper protective measures to prevent pesticide ex-

posure and suggested that farmers should use personal protective equipment, such as gloves, masks, and goggles, to reduce the risk of exposure to pesticides. Another study conducted in India found that educating farmers about the importance of wearing protective clothing and equipment during pesticide application significantly reduced pesticide exposure [64,65].

In conclusion, the study shows that while farmers are aware of the negative effects of pesticide exposure on their health, a significant proportion do not take appropriate precautionary measures during pesticide application. This highlights the need for more education and awareness-raising programs to improve the adoption of protective measures among farmers to prevent pesticide exposure.

Table 6. Protection measures during and after phytosanitary treatments.

Protection Measures during the Application of Pesticides N = 324	**Always**	**Sometime**	**Never**
Use of waterproof gloves	231 (71.3%)	16 (4.94%)	76 (23.46%)
Use of masks	55 (16.97%)	59 (18.21%)	210 (64.81%)
Use of goggles	60 (18.51%)	18 (5.56%)	246 (75.93%)
Use of appropriate combinations of pesticides	53 (16.36%)	15 (4.63%)	256 (79.01%)
Protection Measures after the Application of Pesticides N = 242	**Always**	**Sometime**	**Never**
Hand washing	105(43.39%)	103 (42.56%)	34 (14.05%)
Clothing change	187(77.27%)	50 (20.66%)	6 (2.48%)
Showering	67 (27.69%)	45 (18.59%)	130 (53.72%)
Washing equipment	80 (33.06%)	34 (14.05%)	128 (52.89%)

3.12. Status of Adoption and the Importance of Agroecological Practices

The results presented (Table 7) suggest that farmers are increasingly adopting agroecological practices, which are techniques and strategies aimed at promoting sustainable and environmentally friendly agriculture. The practices identified in the results include crop rotation, direct seeding, intercropping, and agroforestry, all of which have been found to have significant benefits for both the environment and agricultural productivity.

Table 7. The number of adopters and benefits of agroecological practices observed by farmers.

Practices	**Number of Adopters**	**Benefits Noted**	**%**
Rotation	601 (99.67%)	Management and reduction of weeds	41.23
		Crop yields increased	29.79
		Soil fertility improvement	18.99
		Pest and diseases control	9.98
No-till	13 (2.16%)	Save tillage costs	50
		Management and reduction of weeds	50
Intercropping	417 (69%)	Reduces weed density	30.84
		Saves space	100
		Optimal use of resources	47.85
		Controls the spread of diseases and pests	12.37
Agroforestry	561 (93.03%)	Exploitation of space	100
		Exploitation of irrigation water by trees	100

Crop rotation, for example, has been shown to help control pests and diseases, reduce weeds, and improve soil fertility [66]. Similarly, direct seeding has been found to be an effective way of reducing tillage costs and managing weeds [67]. Intercropping, which involves planting different crops in close proximity, has been shown to have a range of benefits, including reducing weed density, saving space, and controlling the spread of diseases and pests [68].

Agroforestry, which involves integrating trees with crops or livestock on agricultural land, has also been found to have numerous benefits, including maximizing space and irrigation water [69]. However, the results suggest that many farmers may not be fully aware of all the benefits that agroforestry can provide.

Overall, the findings indicate that farmers are increasingly adopting agroecological practices, which can help promote sustainable and environmentally friendly agriculture. By incorporating techniques such as crop rotation, direct seeding, intercropping, and agroforestry into their farming practices, farmers can improve their yields, reduce their environmental impact, and promote more sustainable agricultural practices.

3.13. Obstacles and Motivations to Adopt Agroecological Practices

The results suggest that farmers' motivation to adopt agroecological practices is influenced by various factors, including success stories from other farmers, traditions, training from experts, and consumer demand for environmentally friendly products (Table 8). These findings are consistent with previous research that has shown the importance of social norms, knowledge, and market demand in driving the adoption of sustainable farming practices [14,70,71].

Table 8. Obstacles and motivations for the application of agroecological practices in the Fez-Meknes region by farmers.

Barriers	**Percentage**
High perception of the efficacy of pesticides	53.6%
lack of agroecological training for farmers	44.7%
Lack of technical advice and support	70.8%
Lack of knowledge about new biological plant protection products	20.2%
Lack of citizen and consumer awareness	11.34%
Difficulties to control diseases, pests, and weeds without pesticides	73.2%
Low efficiency of organic products	54.6%
Low yields of agroecological practices among others	58.7%
Marketing difficulties due to the price	40.9%
Motivations	**Percentage**
Success of other farmers	50%
Tradition practiced for a long time	50%
Consumer demand for sustainable products	20%
Training received by experts to promote the adoption of agroecological practices	1.33%

However, the results also suggest that there are significant barriers to the adoption of agroecological practices. Farmers perceive managing pests, diseases, and weeds without pesticides to be challenging, and more than half of them believe that pesticides are more effective than organic alternatives. These findings are consistent with previous research that has shown that farmers often perceive chemical inputs as necessary for ensuring crop productivity and profitability [72].

Furthermore, the results indicate that the lack of access to technical advice and support is a significant barrier to the adoption of agroecological practices. This finding is consistent with previous research that has highlighted the importance of extension services in promoting sustainable farming practices [14,73].

Overall, the results suggest that promoting the adoption of agroecological practices requires addressing the barriers that farmers face while emphasizing the benefits of these practices. Providing technical advice and support, training programs, and creating markets for environmentally friendly products are crucial steps in promoting the adoption of sustainable farming practices.

3.14. Major Problems Encountered in the Production of Vegetable Crops

According to the descriptive analysis of the data, the top constraints in vegetable production identified by farmers were invasive weeds, which were mentioned by 95.85% of them. Pests and diseases were also a major issue for 80.27% of farmers, followed by the high price of fertilizers and pesticides, which was a concern for 79.44% of them (Table 9). These findings are consistent with previous research [74,75].

Table 9. Percentage of major problems encountered by farmers in the production of vegetable crops.

Major Problems Encountered in the Production of Vegetable Crops	Percentage
Invasive weeds	95.85%
High price of fertilizers and pesticides	79.44%
Diseases and pests	80.27%
Commercialization	4.15%
Labor too expensive	18.57%
Dryness	12.49%

Table 10 revealed that a significant number of farmers (48.48%) strongly agreed to convert their farms to more eco-friendly and organic practices in the future. Additionally, 58.54% of farmers desired to have more organic alternatives available on the market at a reasonable cost. Furthermore, 64.5% of farmers expressed their willingness to convert to organic farming in the future; the same findings were found in previous research [14].

Table 10. Reflection on the likelihood of farm conversion to organic agriculture and the desire to have organic alternatives available on the market at a reasonable cost.

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean
Likelihood of converting my farm to organic in the future	152 (25.21%)	5 (0.01%)	60 (9.95%)	94 (15.59%)	292 (48.42%)	603 (100%)	3.61
Availability of more organic alternatives in the market with a reasonable cost	4 (0.66%)	15 (2.49%)	1 (0.17%)	233 (38.64%)	353 (58.54%)	603 (100%)	1.47

Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

3.15. Relationships between Farmers' Attributes and Management Behavior in Vegetable Farming Systems

Multiple Component Analysis (MCA) was conducted to assess the relationship between farmers' attributes and their fertilization and pesticide behaviors (Figure 7). The MCA analysis showed that the two dimensions accounted for 25.08% and 68.72% of the variance, respectively. The study considered four characteristics related to farmers, their academic level, age, agricultural supervision, and years of experience. The results indicated that fertilization patterns were closely associated with academic level and years of experience, particularly when using both chemical and organic approaches. The same findings were obtained in previous studies conducted in a similar manner [76–78]. For instance, Han and Zhao [76] found in a study conducted in China that farmers' characteristics (e.g., farming experience, and current technical knowledge) were positively correlated with fertilization attributes. Organic fertilization was preferred due to the benefits gained through experience, while age played a role in this decision. Availability and affordable prices of organic fertilizers were the most common reasons, which were influenced by agricultural supervision and the Agricultural Cooperative Society (ACS). The latter has a significant role in channeling fertilization behavior in farming systems [79,80]. Ibitoye [79] highlighted the inclusion of Nigerian ACSs in the application patterns of fertilizers in agricultural fields, while Qu et al. [80] indicated the strong impact of these cooperative structures on fertilization efficiency. In contrast, chemical fertilization was highly associated with farmers' age and experience, primarily in terms of efficacy and mode of action. Additionally, farmers' experience was linked to high yields when using a chemical approach. Similarly,

the use of pesticides was linked to farmers' experience and age, with the latter being a significant factor in determining usage. The MCA demonstrated that fertilization behavior was strongly linked to farmers' attitudes and characteristics.

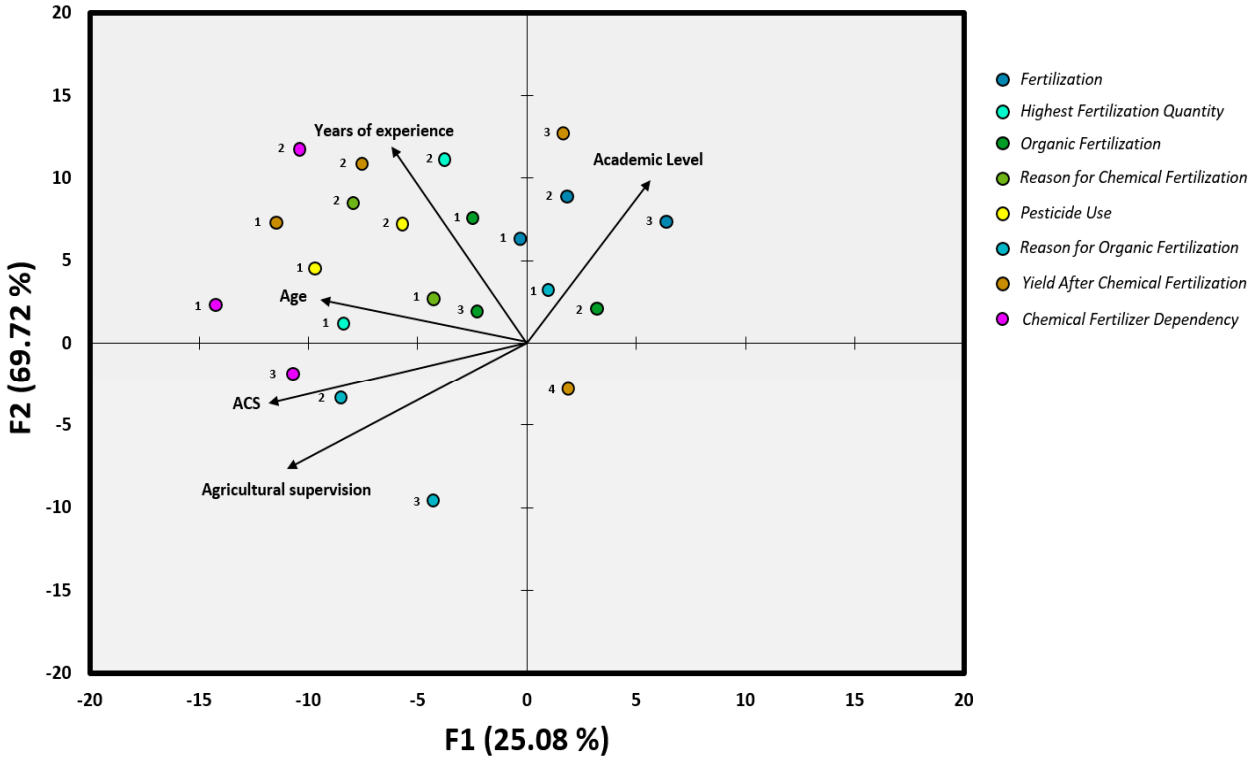

Figure 7. Multiple Component Analysis (MCA) depicting fertilization and pesticide behaviors in terms of farming attributes. The arrow direction indicates the correlation between each variable and the correspondence axes (F1 and F2). The arrow length shows the relative contribution of the variables to the axes and the farming characteristics. Each number (1, 2, 3 . . .) represents the attributes of each fertilization and pesticide variable based on the survey.

4. Discussion

Agroecological practices have gained increasing attention as a promising solution for sustainable agriculture [15–17]. This approach is based on the principles of ecology, emphasizing the relationships between crops, soil, water, climate, and other environmental factors. Agroecology aims to create a more sustainable, resilient, and diversified food system that benefits both farmers and consumers [14–17]. This article will discuss the scientific contribution, opportunities, challenges, and constraints of agroecological practices, with a particular focus on soil fertilization and pesticide use.

4.1. Soil Fertilization

Soil fertilization is essential for maintaining crop yield, quality, and sustainable productivity. However, it must be carried out with consideration for several parameters, including the levels of elements already present in the soil, the processes of absorption, the plant's needs, the stage of development, and the climate (rainfall, temperature) to avoid problems of over-fertilization or fertilizer deficiency [10,16]. Unfortunately, many farmers still rely on their own experience when it comes to fertilization, without knowing or calculating the amount of fertilizer, the plant's needs, or soil composition [81–83]. This lack of knowledge and awareness of the importance of soil testing can be attributed to low levels of education and insufficient knowledge, among other factors [81].

Agroecological practices offer several opportunities for soil fertilization [14,15]. For example, the use of compost or organic fertilizers can increase soil fertility and improve

soil structure [82,83]. Compost is an excellent source of plant nutrients, including nitrogen, phosphorus, and potassium, as well as other micronutrients [84]. Organic fertilizers, such as animal manure, also provide nutrients and improve soil structure. These practices help reduce the use of synthetic fertilizers and promote soil health, which is essential for sustainable agriculture [82,83].

However, the adoption of agroecological practices faces several challenges and constraints related to soil fertilization. One of the main challenges is the increasing use of chemical fertilizers by farmers worldwide [85]. The use of synthetic fertilizers has several negative impacts on the environment, including soil degradation, water pollution, and greenhouse gas emissions [10,86,87]. In addition, synthetic fertilizers can harm soil microbes, which are essential for soil health and nutrient cycling. Therefore, reducing the use of synthetic fertilizers is essential for sustainable agriculture [35,36,86].

Another challenge is the cost of organic fertilizers, which can be higher than synthetic fertilizers. This cost can be a barrier for small-scale farmers, who may not have access to these fertilizers or the resources to produce them. In addition, the use of compost or organic fertilizers requires careful management to avoid the risk of pathogen contamination, which can harm crops and human health [87].

4.2. Pesticide Use

Pesticides are substances used to control pests, diseases, and weeds in agriculture. However, their use presents several challenges and constraints related to environmental and human health [10,13,40,87]. Pesticides can harm non-target organisms, including beneficial insects, birds, and soil microbes, and can lead to soil degradation and water pollution [7,10–12]. In addition, pesticide residues can remain in food products and harm human health, especially in regions where pesticide regulation is weak or non-existent [13,40,87].

The heavy use of pesticides presents a great risk, especially in regions characterized by high consumption of vegetables, and can cause damage to crops and the environment as well as human health [11–13,40,41]. Therefore, training and sensitizing farmers to good practices in the use of pesticides or the adoption of agroecological practices are necessary to influence other farmers and increase awareness of the totality of farmers.

Agroecological practices offer several opportunities for reducing pesticide use [14,16]. For example, crop rotation [88], intercropping [89], and agroforestry [90] can help reduce pest pressure and increase biodiversity. In addition, the use of biological control agents, such as beneficial insects and fungi, can help control pests and reduce pesticide use [91].

In addition to training and sensitization, policies and incentives can also play a crucial role in promoting the adoption of agroecological practices. Governments can provide financial support for the implementation of agroecological practices, such as subsidies for soil testing, composting, or other organic fertilizers, and for the purchase of equipment for drip irrigation or other water-saving techniques. They can also establish regulations and standards for pesticide use [13], require farmers to obtain licenses and follow good agricultural practices, and enforce penalties for non-compliance. Moreover, agricultural extension services can be reformed to better meet the needs of small-scale farmers and to provide them with accurate and up-to-date information on agroecology and sustainable agriculture [16,17]. Research institutions can also play a role in developing and testing new agroecological practices and technologies that are adapted to the local context and that take into account the knowledge and needs of farmers. In conclusion, a shift towards agroecological practices is not only necessary for the sustainability of agriculture but also offers significant opportunities for improving food security, rural livelihoods, and environmental conservation [15,92]. It requires concerted efforts and collaboration between farmers, governments, civil society organizations, research institutions, and consumers to achieve a food system that is healthy, resilient, and just for all.

Our findings have significant implications for the global agricultural sector, particularly in the context of increasing concerns over food security, climate change, and environmental degradation. The adoption of agroecological practices can help reduce

reliance on synthetic inputs such as pesticides and fertilizers, increase soil fertility and biodiversity, and promote more resilient and diverse farming systems that can adapt to changing climatic conditions [15,16,92].

Moreover, our study highlights the importance of providing farmers with accurate and reliable information on sustainable agricultural practices, which can be achieved through practical tests and field experiments. By doing so, we can improve awareness and confidence in agroecological techniques, thereby contributing to sustainable agricultural practices.

5. Conclusions

The agricultural sector is a vital component of the global economy, but its excessive use of pesticides and agrochemicals poses negative environmental impacts and human health risks. Our study aims to shed light on the current state of awareness and practices among farmers regarding agroecological techniques and the use of pesticides. Our findings demonstrate that while most farmers lack training in the application, management, and protection measures of pesticides, they are adopting some practices to reduce chemical use. The most promising finding is that the experience of other farmers is the main source of information and motivation for adopting new practices.

To promote the adoption of agroecological practices, it is essential to provide farmers with accurate and reliable information through practical tests and field experiments. This can improve awareness and confidence in agroecological techniques, thereby contributing to sustainable agricultural practices. Furthermore, the study highlights the need for active state intervention in promoting sustainable agricultural practices. Governments can play a vital role in supporting farmers by providing subsidies during the transition period to agroecological techniques, establishing sales networks for agroecological products, and investing in scientific research to support innovation and the development of new agroecological techniques. In addition, scientific research should be encouraged to allow for innovation in agroecological techniques.

The findings of the study suggest that peer-to-peer learning is a significant motivator for farmers to adopt new practices. Therefore, promoting farmer-to-farmer knowledge sharing and collaboration can be an effective way to encourage the adoption of sustainable agricultural practices.

On the other hand, it is important to recognize that the transition to agroecological practices will not be without challenges. For instance, there may be resistance from farmers who are accustomed to using conventional practices or a lack of resources to implement agroecological techniques. Thus, there is a need for continued education, research, and support to help farmers overcome these challenges and promote the adoption of sustainable agricultural practices.

Overall, the study provides important insights into the current state of agricultural practices and highlights the urgent need for a shift towards sustainable agroecological techniques. By promoting these practices, we can ensure the long-term viability of agriculture while mitigating negative environmental impacts and protecting human health. Therefore, we hope that our study will contribute to this important endeavor by raising awareness and highlighting the opportunities, challenges, and constraints of agroecological practices.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15097412/s1, Figure S1. Frequency of damages caused by fungicides, insecticides, herbicides, and their alternatives on crops; Table S1. Main vegetables grown among the respondents of the survey (N = 603) in different provinces; Table S2. Surface area, origin of seeds or seedlings, and irrigation modeled by the farmers (N = 603); Table S3. State of use of alternative and chemical methods in crop management (N = 603); Table S4. Phytosanitary problems of vegetable crops and pesticides used by farmers in percentage (N = 573).

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writing—review and editing, R.L., S.-E.L., M.E.J., S.B., J.A.F. and A.B.; visualization, S.-E.L. and S.B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare that there is no conflict of interest.

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