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Weed control practices and awareness of herbicide resistance among cereal farmers of northern Greece

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Abstract

Knowledge of weed control practices and farmers' awareness of herbicide resistance could be a basis for improving weed management programs with respect to herbicide resistance, but research on this topic is limited. This study reports current weed control practices and levels of awareness of herbicide resistance among cereal farmers of northern Greece. Face-to-face interviews were conducted with 250 cereal farmers of Evros district, based on a structured questionnaire. Most farmers (82.8%) used herbicides in cereal production, with one application per growing season. Farmers appeared divided with respect to using the same herbicide each year; the majority of the farmers (90.8%) applied crop rotation. Almost half of the farmers (47.2%) did not know what herbicide resistance is, but most farmers (75.1%) felt herbicide resistance would be a problem for them. According to their answers on nine knowledge questions about herbicide resistance, 66.8% of the farmers had good knowledge, and 33.2% had poor knowledge. Almost seven in 10 farmers (69.8%) did not consider herbicide resistance when purchasing an herbicide for use, and only 40.4% were willing to change common weed control practices to prevent herbicide resistance. Awareness of herbicide resistance did not differ by sex; poor awareness levels increased with advanced age, low education levels, and small farm size. Farmers who used chemical weed control had higher awareness levels of herbicide resistance than farmers who never used herbicides. Farmers who were keeping records of herbicide applications, those who observed low efficacy of herbicides in their field, and those who applied crop rotation had high awareness levels of herbicide resistance, whereas farmers who used the same herbicide each year had poor awareness. Findings shed light on interrelationships between farmers' awareness of herbicide resistance and current weed control practices that could be useful for targeted extension education.

Introduction

Herbicide resistance has increased rapidly over the past decades, greatly increasing costs of weed management, especially with the lack of new herbicides (Norsworthy et al. 2012). The use of alternative practices to control a resistant weed population once it evolves or the implementation of preventive measures before weed populations become resistant are common solutions to this serious problem (Beckie 2006; Beckie and Harker 2017; Owen 2016). Switching to a different herbicide that is still active on the resistant weed population is often the immediate response, but integration of appropriate tactics based on adequate knowledge of the weed biology and of the herbicide mode of action is required for long-lasting management of herbicide resistance. Nevertheless, herbicide resistance is affected by several factors, with human decision-making interacting with all preventive efforts (Shaw 2016).

The development of herbicide resistance is greatly affected by farmers' decisions and actions, but little analysis has been conducted on this dimension (Shaw 2016). Indeed, intentional decisions of growers to apply herbicides or other weed control practices can contribute to herbicide-resistance development, whereas poor attention has been paid to the role of farmers in herbicide-resistance evolution and management with respect to related decisions (Ervin and Jussaume 2014; Jussaume and Ervin 2016; Ward 2016). Farmers' decision-making and behavior are complex processes that can vary largely from grower to grower (Damalas and Koutroubas 2018). This variation is often dictated by the economics of weed management practices, ability to access financing, availability of equipment and labor, knowledge, perceptions, and personal experience of the grower, which all interact with farmers' decision-making.

Farmers' surveys have been used by weed scientists to determine perceptions of weed problems (Gibson et al. 2005), understanding producers' needs (Norsworthy 2003), and recording

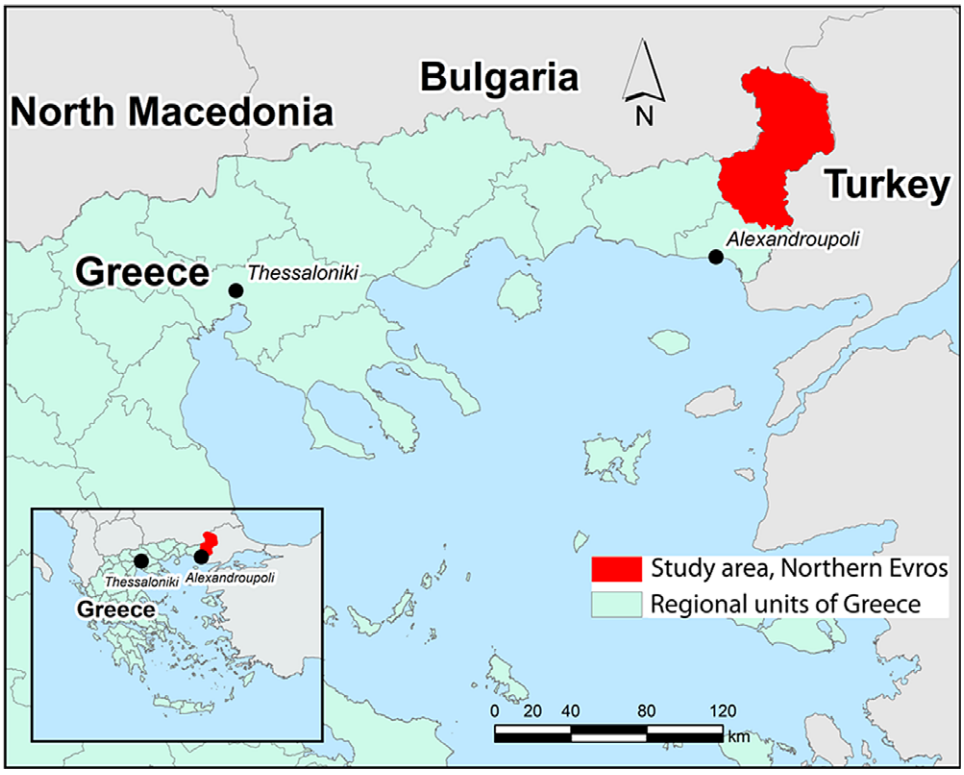

Figure 1. Map of Greece showing the study area in Evros Prefecture.

shifts in weed flora and herbicide-resistance development (Scott and VanGessel 2007). However, few studies have examined farmers' awareness of herbicide resitance (Johnson et al. 2009; Llewellyn et al. 2002). In Australia, growers had a high level of awareness of herbicide resistance and perceived a high potential cost (Llewellyn et al. 2002). In the United States, 30% of surveyed farmers perceived glyphosate-resistant weeds as a serious concern, whereas most farmers underrated the possibility for resistance evolution to glyphosate in an agroecosystem dominated by glyphosate as the common tactic of weed control (Johnson et al. 2009). In Germany, the majority of the farmers (88%) knew about herbicide resistance cases in the country and 64% of the farmers mentioned that such cases had been identified in their county (Ulber and Rissel 2018). Because herbicide-resistant weeds occur all over the world, information about farmers' weed control practices, perceptions, and awareness of herbicide resistance would be useful for designing effective strategies and outreach programs (Jussaume et al. 2019). This information could help in the design of proper educational programs targeting promotion of farmers' awareness of herbicide resistance and modification of farmers' behavior toward weed management practices. Even if farmers are aware of herbicide resistance, understanding how farmers react toward this issue and adjust their management practices under certain conditions is essential for selecting interventions for the promotion of sustainable agriculture (Jussaume and Dentzman 2016).

The aim of the survey we conducted was to assess current weed control practices in cereal cultivation and farmers' awareness of herbicide resistance in the Evros district of northern Greece. Such information is expected to be useful and could be exploited for targeted extension education.

Materials and Methods

Survey Details

The survey was conducted in the area of northern Evros, Thrace, northern Greece in 2018 (Figure 1). The study area was selected for the survey because its economy is based on agriculture, with cotton (*Gossypium hirsutum* L.), cereal grains, and sunflower (*Helianthus annuus* L.) as the main crops. Multistage sampling was followed by dividing the study area into districts and villages. Then, the districts of interest were selected and villages were chosen at random. A total of 250 farmers were randomly contacted on the basis of formal lists provided by the local authorities. Most farmers were willing to participate after hearing the objective of the study; in cases of no response, another person on the list was contacted. With this procedure, a response rate of 83% was achieved. Respondents were selected because they were active farmers and responsible for decisions concerning purchase of seeds, cultivars, and pesticides. Face-to-face interviews with the farmers were conducted to determine awareness of herbicide resistance among cereal farmers in the study area.

Data Collection

The tool used for data collection was a structured questionnaire developed by the authors, based on experience from previous similar studies (Damalas and Hashemi 2010; Damalas and Koutroubas 2014). The questionnaire contained two sections. The first section consisted of farmers' demographic details like age, sex, educational status, and farm size. The second section consisted of nine questions assessing the level of farmers' awareness about herbicide resistance (Table 1). The responses to those

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Table 1. Socioeconomic background of the surveyed cereal farmers in northern Greece.

Variable	Frequency	%
	No.	
Sex		
Male	168	67.2
Female	82	32.8
Age, y		
≤30	14	5.6
30–39	16	6.4
40–40	53	21.2
50–59	89	35.6
≥60	78	31.2
Education		
≤Elementary school	100	40.0
Lower secondary	42	16.8
Vocational education	29	11.6
Upper secondary	54	21.6
≥Tertiary education	25	10.0
Farming as main profession		
Yes	235	94.0
No	15	6.0
Farm size, ha		
≤10	50	20.0
10.1–20	58	23.2
20.1–30	46	18.4
30.1–40	25	10.0
≥40.1	71	28.4

Table 2. Weed control practices of the surveyed cereal farmers of northern Greece.

Variable	Frequency	%
	No.	
Use of herbicides for weed control		
Always	207	82.8
Sometimes	30	12.0
Never	13	5.2
No. of herbicide applications y^{-1}		
1	223	89.2
≥2	26	10.4
Missing data	1	0.4
Keep records of herbicide applications		
Always	74	29.6
Sometimes	43	17.2
Never	129	51.6
Missing data	4	1.6
Observe low efficacy of herbicides in your field		
Yes	46	18.4
No	195	78.0
Missing data	9	3.6
Use of the same herbicide each year		
Yes	119	47.6
No	129	51.6
Missing data	2	0.8
Apply crop rotation		
Yes	227	90.8
No	23	9.2
Apply nonchemical control practices		
Yes	180	72.0
No	68	27.2
Missing data	2	0.8

nine questions were documented as "no,", "yes," or "do not know." For each yes response, a score of 1 was given; for each no or do not know response, a score of 0 was given. In this sense, our scale of awareness ranged from 0 to 9, with a score of 5 (the middle point of the scale) or above considered as good awareness (good knowledge), and a score less than 5 was considered as poor awareness (poor knowledge). The questionnaire was validated by two agronomy professors and members of the specialized laboratory and teaching staff of the university. A pilot survey with 10 farmers tested whether the questions were well defined, presented consistently, and clearly understood to smooth out difficulties before administering the main survey. Minor corrections in wording were applied according to feedback. Questionnaires of the pilot study were included in the analysis. The survey was conducted by the authors. Respondents gave oral consent to participate in the project.

Data Analysis

Percentages of poor knowledge and good knowledge were calculated for each question. Then, the data were arranged in contingency tables and the Fischer exact test was used to examine the significance of the association between variables. According to this test, if the proportions in the table columns vary significantly between rows (or vice versa), the two variables are not independent. In the opposite case, it is said that the two variables are independent. Moreover, a binary model was applied to examine the effect of some variables on the levels of poor knowledge and good knowledge of herbicide-resistance issues. In this model, poor knowledge and good knowledge were the dependent variables, and demographic variables and weed control variables were the independent variables. Differences were declared significant at $P < 0.05$.

Results and Discussion

Approximately two-thirds of respondents were men (67.2%) (Table 1). Most farmers were older than 50 years. Their education levels varied, ranging from less than elementary school to tertiary education (university degree and above). Most farmers used herbicides in cereal production, making one application per growing season (Table 2). However, the majority of the farmers never kept records of herbicide applications. Farmers appeared divided with respect to using the same herbicide each year. Most farmers did not observe low efficacy of herbicide applications in their fields. The majority of the farmers stated that they applied crop rotation and nonchemical weed control practices in their fields (Table 2).

Almost half of the farmers (47.2%) did not know what herbicide resistance is, but most farmers (75.1%) felt that herbicide resistance would be a problem for them in terms of yield losses and would increase production cost (Table 3). Almost seven in 10 farmers (69.8%) did not consider herbicide resistance when purchasing an herbicide, and only 40.4% were willing to change common weed control practices for preventing herbicide resistance. Based on nine knowledge questions about herbicide resistance, 66.8% of the farmers had good knowledge, and 33.2% had poor knowledge of herbicide resistance. Knowledge levels did not differ by sex, whereas poor knowledge levels increased with advanced age, low education levels, and small farm size (Table 4). Farmers who always used chemical weed control had higher knowledge levels of herbicide resistance than did farmers who never used herbicides (Table 5). Farmers who always kept records of herbicide applications had higher knowledge levels of herbicide resistance than did farmers who never kept records of herbicide applications. Farmers who observed low efficacy of herbicides in their field, those who

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Table 3. Cereal farmers' knowledge of herbicide resistance in northern Greece.

Question	Poor knowledge	Good knowledge
	%	
Do you know what herbicide resistance is?	47.2	52.8
Do you consider herbicide resistance a problem?	24.9	75.1
Do you know how herbicide resistance can be prevented?	49.0	51.0
Does herbicide resistance depend on weed species?	33.1	66.9
Does herbicide resistance depend on herbicide?	33.5	66.5
Does herbicide resistance depend on herbicide rate of application?	29.8	70.2
Does herbicide resistance depend on herbicide frequency of application?	44.0	56.0
Do you consider herbicide resistance when purchasing a herbicide for use?	69.8	30.2
Are you willing to change common weed control practices to prevent herbicide resistance?	59.6	40.4
Overall	33.2	66.8

Table 4. Association of cereal farmers' awareness of herbicide resistance with demographic variables.

Variable	Poor knowledge	Good knowledge	χ^2	P
	%			
Sex			0.04	0.949
Male	67.5	67.1		
Female	32.5	32.9		
Age, y			20.27	0.000
≤30	4.8	6.0		
30–39	0.0	9.6		
40–49	13.3	25.1		
50–59	36.1	35.3		
≥60	45.8	24.0		
Education			48.58	0.000
≤Elementary school	69.9	25.1		
Lower secondary	12.0	19.2		
Vocational education	7.2	13.8		
Upper secondary	8.4	28.1		
≥Tertiary education	2.4	13.8		
Farming as main profession			2.92	0.088
Yes	90.4	95.8		
No	9.6	4.2		
Farm size[a], ha			11.830	0.019
≤10	27.7	16.2		
10.1–20	25.3	22.2		
20.1–30	13.3	21.0		
30.1–40	14.5	7.8		
≥40.1	19.3	32.9		

[a]Mean, 9.12 ha.

used different herbicides each year, and those who applied crop rotation had good knowledge of herbicide resistance, whereas farmers who always used the same herbicide had poor knowledge of herbicide resistance. Moreover, farmers who applied nonchemical control practices had good knowledge of herbicide resistance (Table 5).

According to the results of the binary model, advanced age (50–59 years), low education level (elementary school or less), systematic use of herbicides for weed control, and use of the same herbicide each year were negatively associated with knowledge of herbicide resistance (Table 6). On the other hand, keeping records of herbicide applications, observing low efficacy of herbicides in the field, applying crop rotation, and applying nonchemical

Table 5. Association of farmers' awareness of herbicide resistance with weed control practices.

Variable	Poor knowledge	Good knowledge	χ^2	P
	%			
Use of herbicides for weed control			12.68	0.002
Always	79.5	84.4		
Sometimes	8.4	13.8		
Never	12.0	1.8		
No. of herbicide applications y^{-1}			11.36	0.001
1	98.8	84.9		
≥2	1.2	15.1		
Keep records of herbicide applications			7.38	0.025
Always	19.3	35.6		
Sometimes	18.1	17.2		
Never	62.7	47.2		
Observe low efficacy of herbicides in your field			19.15	0.000
No	96.3	73.0		
Yes	3.7	27.0		
Use of the same herbicide each year			29.53	0.000
No	27.7	64.2		
Yes	72.3	35.8		
Apply crop rotation			15.10	0.000
No	19.3	4.2		
Yes	80.7	95.8		
Apply nonchemical control practices			37.28	0.000
No	51.8	15.2		
Yes	48.2	84.8		

control practices were positively associated with knowledge of herbicide resistance (Table 6). The main information source about weed control practices among cereal farmers was the personnel of agricultural supply centers; 20% of the farmers reported multiple sources of information (Table 7).

In this study, we assessed weed control practices and awareness of herbicide resistance among cereal farmers in the Evros district of northern Greece. Because similar studies do not exist for the area, the collected information provides a good view of cereal farmers' situation concerning weed control and herbicide resistance. Most farmers used herbicides in cereal production, with one application per growing season. Farmers appeared divided with respect to using the same herbicide each year, and the majority of the farmers applied crop rotation.

Weeds compete with cereals for space, water, and nutrients, thereby reducing yields, slowing harvest, and increasing combine repair costs. These aspects are particularly important in the case of monoculture cropping, a common system for cereal production that increases the need for chemical weed control (Dauer et al. 2009; Ervin and Jussaume 2014). Previous research reported that farmers felt trapped to a forced dependence on herbicides (Dentzman 2018). Similarly, the majority of the farmers in this study relied on information provided by agricultural retailers, who might have pushed farmers to use chemical weed control. Agricultural retailers are unlikely to promote integrated weed management (IWM), emphasizing the potential of new herbicide options of weed control (Bonny 2016; Mortensen et al. 2012).

The tendency toward chemical weed control among farmers in the study area shows a high possibility of development of herbicide resistance, but this possibility has not translated into confirmed cases of herbicide resistance, probably because half of the farmers used a different herbicide each year and the majority of them applied crop rotation. Indeed, although herbicide resistance cases have been confirmed in cereal fields of northern Greece

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Table 6. Binary logistic regression results.[a, b]

Variable	B[c]	SE	Wald	Sig.	Exp(B)
Sex (referent: female)					
Male	0.051	0.489	0.011	0.917	1.052
Age, y					
≤30	0.387	1.893	0.042	0.838	0.679
30–39	1.009	0.420	0.000	0.998	2.743
40–40	−0.999	0.643	2.410	0.121	0.368
50–59	−1.772	0.497	12.708	0.000**	0.170
≥60 (referent)					
Education					
≤Elementary school	−1.396	0.598	5.446	0.020*	0.248
Lower secondary	−0.014	0.677	0.000	0.983	0.986
Vocational education	−0.342	0.831	0.169	0.681	0.710
Upper secondary	2.169	1.030	4.433	0.035*	8.750
≥Tertiary education (referent)					
Farming as main profession					
Yes	0.957	1.135	0.710	0.399	2.603
No (referent)					
Farm size	−0.004	0.007	0.276	0.599	0.996
Use of herbicides for weed control					
Always	−2.283	1.053	4.700	0.030*	0.102
Sometimes	−1.035	1.203	0.740	0.390	0.355
Never (referent)					
No. of herbicide applications y^{-1}					
1	−1.979	2.059	0.924	0.336	0.138
≥2 (referent)					
Keep records of herbicide applications					
Always	1.649	0.685	5.792	0.016**	5.203
Sometimes	−0.784	0.562	1.948	0.163	0.456
Never (referent)					
Observe low efficacy of herbicides in your field					
Yes	2.572	0.847	9.221	0.002**	13.090
No (referent)					
Use of the same herbicide each year					
Yes	−1.463	0.482	9.230	0.002**	0.231
No (referent)					
Apply crop rotation					
Yes	1.773	0.862	4.228	0.040*	5.888
No (referent)					
Apply nonchemical control practices					
Yes	1.432	0.489	8.558	0.003**	4.185
No (referent)					

[a]Dependent variables: good knowledge and poor knowledge regarding farmers knowledge of herbicide resistance
[b]Hosmer and Lemeshow test: $\chi^2 = 4.41$; degrees of freedom = 8; Sig. = 0.91; −2 Log likelihood = 141.02; Cox & Snell $R^2 = 0.50$; Nagelkerke $R^2 = 0.69$; overall percentage of right prediction, 86.4%; N = 250 farmers.
[c]Abbreviations: B, regression coefficient; Exp(B), exponentiation of the B coefficient (odds ratio); SE, standard error; Sig., significance; Wald, χ^2 test.
*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

Table 7. Sources of information for weed control practices among cereal farmers in northern Greece.

Source	Frequency	%
	No.	
Personal exploration of various sources	3	1.2
Employees of the local service of the district	0	0.0
Agronomists of the Agricultural Directorate office	0	0.0
Agronomists of the local agricultural supply centers	195	78.0
Neighboring (or other) farmers	1	0.4
Agricultural cooperatives	1	0.4
Agricultural universities	0	0.0
Multiple sources	50	20.0

(Kaloumenos and Eleftherohorinos 2008; Kaloumenos et al. 2011; Papapanagiotou et al. 2020), cases of herbicide resistance have not been confirmed in the study area. Previous research reported that those working with farmers in areas with high occurrence of herbicide resistance will probably share the skepticism of farmers toward the future potential of chemical weed control options by providing IWM (Dentzman et al. 2016). However, this is not the case for the present study because of the lack of cases of herbicide resistance.

The implementation of crop rotation and herbicide rotation with different sites of action is a major tool for the management of herbicide resistance. These practices help in the control of resistant weeds and delay the development of new resistant weeds. Preserving the efficacy of herbicides depends on the awareness of the increasing cases of herbicide resistance and the coordinated action by farmers to address the problem. The evidence we have presented demonstrates that despite heterogeneity, farmers had knowledge of herbicide resistance and followed good agricultural practices in their fields. This response, even among farmers who had not yet experienced cases of herbicide resistance on their farm, can be regarded positively in terms of proactive behavior, as reported elsewhere (Ulber and Rissel 2018).

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The implemented weed control practices did not seem to contribute significantly to the development of herbicide resistance. Nevertheless, more action is required to promote farmers' knowledge of herbicide resistance, because one-third of the farmers had poor knowledge of herbicide resistance. Advanced age was negatively associated with knowledge of herbicide resistance. Although advanced age is linked with great farming experience, the more farmers age, the less knowledge they have about technical issues such as herbicide resistance (Abdulai et al. 2020; Ogunmodede and Awotide 2020; Prashanth et al. 2018), a situation probably related to poor education and limited access to new information technologies that tend to be more accessible to the younger generation. The negative association with low level of education and the positive association with higher education probably reflect educated persons' high levels of knowledge and good access to information sources. Farmers who always used herbicides for weed control had less knowledge about herbicide resistance compared with farmers who never used herbicides. The latter group probably used other options of weed control, perhaps after understanding the concept of herbicide resistance, and thus they reduced their dependence on herbicides. Farmers who always kept records of herbicide applications had more knowledge compared with farmers who never kept records of herbicide applications. Pesticide record keeping is usually a weak point of farmers and has been identified as a priority of farmers' training in pest management in Iran (Hashemi et al. 2009). Keeping records of herbicide applications is a measure for monitoring the effectiveness of herbicides, so farmers who keep records of herbicide applications definitely pay more attention to herbicide efficacy and thus have more knowledge of herbicide resistance. Observing low efficacy of herbicides had a positive effect on knowledge of herbicide resistance. In fact, farmers who observed low efficacy of herbicides in their field had more knowledge compared with the other group. Farmers who used the same herbicide each year compared with the other group had less knowledge of herbicide resistance. Using the same herbicide each year increases the chances of resistance to herbicides; thus, farmers who did not follow this practice were probably influenced by their greater knowledge of herbicide resistance. Applying crop rotation had a positive effect on knowledge of herbicide resistance. Farmers who applied crop rotation had more knowledge compared with the other group probably because crop rotation reduces the likelihood of using same herbicides.

Understanding why farmers decide on some weed control tactics but are hesitant to adopt other practices that could delay herbicide resistance is essential, considering the changing demographics in agriculture (Owen 2016). The information reported in this study provides a good sense of weed control practices used by cereal growers of the Evros district. Thus, opportunities for varying weed control practices to reduce possibilities for herbicide-resistance evolution are highlighted. Because farmers count on simple solutions for weed control, educational programs could emphasize how IWM can preserve and support the potential continued use of certain chemical herbicides (Jussaume and Dentzman 2016). Considering the adoption of IWM practices in western Australia, research has found that extending the impacts of farming systems beyond resistance management was likely to be more effective than just aiming at the efficacy of practices for controlling major weeds (Llewellyn et al. 2005). Also, IWM adoption and the management of herbicide resistance required intensive information and decisions based on an intertemporal management of resources (Llewellyn et al. 2007).

Our study also provides a good picture of farmers' awareness of herbicide resistance and could function as a comparative benchmark study for future research in the area and as a guide in other areas where growers have been highly affected by instances of herbicide resistance. Similar research in areas with cases of herbicide resistance could reveal differences in personal experiences with and risk perceptions of herbicide resistance that can drive farmers' decisions regarding the choice of resistance management strategies, not excluding diversity in farmer and farm management characteristics that can also influence weed management strategies. Therefore, similar research is expected to enhance opportunities for university personnel, crop consultants, and pesticide retailers to provide more accurate information to help farmers make decisions about avoiding and/or managing herbicide-resistant weeds. In particular, weed scientists could use this information to provide targeted advice on best management practices for promotion of sustainable weed control on cereal farms.

It should be noted that farmers in this study are located within a specific area of northern Greece where no cases of resistance have been confirmed and thus findings are not generalizable to other areas where herbicide-resistant weeds are more common. This emphasizes the need for additional studies of different groups of farmers from different areas to determine whether trends are consistent across groups. Apart from guides to action by extension officers, farmer surveys are important tools available for policy formation and evaluation. Concerning areas where growers have been highly affected by instances of herbicide resistance, future similar research could evaluate which management practices are most cost-effective in adapting to herbicide-resistant weed infestations and how to effectively assist farmers to adopt those practices.

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