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Weed Management Challenges in Rice Cultivation in the Context of Pesticide Use Reduction: A Survey Approach

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Abstract: Weeds are the main phytosanitary problem in rice crop. Over-reliance on herbicides and lack of crop operations range in the rice system have produced intense selection for the evolution of resistant weed populations. This study focused on rice farmers' perceptions and attitudes towards weeds and agricultural practices for weed management. The methodology of a questionnaire was used, carried out in person with rice producers in the main rice producing regions in Portugal, complemented by three focus groups. The outcomes reveal that *Echinochloa* spp. is the weed of greatest concern, followed by *Oryza sativa* var. *sylvatica*. New weeds are about to emerge, mainly *Leptochloa fusca* ssp. *fascicularis*. It will be critical for performance at the innovation ecosystem level to achieve evolution in social capital. Policies that promote innovation for the performance of more ecological and sustainable practices must be settled. The problem of herbicide resistance is increasing with the reduction in the number of active substances. There is great difficulty in adopting non-chemical weed control to meet the requirements of the European Ecological Pact. The implementation of these alternatives cannot be widespread, but must be studied on a case-by-case basis and requires technical monitoring adapted to the region and to the plot.

Keywords: weeds; resistance; rice; clearfield technology; non-chemical control; European Ecological Pact

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Citation: Calha, I.; Oliveira, M.d.F.; Reis, P. Weed Management Challenges in Rice Cultivation in the Context of Pesticide Use Reduction: A Survey Approach. *Sustainability* **2023**, *15*, 244. https://doi.org/10.3390/su15010244

Academic Editor: Teodor Rusu

Received: 29 November 2022
Revised: 20 December 2022
Accepted: 20 December 2022
Published: 23 December 2022

1. Introduction

Weeds are the main phytosanitary problem in rice, causing losses close to 30% of production [1]. Rice growers essentially rely on chemical control to reduce yield loss. However, the excessive dependence on herbicides and the lack of cultural diversity in the rice cultivation system produced intense selection pressure for the evolution of resistant weed populations. The cost of herbicides is the main cost associated with the crop, 18% of the total, and weed management is the main concern of rice farmers in Portugal [1].

Weed resistance affects the main rice-producing countries of the European Union (EU): Italy, Spain, Greece, and Portugal. Portugal, with a rice area of 25,939 hectares (ha), in 2020, represents approximately 6% of the total rice area in Europe [2], distributed over three rice growing regions: the *Tejo* (Tagus) and *Sorraia* valleys (*Ribatejo*), the *Sado* river valley (*Alentejo*) and the *Mondego* valley (*Beira Litoral*). The cultivated area and national production of rice decreased over the past decade. Between the three-year periods 2010–2012 and 2018–2020, area decreased by 8.3% and production decreased by 16.1% [3].

The current average productivity is 5.12 tons/ha in 2020, against 5.48 t/ha in 2018 [4,5], corresponding to a reduction in relation to the 2016–2018 triennium. The area (in the three-year period) is 29 thousand ha and production is 170 thousand tons [1]. National production guarantees 60% of the needs of Portuguese consumers, with a per capita consumption of 14.9 kg per year (2019/20). This consumption is the highest in Europe, a region that is also deficient in rice [4].

Rice cultivation is both a commitment and a challenge for sustainability. The crop is grown in swamp ecosystems, wetlands, and lowlands with very saline soils, contributing to the stability of rural populations in rural areas where other crops could not thrive. In addition, it has environmental benefits, contributing to diversity in fauna and flora and playing a fundamental role in the integrated management of these particularly sensitive ecosystems. However, high water consumption and water contamination with herbicide residues, and the resulting impact on non-target organisms, constitute a high risk requiring urgent mitigation measures [6] in line with the goals established by the Farm to Fork (F2F) strategy: to reduce the use of pesticides by more than 50% by 2030. These measures could simultaneously contribute to reducing resistance, improving weed management, and reducing environmental impact, but imply greater knowledge about the biology and ecology of the most problematic weeds. After the withdrawal of traditional herbicides (molinate and propanil) from the European market [7], weed management was essentially based on acetolactate synthase (ALS) and AcetylCoenzymeA-carboxylase (ACCase) inhibitor herbicides, mainly for the control of *Echinochloa* spp. (watergrass). These herbicides carry a high risk of resistance expressed by the numerous cases of resistant *Echinochloa* spp. populations recorded worldwide [8]. National authorities have revealed growing concern about weeds in rice cultivation, considering herbicide resistance a potential threat status to the rice crop [9]. The situation could worsen if the current lack of diversity in modes of action (MoA) continues. Thus, it is critical to develop resistance risk assessment tools for the early detection of weed resistance and to implement integrated weed management strategies [10].

The assessment of resistance risk to the main weeds of rice crops was based on the parameters proposed by Moss [11], who considers the impact of biological, chemical, and agronomic factors on the selection of resistant populations. The results were analyzed by region considering three main sections: (1) problematic weeds and resistance (biological factor); (2) weed management using herbicides (chemical factor); and (3) other weed control measures (agronomic factor), as shown in Figure 1. The joint analysis of these factors allowed the assessment of risk levels for weeds and herbicides by region.

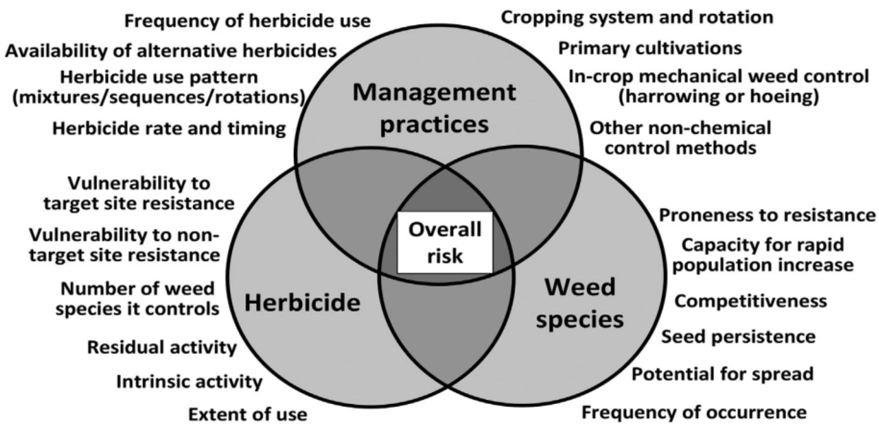

Figure 1. Components associated with each of the main resistance factors [11].

To contribute to sustainable production of rice, the research project GO +Arroz (https://www.maisarroz.com, accessed on 30 September 2022: 2017 to 2020) was implemented. The project aimed at assessing resistance risk in the main rice producing areas in Portugal, mapping confirmed cases of resistance, and assessing the impact on resistance of cultivation measures and the use of alternative modes of action. The main goal of this paper was to identify the main risk factors for herbicide resistance in rice fields and to assess the adoption level of alternatives to reduce the use of herbicides. The innovative character of this work was to study the practices and attitudes of rice producers towards weed management, herbicide use and herbicide resistance risk.

2. Materials and Methods

The research focused on rice farmers' perceptions and attitudes towards weeds and agricultural practices related to spontaneous vegetation management. The methodology of a questionnaire survey was used, carried out in person with rice producers in the main Portuguese rice producing regions, and was accompanied by three focus group meetings to discuss the results and collect contributions. The study focused on the main Portuguese rice-growing regions: the *Sorraia* and *Tejo* valleys and *Sado* and *Mondego* river valleys (Appendix A).

The focus group follows its own methodology, with group interviews supported by communication and interaction [12]. Its essence is to gather information and produce data on a selected topic; it is a flexible method, ideal for exploring understanding and perception of an issue or theme [13]. Considering the different cultural perceptions and practices used for weed management in each region, this method added and helped to understand the results of other surveys, namely, on risks, different perceptions of risk, and solutions for herbicide resistance. Sometimes, for two discussion groups, groups that are identical in terms of demographics and their life experiences can have different thoughts on the same topic [14]. This condition is important since it allows for the clarification of some questions emerging from the survey results.

In resumé, the work follows three steps: elaboration of the questionnaire and the pre-test; interviews of the farmers; focus groups to validate and complement the survey results.

2.1. The Survey

A total of 82 rice-growers were interviewed, distributed relatively equitably among the three rice growing regions. The majority followed Integrated Crop Production (ICP), including 92% in the *Baixo Mondego* region, 85% in the *Sorraia* valley and all rice farmers in the *Sado* valley. There were only two organic rice producers in the *Sorraia* region. Most respondents had been rice producers for over 25 years. The average number of years as rice producers was 24.3 years in *Mondego*, 25.4 years in *Sorraia* and 26.5 years in *Sado*. Table 1 summarizes some statistical data regarding the characteristics of farms and rice farmers surveyed. Differences can be observed in the three regions in relation to the land tenure structure. In Mondego, the average surface area is 105.1 ha, with 90.1 ha of used agricultural area (Utilized Agricultural Area: UAA) and 55.6 ha of rice cultivation (61.7% of the UAA). In the *Sorraia* valley, the average area is 100.5 ha, with UAA of 78.7 ha and 70.9 ha of rice (90.1%). In this region, there is greater specialization in rice farming. In *Sado*, the property and farm areas are larger, but the rice areas per farmer are close to those in the *Mondego* valley. The average total surface area is 248.8 ha, with 264.5 ha of UAA and rice cultivation of 58.4 ha (22.1%). In this region, rice cultivation takes place on the banks of the river *Sado* on farms with extensive areas of cork oak forests, often with stone pine.

Table 1. Survey characteristics.

Region	Statistic	UAA (ha)	Total Area of Rice (ha)	Rice Agricultural Plot (ha)	Years as Rice Producer	% of Rice Area in UAA
Mondego	Average	90.1	55.6	11.5	24.3	62
	Sum	2343.5	1444.4	299.7		62
Sado	Average	264.5	58.4	16.7	26.5	22
	Sum	7671.5	1693.6	500.3		22
Sorraia	Average	78.7	70.9	35.8	25.4	90
	Sum	2464.9	1843.9	896.0		75
	Total	12,479.9	4981.9	1696.0		40

2.2. The Questionnaire

The survey was made up of three sections: (1) Background of the cropping system: agricultural holding area; agricultural plot; ownership and cultivation system, crop rotation and rice varieties. (2) Field operations: indication of the entire technical itinerary, from soil preparation for sowing to harvesting. In this part, emphasis was given to practices related to weed management and the various factors associated with the risk of resistance. Inquiries were made about main weeds, herbicide history in the last five years, and the farmer's perception of the most challenging weeds and the efficacy of herbicides. In addition to chemical methods, other weed control measures were also recorded, namely, stale seedbed and tillage. (3) Technology and organization: associations and advice, training and agro-environmental measures, and technology innovation were surveyed. Specialists from different rice producing areas contributed to the elaboration of the survey form in the socio-economic, crop protection and crop technology domains. The development of the study brought together the scientific community providing technical services to rice producers.

2.3. Statistical Analysis

The survey was carried out by technicians from producer associations and technicians from regional agricultural services after the 2018 and 2019 rice cropping seasons in the months with lower agricultural activity, from September to February, in the three regions. Before fieldwork was carried out, the pre-testing survey was fulfilled. The results were analyzed using IBM® SPSS® Statistics software version 25.0, using non-parametric methods for the analysis of most variables. The chi-square test was used to analyze whether there were significant differences between rice-growing regions. In tests in which more than 20% of the cells in the contingency tables had less than five cases, the Monte Carlo method was used, with a confidence interval of 95%.

2.4. Focus Groups

In 2019 and 2020, three focus group meetings were held, one in each rice growing region with around 20 people per region, involving various stakeholders in the rice sector (producers, irrigation associations, researchers, technicians from producer organizations, company input suppliers). At each meeting, three groups were formed with a facilitator. The discussion focused on weed resistance to herbicides. The following topics were discussed: (1) perception of resistance in the region; (2) what strategies are being implemented and what their results are; (3) which crops are best suited for crop rotation and what to consider in a three-year economic assessment; (4) how to implement a stale seedbed; and (5) expectations regarding the results of the project GO +Arroz, within which the present study was carried out.

3. Results

3.1. Main Weeds and Weed Resistance

The survey's results showed that about 90.2% of rice producers indicated the existence of herbicide resistance, but only 54.9% had problems with rice crop diseases and 18.5% with pests. These results confirmed that weeds are the main phytosanitary problem in rice, contributing to significant productivity losses if not controlled. Diseases and pests, on the other hand, are considered less important than weeds.

3.1.1. Main Weeds

In Portugal, the main rice weeds are *Alisma plantago-aquatica* L. (Alismataceae); *Cyperus difformis* L. (Cyperaceae); *Echinochloa*, *crus-galli* ssp. *hispidula* (Stapf) Koss./Vasc. (Poaceae); *Echinochloa phyllopogon* (Stapf) Koss./Vasc. (Poaceae); *Heteranthera reniformis* L. (Pontedereaceae); *Leptochloa fusca* ssp. *fascicularis* (Lam.) Gray (Poaceae); *Oryza sativa* L. var. *sylvatica* (Poaceae) [15]. In Figures 2 and 3, weed species are identified by EPPO code (Appendix B). To identify the most problematic weeds, rice growers were asked to rank five weeds in order of importance. It was not always easy for farmers to correctly identify plants, as in the case of sedges, which include several species, out of which *Cyperus difformis* is the most consequential. However, this species in Sorraia valley (Ribatejo) was referred to by some as 'rice field bulrush', a common name that corresponds to another species (*Schoenoplectus mucronatus* (L.) Palla) that is not relevant in the region. According to the perception of rice growers, the most worrying weeds are *Echinochloa* spp., which are suspected of resistance.

These weed species outperformed all others when farmers were asked about examples of resistant weeds in their fields. Other weeds were also mentioned, particularly *O. sylvatica*, *A. plantago-aquatica* and *Heterantera* spp. (Figure 2).

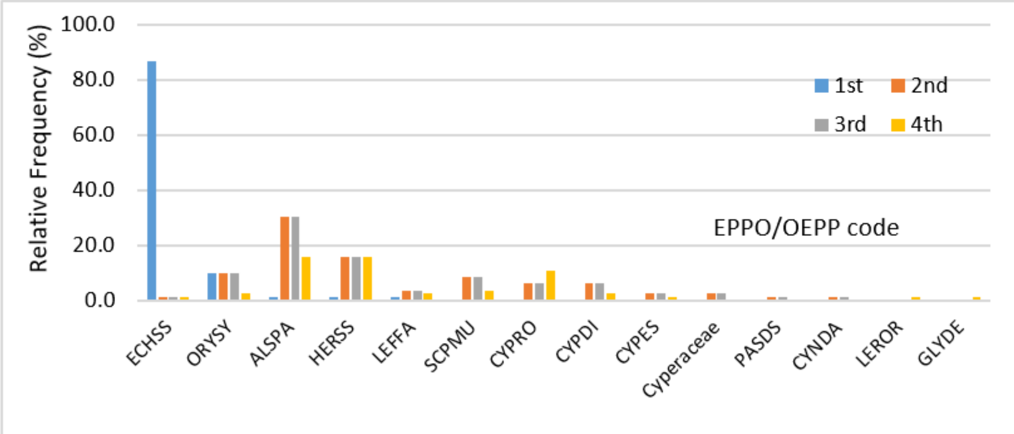

Figure 2. Rice growers' perception of the importance (1st to 4th) of weeds in rice fields. Note: EPPO/Code: Appendix B. In the *Cyperaceae*, the farmers did not identify which species, but only indicated the family, which includes the following species: *Cyperus rotundus*, *C. difformis*; *S. mucronatus*; *C. esculentus*.

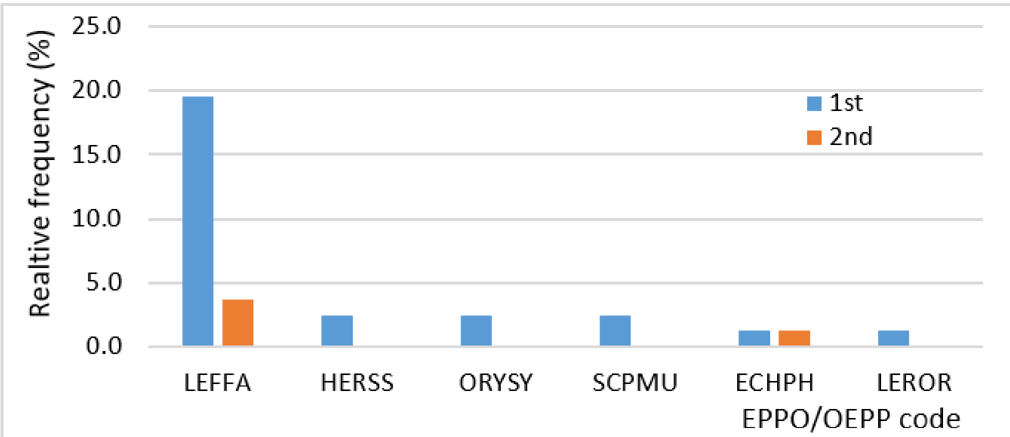

Figure 3. Rice farmers' perception of the emergence of new weeds in rice fields.

After analyzing the differences in the main weeds by rice crop region it was verified that there are significant differences between the regions in terms of the four degrees of importance, with significance levels equal to or less than 2% for the chi-square test and 3% using the Monte Carlo method, with a confidence interval of 95%. The Monte Carlo method was used because, in the four chi-square tests (one per degree of weed importance), more than 20% of the cells in the crossover tables had an occurrence of less than five cases. Considering the weeds that most concern farmers, as mentioned above, we only present the results for the two highest levels of importance (1st and 2nd), and the weeds for which there are statistically significant differences between rice crop regions (Table 2).

Echinochloa spp. stand out as the weeds that most concern producers in the three regions. When rice farmers were asked about the most important, these species had greater importance in *Sado* and *Sorraia* than in *Mondego*. In the second position is *O. sylvatica*, Alisma spp., *Heterantera* spp. and others. It should be noted that emerging weeds such as *L. fascicularis* appear with greater importance in rice fields in *Sorraia* (*Ribatejo*). In *Mondego, O. sylvatica* is the biggest concern for farmers after *Echinochloa* spp. *Cyperaceae* have begun to gain importance in the southern region of *Sado* river valley. This fact is confirmed not only by the perception of farmers, but also by the diversity of herbicides applied to control this group of weeds. It should be noted that several active substances such as MCPA, bentazone and halosulfuron are used in several applications on the same plot in a campaign, which raises doubts about the efficacy of these applications.

Table 2. Comparative analysis of the main weeds by rice growing region.

		Most Important Weed				Second-Most Important Weed			
		Mondego	*Sado*	*Sorraia*	**Total**	*Mondego*	*Sado*	*Sorraia*	**Total**
Echinochloa spp.	Score	19	27	25	71	7	4	0	11
	Adjusted residues	−2.4	0.7	+1.7		+2.4	+0.1	−2.5	
Oryza sativa var. *sylvatica*	Score	7	1	0	8	14	10	7	31
	Adjusted residues	+3.6	−1.5	−2.0		+1.9	−0,4	−1.5	
Alisma spp.	Score					4	0	4	8
	Adjusted residues					+1.1	−2.2	+1.1	
Leptochloa fusca ssp. *fascicularis*	Score					0	1	7	8
	Adjusted residues					−2.1	−1.4	+3.5	
Schoenoplectus mucronatus	Score					0	1	5	6
	Adjusted residues					−1.8	−1.0	+2.8	

3.1.2. New Weeds

In the study, rice producers were asked to identify the emergence of new weeds in the last three years for the reference plot of each of the respondents. More than a fifth of respondents mentioned the emergence of *L. fascicularis* in the last three years (Figure 3).

One to two references were made to other weeds, such as *Heterantera*, *O. sylvatica*, *C. difformis*, *E. phyllopogon* and *Leersia oryzoides*. *Leptochloa fusca* ssp. *fascicularis* appeared recently in Portugal; it was first identified in a rice field located in *Benavente*, in the *Sorraia* valley [16]. Its introduction in Portugal and Spain in the 1990s [17,18] was often due to seed contamination at source [19]. *Heteranthera* spp. are weeds that are no longer new in any of the regions. The first records in Portugal date back to the late 1990s in rice fields in the *Mondego* valley [20]. It may be emerging with greater importance, probably because the herbicide that controlled it most effectively was Oxadiazon, which is no longer authorized on the market after 2010, due to harmful effects on the environment and risk of groundwater contamination [21]. *Leersia oryzoides* cannot be considered a new weed in rice fields either. It is a lively plant that tends to occur in small dikes and may have started to enter rice fields recently. In Spain, it was identified as a 'new weed' in rice fields in Valencia in 2013, possibly from contaminated seeds. The situation was brought under control using Clearfield® technology and glyphosate [22].

Regarding the appearance of new weeds and comparative analysis between regions, there are no significant differences, with significance levels above 0.344 (for both the chi-square test and the Monte Carlo method).

3.1.3. Perception of the Emergence of Herbicide Resistance

When evaluating the perception of herbicide resistance, it appears that almost 90% of the surveyed rice growers say that herbicides no longer control *Echinochloa* spp. as well as before. These results are very similar to the values obtained for the indication of the most problematic weeds, which also pointed towards *Echinochloa* spp. (Figure 3). This fact demonstrates that the greatest concern of rice farmers is with this weed and that this issue is strongly associated with the perception of herbicide resistance (Figure 4).

Other cases of resistance were registered, such as *L. fascicularis* and *O. sylvatica*, but with secondary importance and only in very few cases. L. fascicularis, as mentioned above, was recently introduced into rice fields in the Mediterranean basin and is a difficult weed to control because, until recently, the efficacy of currently available herbicides on this species was not known. That is why it was considered resistant to herbicides. Worldwide, three cases of *Leptochloa chinensis* resistant to ACCAse-inhibitor herbicides (Herbicide Resistance Action Committee "HRAC"'s HRAC-1) and *Leptochloa fusca* ssp. *fascicularis* resistant to clomazone (HRAC-13) were identified. The above-mentioned cases of resistance were found in the US and in Italy, respectively [8]. In Mediterranean countries, namely Spain, there were reports of failure of efficacy in ALS and ACCAse-inhibitor herbicides when used on *Leptochloa. fusca* ssp. *uninervia* [23]. *Oryza sativa* var. *sylvatica* has always been particularly difficult to chemically control because of its similarity to cultivated rice, and therefore it is considered resistant to herbicides by the farmers. Other cultural measures such as Clearfield® technology [24] and stale seedbeds have been used successfully in Italy and in California [25].

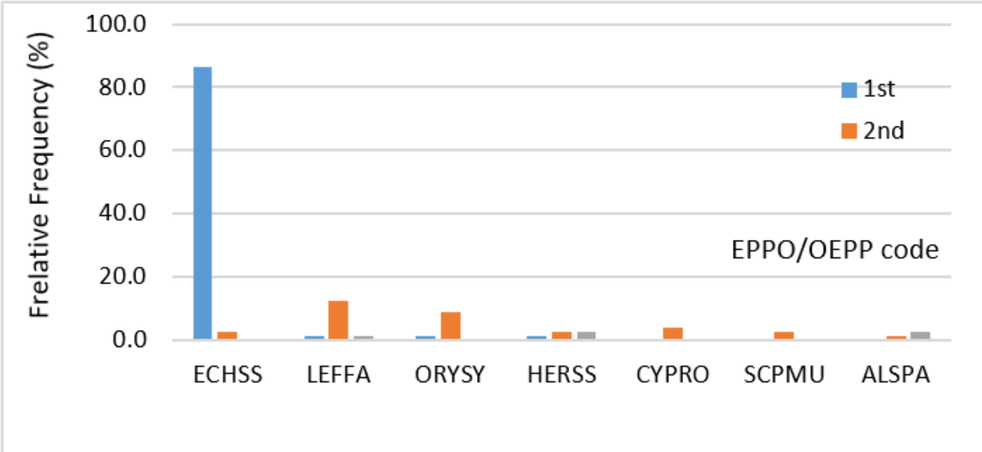

Figure 4. Rice growers' perception of the emergence of resistance among weeds in rice fields.

3.2. The Use of Herbicides in Weed Management

The principles of sustainable weed management affect long-term strategy for weed management throughout the crop system (rotation) and not just during the rice crop cycle; reduction in seed production and dispersion (acting in the soil seed bank) and, finally, diversification of control measures, contributing to a reduction in the use of herbicides. However, for the rice crop, there are not many alternative methods to chemical herbicides. The lack of diversity in the MoA of herbicides caused high pressure in the selection of weeds and the occurrence of populations resistant to the main herbicides used in rice. For this reason, a more in-depth analysis of the use of herbicides was carried out concerning time of application, including herbicides for pre- and post- emergence, herbicide history (evolution in the last five years), and the farmer's degree of satisfaction with the control of *Echinochloa* spp.

To avoid resistance and contribute to sustainable weed management, three parameters must be considered: prevention (implementation of cultural measures); diversity in control measures and herbicide MoA; and precocity (opportunity for intervention, phenological stage of weeds). On this last point, it is recommended to apply the labeled herbicide rate at the recommended weed sizes [10]. In rice, water management is a fundamental parameter for weed management. It not only controls the initial development of the weeds (time between the entry of water into the plot and sowing), but also determines the efficacy of herbicides (depth of the water in the plots, dry plots and submersion of weeds).

3.2.1. Pre-Emergence Herbicide Application

The use of pre-emergence residual herbicides makes it possible to effectively control some rice weeds, such as *Heteranthera* spp., and keep the field free of weeds during the emergence of rice, the period when the rice crop is most sensitive to competition with weeds. The herbicides used by farmers (oxadiazon and clomazone) belong to different MoA than those used in post-emergence. The survey revealed that in a universe of 82 farmers, 71 used pre-emergent herbicides (86.6% of respondents), of which 71 used oxadiazon and only four farmers used clomazone. Clomazone was only used in the *Sado* valley (*Alentejo*), associated with dry sowing in rows with buried seed. It should be noted that the survey was implemented after the 2018 campaign. Most producers were 'Not satisfied' or

'Average satisfied' with the efficacy of pre-emergence herbicides for *Echinochloa* spp. control (Figure 5). There are no significant differences among the three rice-growing regions, which indicates high density of weeds at the beginning of the rice cropping cycle and arises suspicious of resistance.

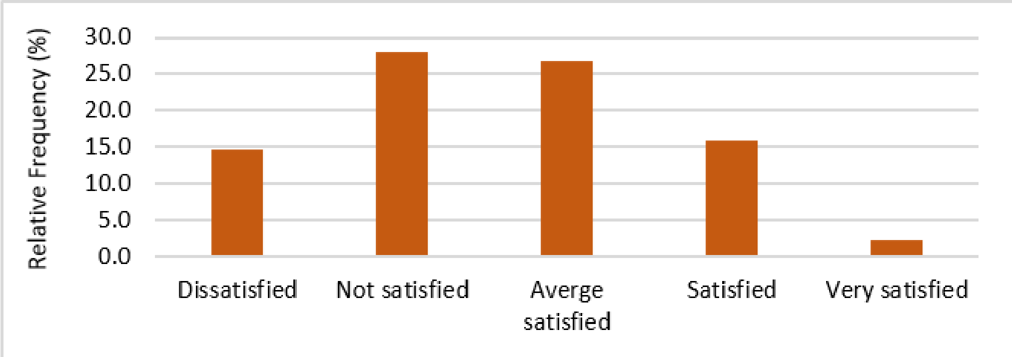

Figure 5. Degree of satisfaction with pre-emergence herbicides with respect to *Echinochloa* spp.

3.2.2. Application of Post-Emergence Herbicides

Post-emergence herbicides are the farmers' main tool for weed control. The survey shows that profoxydim was the most widely used herbicide (53.8%) in all three regions as the main herbicide in the programs. It was possible to assess through the surveys that the use of the herbicide profoxydim, either alone or together with other herbicides such as imazamox, bispyribac–sodium or the formulated mixture penoxsulam + cyhalofop, had a prevalence of 92% in *Mondego* (*Beira Litoral*), 77% in *Sorraia* (*Ribatejo*) and 83.3% in *Sado* (*Alentejo*). Growers were even less satisfied with the efficacy of post-emergence herbicides to control *Echinochloa* spp. than with that of pre-emergence herbicides. More than half were "Not satisfied or dissatisfied" (Figure 6).

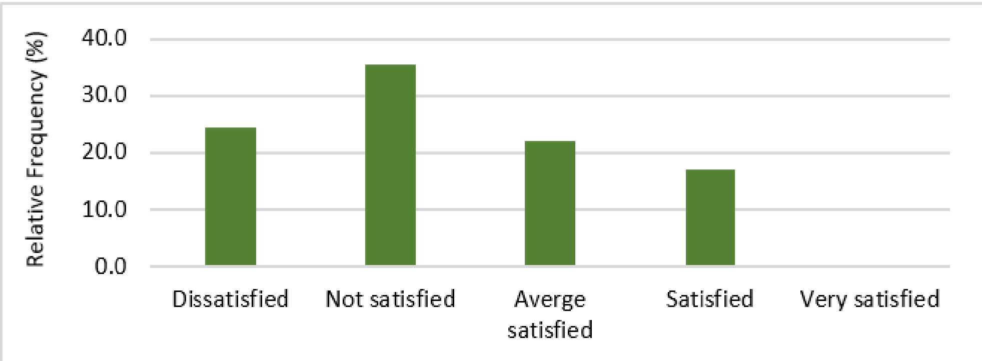

Figure 6. Degree of satisfaction with post-emergence herbicide with respect to *Echinochloa* spp.

There are significant differences between the three regions (significance levels less than 0.1% for the chi-square and Monte Carlo tests). The differences occurred in the cases where rice farmers were satisfied or average satisfied (Table 3).

Table 3. Comparative analysis of satisfaction levels with post-emergence herbicides in *Echinochloa* spp. controlled by rice-growing region.

		Mondego	*Sado*	*Sorraia*	**Total**
Satisfied	Score	10	1	3	14
	Adjusted residues	+3.5	−2.5	−0.9	
Average Satisfied	Score	0	14	4	18
	Adjusted residues	−3.3	+4.2	−1.0	

Rice growers in the *Mondego* valley are more satisfied with the effectiveness of post-emergence herbicides than growers in the *Sado* valley. *Sorraia* producers are the least satisfied. These results could be related to herbicide use in each region, as referenced above, and farmers' perception of weed resistance.

3.2.3. History of Herbicide Application

Farmers were asked to indicate which herbicides had been applied in the last five years (between 2013 and 2017). In Figure 7 we can observe the evolution of herbicide use.

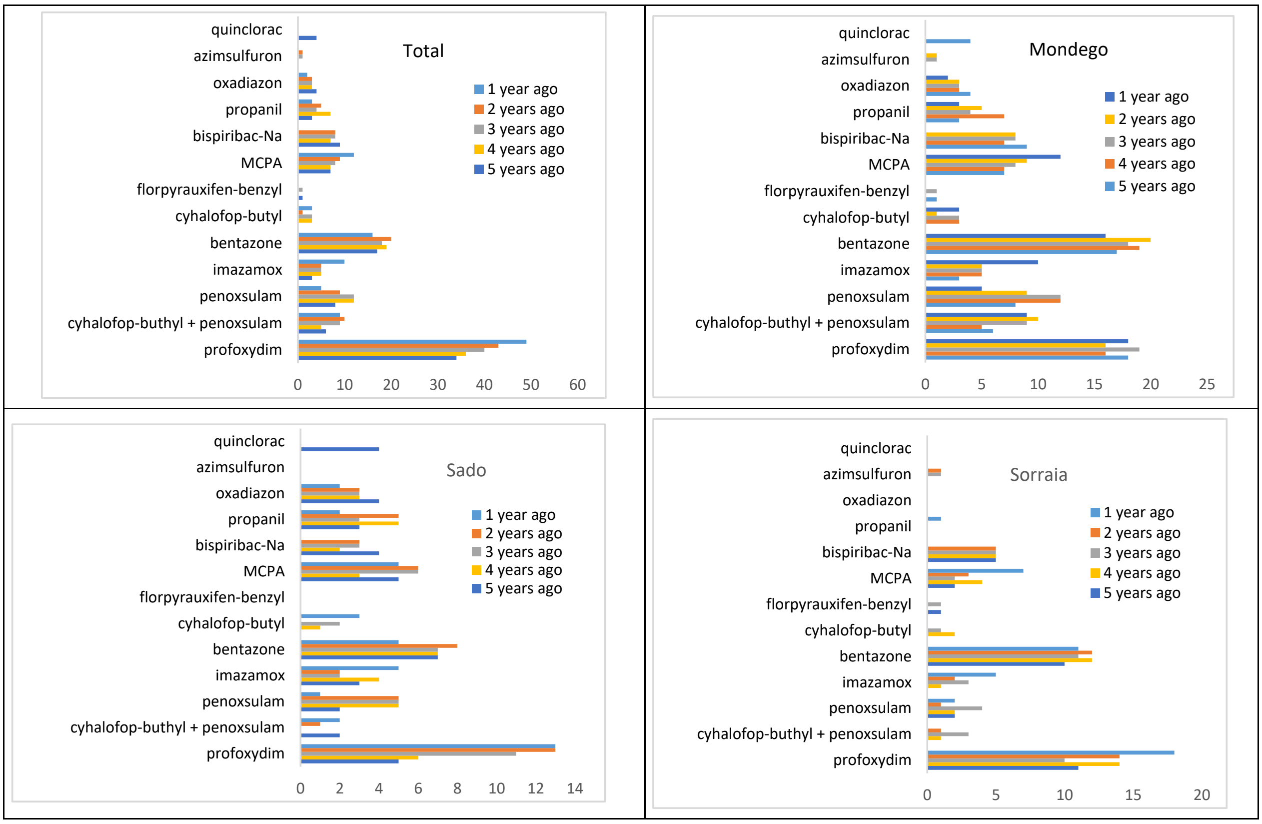

Figure 7. Herbicide use in rice fields (2013–2017).

There are five herbicides that stand out, being mentioned by more than 50% of the growers in all regions over the five-year total. These are, in descending order of importance: profoxydim, bentazone, penoxsulam (applied alone or mixed with cyhalofop-P-butyl), MCPA and bispyribac–sodium (Figure 7). It is worth mentioning that, although imazamox is in sixth place, this herbicide presents differences between regions, as we will see below.

Comparing this set the MoA of herbicides, which is the most relevant factor for the determination of acquired resistance, we confirmed that only two MoA stand out for *Echinochloa* spp. control: ALS-inhibiting herbicides (penoxsulam, bispyribac–sodium, imazamox) and ACCAse inhibitors (profoxydim and cyhalofop-P-butyl). For other weeds, three different MoAs are available: Synthetic Auxin Herbicides -SAH- (MCPA and florpyrau xifen–benzyl), photosynthesis inhibitors (bentazone), and inhibitors of chlorophyll biosynthesis (oxadiazon). However, a detailed analysis by region reveals some significant differences. While the first two herbicides, profoxydim and bentazone, remain the main active substances employed with increasing importance over the last few years in all regions, the positions between third and sixth place vary from the north to the south of the country.

In *Baixo Mondego* (*Beira Litoral*) and for control of *Echinochloa* spp., penoxsulam is in third place, with greater importance than in the other two regions. In the same region, occupying fourth place is bispyribac–sodium and fifth is imazamox. This herbicide was essentially applied more only in the last year.

It is important to make a brief note for propanil active substance (s.a), with Exceptional Emergency Authorization-AEE [Article nº 53 under Regulation (EC) Nº 1107/2009], to deal with resistant *Echinochloa* spp., which, having a different MoA (C2/6), has also been a fallback herbicide. Its use in *Baixo Mondego* was not as high as in the *Sado* valley rice fields, but far exceeded that in the *Tejo* and *Sorraia* valleys, where propanil application was almost nonexistent. For the control of other weeds, MCPA and oxadiazon were preferred. In the rice fields of *Tejo* and *Sorraia* (*Ribatejo*) bispyribac–sodium ranks third, and the application of penoxsulam is practically residual, compared to other regions. Propanil on the other hand was only applied in one year.

In the *Sado* valley (*Alentejo*), penoxsulam also ranks third, but with much less importance than in the *Baixo Mondego*, being applied mainly alone followed closely by bispyribac–sodium for *Echinochloa* spp. control. The application of imazamox has increased over the last year and propanil shows relevant importance in *Sado* valley region, as already mentioned. For other weeds, the importance of MCPA is similar to that in *Baixo Mondego* and higher than that in *Sorraia*. Oxadiazon also presents a distinct distribution between regions, clearly higher in *Sado* rice fields, followed by the *Baixo Mondego* region and incipient in the Ribatejo region. This may be associated with the lower importance of *Heteranthera* spp. in the rice fields of the *Sorraia* valley [15], weeds for which this herbicide is particularly effective. By contrast, the new herbicide florpyrauxifen–benzyl was not even applied in this region, and only occasionally in the other regions, because it only entered the market in 2020 as an EEA. In previous years, it was under experimental use.

In summary, we can conclude that in all regions the increasing importance of profoxydim use over the last five years (2013–2018) in all rice regions stands out, closely followed by bentazone. This situation is probably due to the reduced effectiveness of penoxsulam-based herbicides in the control of *Echinochloa* spp., which led to a search by technicians and producers for alternatives. These two active substances have different modes of action. Penoxsulam inhibits the activity of AcetoLactate Synthase (ALS) (HRAC 2), a key enzyme in the biosynthesis of amino acids. Profoxydim, on the other hand, acts on fatty acid synthesis by inhibiting the activity of the enzyme Acetyl-Co-A carboxylase (ACCAse)–HRAC 1 (HRAC, 2020).

3.3. Other Weed Control Measures

Sustainable weed management involves other practices that contribute to reducing weed pressure in the early stages of the crop, when competition is most intense. These methods have already been mentioned above, and are the so-called cultural measures (rotation, stale seedbed, sowing density, varieties that are more competitive or more tolerant to the presence of weeds) and physical methods (lowering, tillage and mowing). In order to allow a structured reading of this work in agreement with the technical itinerary of rice we present, we present the results on three points: production system (production modes and rotation); physical methods associated with soil preparation for sowing; and cropping practices from sowing to harvest, including also the stale seedbed technique, the incorporation of organic matter into the soil (seed bank issue) and irrigation systems between beds.

3.3.1. Production Modes and Crop Systems

Through the results of the survey, we observe that the majority of producers used ICP (91.5% of the cases not omitted). Only two farmers produced organic rice (2.8% of the valid cases). Three producers indicated conventional production, and one stated that he had part in conventional production and part in integrated production mode. Most farmers produced rice in monocropping for at least five years (90.1% of the non-missing cases; only one case omitted). There are significant differences between the three regions (chi-square and Monte Carlo tests of 0.5%). Crop rotation was followed by seven farmers in *Sado*, one in *Sorraia* and none in *Mondego*. Crop rotation in the *Sado* valley (*Alentejo*, South) is associated with water limitations, which are frequent in this region, pushing producers to reduce the area devoted to rice and introduce different crops on the plots (e.g., leguminous plants such as cowpeas (*Vigna onguiculata* L. Walp) and chickpeas (*Cicer areatinum* L.).

3.3.2. Physical Methods: Preparation of Soil for Seeding

Regarding the planning of soil for seeding, we focused on the management of straw and stubble, and the methods of tillage and leveling of the soil. The survey responses were classified into four options: incorporation of straw and stubble by harrowing (without water), incorporation of straw and stubble by harrowing (with water), burning of straw and stubble, and mixed practice of burning and incorporation of straw and stubble, along with missing cases or those who indicated none of the above practices. Most rice growers (61%) incorporate straw and stubble by harrowing or with downgrade, with a significant difference between the two practices. Even so, a quarter of the producers who answered this question use burning (Table 4).

Table 4. Management of straw and stubble.

Type		*Mondego*	*Sado*	*Sorraia*	Total
Incorporation with harrowing		6	8	9	23
Incorporation with downgrade	Score	1	17	9	27
	Adjusted residues	−3.8	+3.5	+0.2	
Burning the straw and stubble	Score	9	1	4	14
	Adjusted residues	+2.9	−2.5	−0.3	
Incorporation and burning		1	1	3	5

The management of stubble and straw differs between regions. In the *Mondego* valley there is a preference for burning (56.3%), while in the *Sado* valley incorporation of straw and stubble without burning is performed almost exclusively (96.2%). The *Sorraia* valley is an intermediate situation. In the *Sado* valley (*Alentejo*), incorporation with water into plows and rice wheels is the main way to incorporate straw and stubble. However, in *Mondego* (*Beira Litoral)*, incorporation of straw and stubble with a disc harrow on dry soil is the method applied. The incorporation of straw and stubble with water into the rice beds and wheels, known as the "lowering" operation, is an old practice that has fallen out of use since the implementation of leveling of the beds with laser technology, but this fact may have had an influence on weed emergence [26,27].

Tillage with a rotary ley allows for reducing the seed bank that develops after sowing. The cost of this operation, the time required for its execution and the risk of hindering the leveling operation are some of the factors pointed out by farmers for not performing it anymore.

Only 37.5% of respondents (not omitted) indicated that they use this tillage technique. There are significant differences between regions, particularly between *Mondego* and *Sorraia*. In the former case, there is a greater frequency of tillage with ley turning, while in the latter valley it is rarely used. (Table 5)

Table 5. Comparative analysis of satisfaction levels with post-emergence herbicides for *Echinochloa* spp. control, by rice-growing region.

		Mondego	*Sado*	*Sorraia*	Total
Tillage	Score	17	9	4	30
	Adjusted residues	+3.6	−0.9	−2.7	
Laser-leveling	Score	24	26	25	75

Laser leveling allows the water sheet covering the plot to be uniform and the inflow and outflow of water to be faster. The benefits of this operation are evident, particularly for weed management, as both operations of lowering and raising the water are needed for herbicide application and efficacy. More than 96% of producers (not omitted) use this practice. There are no differences between rice growing regions.

3.3.3. Cultural Weed Control Methods

Concerning the irrigation and drainage system between beds, we verified that the inflow and outflow of water is independent for each bed in 57.3% of the cases. In 41.5% of cases the water transits between beds, or the situation is mixed (Table 6).

Table 6. Inter-bed hydraulics.

		Mondego	*Sado*	*Sorraia*	Total
Water flow between beds	Score	2	22	10	34
	Adjusted residues	−4.2	+4.4	−0.4	
Independent for each bed	Score	23	8	16	47
	Adjusted residues	+3.9	−4.3	+0.5	

There are significant differences between the three regions (chi-square and Monte Carlo method). In the *Mondego* region, independent inlets and outlets between beds predominate (in 80.5% of cases). In the *Sado* valley, there is a predominance of cases with water passing between beds (73.3% of cases). In *Sorraia*, it is an intermediate situation (61.5% with independent water inlets and outlets between beds). The stale seedbed is a technique that allows for drastic reductions in the pressure from *O. sylvatica* and *Echinochloa* spp.

However, there are some difficulties in its implementation, as evidenced by the survey results. Only 8.1% respondents (non-missing) say they use this crop practice. It should also be noted that some producers have difficulty in distinguishing the stale seedbed practice from the simple elimination of weeds that germinate between soil preparation operations (9.8% of respondents did not answer this question). Although we have few cases, there are no significant differences between regions. Three producers from *Mondego* follow stale seedbed, two from the *Sado* region and only one from *Sorraia*.

The incorporation of organic matter in the soil through fertilization is not a usual practice, as only three rice growers affirmed that they performed this practice. Sowing is still conducted mainly by tractor. Only 25.6% use an airplane for sowing. In all regions, sowing with water in the seedbed predominates (86.6%). Regarding the sowing system (Table 7), it is worth noting statistically significant differences between the three rice regions. In the Mondego Valley, sowing is performed with a tractor in flooded beds.

In *Sorraia* (*Ribatejo*), sowing is also performed with a flooded bed, but sowing by airplane predominates, although almost half of the respondents indicated sowing with a tractor. In the *Sado* rice fields there is greater dispersion in the ways of sowing. Dry seeding has some advantages, such as water savings; the use of herbicides with different MoA in pre-emergence, namely, pendimethalin (HRAC-15) and clomazone (HRAC-13); and the reduction of competition with aquatic weeds, due to the diversity of flora that occurs in aerobic conditions. It has, however, some difficulties in implementation, and can only be recommended in certain types of soil. In Italy the adoption of rice dry seeding is much higher than in Portugal; it covers more than 44% of rice fields, mainly because it reduces water consumption [25].

Table 7. Type of sowing.

		Mondego	*Sado*	*Sorraia*	Total
With water in the seedbed, with tractor	Score	25	16	10	51
	Adjusted residues	+4.3	−1.3	−3.0	
No water in the seedbed, with tractor	Score	0	8	1	9
	Adjusted residues	−2–2	+3.5	−1.4	
With water in the bed, with airplane	Score	0	6	13	19
	Adjusted residues	−3.4	−0.5	+3.9	
Mix	Score	1	0	2	3

Rice farmers choose conventional varieties over Clearfield® rice varieties (tolerant to the herbicide imazamox). Imidazolinone tolerant varieties are used mainly in the *Sado* valley (*Alentejo*), where half of rice farmers use this type of seed and 40% use only this type. In the regions of *Beira Litoral* (*Mondego*) and *Ribatejo* (*Sorraia* valley), this practice is less usual. In general, rice farmers in these two regions use only non-imidazolinone-tolerant varieties or sow with both types. Farmers use this technology to control *Oryza sativa* var. *sylvatica*, a weed for which other herbicides have no selectivity because it belongs to the same species as the crop (Table 8).

Table 8. Use of Clearfield technology.

		Mondego	*Sado*	*Sorraia*	Total
Only NO 'Clearfield'	Score	15	15	17	47
	Adjusted residues	0.0	−1.1	+1.2	
Only 'Clearfield '	Score	1	12	2	15
	Adjusted residues	−2.3	+3.8	−1.6	
Both types	Score	10	3	6	19
	Adjusted residues	+2.2	−2.2	+0.1	

The Clearfield® Production System was developed by BASF for the control of wild rice in the early 2000s. It is based on the use of herbicide-tolerant rice varieties resistant to the imidazolinone (imazamox) family, obtained by conventional breeding [24]. The greatest threat to the efficacy of Clearfield® technology is the risk of transfer of tolerance to imidazolinones (IMI) between rice varieties and *Oryza sativa* var. *sylvatica*. This situation can occur by three routes: (a) selection of spontaneous mutations conferring IMI resistance, (b) cross-pollination between the Clearfield® variety and wild rice, and (c) contamination of Clearfield® seed lots [28].

In some rice production areas, there are already known cases of *O. sylvatica* resistant to imazamox selected by gene flow from the crop to the weed [8]. The first was recorded in Arkansas in 2002 [29], and more recently also in Italy and Greece [30]. They are being selected because of misuse of the technology, including seven consecutive years of imazamox-tolerant varieties in the same field. In Italy, 60% of the rice area uses Clearfield® technology [25]. In regions where Clearfield® technology imazamox-tolerant rice varieties predominate, the herbicide provides effective control of *O. sylvatica*. However, best practice recommends not using these varieties more than a given number of years consecutively. It is advised to reduce *O. sylvatica* seed in the meantime.

It should be noted that in the Mondego region, where this technology is little used, wild rice species are the first and second most troublesome weeds, followed by *A. plantago-aquatica* and *Heteranthera* spp. in third and fourth place, respectively. The survey revealed that 13 varieties of rice were grown, with significant differences among the three rice-growing regions, both in the main varieties sown and in variety diversity (Table 9). These results of our survey reflect Portuguese preferences for japonica type varieties due to traditional gastronomic dishes.

In the Mondego valley, the Ariete variety strongly predominates, highlighting the small number of varieties grown. In the *Sorraia* and *Sado* regions there is a greater diversity of varieties, without much predominance of any specific variety. However, the Teti, Sirio and Guadiagran varieties stand out in *Sado* (*Alentejo*), and the Greenfield and Presto varieties in *Sorraia* (*Ribatejo*). In *Mondego* most farmers are in integrated production and are beneficiaries of agro-environmental measures. To access this support, they need to use certified seeds of rice (*Oryza sativa*) of the Carolino variety, japonica type.

Table 9. Rice varieties by region.

Rice Variety	Region			Total
	Mondego	***Sado***	***Sorraia***	
Teti *	6	5	0	11
Ariete *	25	0	6	31
Nemesis	3	1	1	5
Corigan	1	0	0	1
Opal	1	1	4	6
Guara	0	1	3	4
Greenfield *	0	0	4	4
Sirio *	0	7	1	8
Presto *	0	2	10	12
Sprint	0	3	0	3
Ronaldo	0	4	5	9
Guadiagran *	0	6	2	8
Lusitano	0	1	4	5
Number of varieties	5	10	10	

* Differences significant for a significance level of 5%.

3.4. Resistance Risk Assessment

In this work, we evaluated the risk of resistance based on the number of different types of herbicides applied annually and an analysis of the MoA of the different herbicides. There is greater diversity in the type of herbicides applied in the *Alentejo* and *Ribatejo* regions than in the *Beira Litoral* region. In the *Sado* valley the diversity is almost double that of the *Mondego* region, either in terms of the number of different herbicides applied annually, or in terms of the number of different MoA over the five-year period. ANOVA proves the existence of statistically significant differences between regions, with a significance level of less than 0.001 (Table 10).

Table 10. Comparative analysis of herbicides by rice-growing region.

Region		Number of Herbicides Applied per Year	Number of MoA (During Five Years)
Mondego	Average	1.1	1.9
	N	25	25
	Error Variance	0.3	0.6
Sado	Average	2.0	3.7
	N	20	20
	Error Variance	1.1	1.5
Sorraia	Average	1.7	3.0
	N	23	23
	Error Variance	0.8	1.2
Total	Average	1.6	2.8
	N	68	68
	7Error Variance	0.8	1.3

In addition to these two indicators, the number of cases in which farmers applied ALS-inhibitor herbicides was also determined. Almost all rice growers apply some type of herbicide that presents this mode of action, with no significant differences between regions. There were only 11 cases (out of 68 valid responses) in which no herbicide with this MoA was applied: six cases in Mondego, one in *Sado* and four in the *Sorraia* valley. These results suggest a high risk of resistance, since we are dealing with systems with intensive use of herbicides.

The maintenance of paddy rice crops in the same monoculture fields favors the predominance of highly competitive weeds adapted to anaerobic conditions, such as *Echinochloa* spp. It is noteworthy that weed management brings with it an almost exclusive reliance on chemical methods with no selection of other alternative methods, either cultural or physical. This scenario is reinforced by the repeated applications of herbicides with the same mode of action, where not only one ALS herbicide but rather two or three are applied in the same year consecutively over five years, contributing to a high cross-section pressure for resistance.

Considering the results of this risk assessment, it is important to compare these with the trends expressed by the rice producers surveyed within the field assessment, which indicated the following dissemination of resistance to penoxsulam in several *Echinochloa* spp. (*Echinochloa phyllopogon* and *Echinochloa. crus-galli* subsp. *hispidula*) populations: 90% in *Baixo Mondego* (*Beira Litoral*), 50% in *Sado* valley rice fields (*Alentejo*) and 25% in the *Tejo* and *Sorraia* valleys (*Ribatejo*) [31].

These results explain the different use of penoxsulam in the three regions, as mentioned above: greater use in the *Baixo Mondego* region, followed by the *Sado* and finally the *Tejo* (Tagus) valley rice fields. The confirmed lack of efficacy of penoxsulam (HRAC-2) may justify the growing trend towards applying profoxydim (HRAC-1) in all regions as an alternative demand by technicians and producers, as it is an active substance with a different mode of action. As in other countries, in general, little has been done to prevent the evolution of resistance. Once resistance evolves, *Echinochloa* populations are mostly managed by switching to herbicides with different modes of action and, in some cases, by applying different agronomic practices [32,33].

Regional comparison indicates a greater concern with *Echinochloa* spp. in the *Sado* and *Sorraia* regions relative to the *Mondego* region. However, *Echinochloa* spp. are the weeds that cause the most concern to rice farmers. *Sado* (*Alentejo*) and *Sorraia* (*Ribatejo*) producers seek greater efficacy by using a broader mixture of herbicides, and this option is expressed in the results of the focus groups.

In the project GO +Arroz that supports this study, resistance to penoxsulam was confirmed in *Echinochloa* spp. populations based on a field survey on three regions with dose–response bioassays.

3.5. Adopting New Practices for Herbicide Application

For the adoption of new practices in herbicide application, the results of the surveys and focus groups revealed that information received by farmers on changing the mode of application is scarce. Only two farmers stated that they receive information from an advisory system, even though the overwhelming majority (92.7%) indicated that they receive support from some entity. There may be some bias here due to the *sampling* method.

Farmers in the Mondego valley receive support mainly from a cooperative, while in the *Sorraia* and *Sado* regions, they are integrated into a producers' organization that provides them with technical support. Six cases reported receiving support from a private company. It is noteworthy that more than a quarter of rice growers (27.5%) stated that they changed their herbicide application scheme from the previous year, with no statistically significant differences between rice producing regions. The changes were various, ranging from the type of herbicide, date of application and volume, to the rice variety and type of weeding.

3.6. Results of the Focus Groups

The conclusions of the three meetings organized based on the five questions posed to the participants are summarized below (Table 11). The Mondego region focus group met on 11 December 2019, the *Ribatejo* focus group met on 29 January 2020, and the *Sado* region focus group met on 6 February of the same year.

It should be noted that weed resistance was mentioned in all regions, with *Echinochloa* spp. identified in all regions as the main concern, as revealed in the results of the survey of rice growers. Decreased efficacy of herbicides against weeds was mentioned in all regions, with the question being whether the cause is acquired herbicide resistance or a failure in herbicide efficacy due to unfavorable conditions at the time of application.

The relationship between resistance, efficacy, and poor herbicide diversity was discussed. As for the strategies that different regions apply or could apply, focus groups in each region presented different proposals and perspectives, with no consensus within the focus groups in each region and between regions. However, all agreed upon the need for better knowledge of herbicide use (time of application, MoA) and the different types of cultural techniques, namely, tillage and dry sowing, as common factors to mitigate the risk of resistance.

Table 11. Summary of focus group findings by region.

Questions	*Mondego*	*Sado*	*Sorraia*
Q1. What is the perception regarding weed resistance in the region?	Increased level of resistance to herbicides. Emergence of new weeds	Water grass (*Echinochloa* spp.) are the most problematic. Doubts about whether we are dealing with herbicide resistance or lack of effectiveness in herbicide application.	Herbicide resistance for some weeds. Lack of efficacy is not always associated with herbicide resistance.
Q2. What strategies are being implemented in that direction, are there results?	Negative to dry soil preparation. Positive: rotation and other cultural practices; change in sowing date, rotation of herbicides and height of water blades after harvest. New solutions not very feasible: cleaning of marrows, manual weeding and thermal weeding.	Several solutions tested: dry seeding with buried seedlings, tillage, herbicide mix, more effective water management. No agreement on the most effective solution. Consensus on the option of manual weeding, but with the problem of a lack of workforce.	Alternation of herbicides with different modes of action (most common) and localized application of herbicides. Crop practices such as tillage, change in soil preparation mode, improved irrigation management, dry sowing with buried seed, rapid soil covering.
Q3. Which crops are most adapted for a rotation, and what to consider in a three-year economic assessment?	Corn and pea. Positive: increases production and decreases the cost of the crop. However, there is the problem of uneven land and runoff from alternative crops.	Leguminous crops, especially chickpeas (low profitability and lack of organization). Difficulty in implementation: saline and heavy soils (hinders cropping alternatives); restrictions in terms of available water (the alternative is autumn/winter crops)	Corn and sorghum. Possibility of producing forage legumes or producing legumes for agro-industry. Implementation difficulties: saline soils and heavy soils (hinder cultural alternatives); problem of unevenness of the land; technical and economic difficulties for the implementation of alternative crops. Herbicide efficacy (with increased cost) preferred to the use of crop rotation.
Q4. False seeding, with or without flooding? How to be implemented?	Positive, but the three-week delay in sowing causes crop losses.	Water for irrigation is only available from late April or early May.	Late sowing problems (lack of early, productive varieties) and possibility of available water restrictions. The alternative is post-harvest tillage, taking advantage of the still favorable temperature.
Q5. What results would you like to see from this project?	Technical manual for crop practices. Mapping of weeds and herbicide resistance. Presentation of best practice cases in other countries, with an exchange of experiences.	Decision support tools for weed control. Raising public awareness about efforts in rice production and technological advances. Mediation between the project team and official entities to improve the search for solutions and their dissemination.	Technical solutions to improve the effectiveness of herbicides and the production of new herbicides; agricultural tools that allow for other forms of soil preparation and the improvement of the "tillage" technique. Dissemination of project results. Financial compensatory measures for the implementation of crop rotation and false sowing.

Crop rotation was considered by all focus groups and in all regions to be a means of controlling weeds. However, at the same time, it was considered to be a difficult, if not impossible, technique to implement from both economic and technical points of view due to the characteristics of the soil in which rice is grown, as well as the cultivation and disposal of alternative crops. The following were identified as possible crops for rotation: corn (*Zea mays* L.), chickpeas (*Cicer arienatum* L.), sorghum (*Sorghum bicolor* L.) and peas (*Pisum sativum* L.). Stale seedbed is recognized as a good technical option for reducing problematic weeds, such as *O. sylvatica* and *Echinochloa* spp. Stale seedbed was found to be difficult to implement due to water scarcity in certain regions and the delayed sowing that such a procedure involves. The groups emphasized that they would like the GO + Arroz (Operational Group +Rice) project to develop decision support tools, such as technical manuals and agricultural extension programs in the sector with technical and scientific dissemination concerning weeds. The intersection between rice stakeholders and those responsible for agricultural policies for the sector, taking into consideration the increasing present-day weed problem, was also pointed out.

4. Discussion

Weed problems are the main concern expressed by farmers in a survey of rice farmers in Mondego, and herbicide costs are the main production cost, accounting for about 18% of total production costs [1]. The results of the present study indicate that *Echinochloa* spp. is the weed of most concern, followed by *Oryza sativa* var. *sylvatica*. It is noteworthy that new weeds of concern are beginning to emerge, especially *Leptochloa fusca* ssp. *fascularis*.

The main means presently used for weed control is through chemicals, despite the high costs, and there is a low degree of satisfaction with the efficacy of herbicides. Rice growers recognize added difficulties associated with their use due to the emergence of resistance, but also raise doubts about the loss of efficacy due to incorrect application, the choice of active substance, and the date and technical form of application. Water management in rice weed control also plays a major role.

Rice producers seek to adjust by adopting new products and using herbicide mixtures, with more than a quarter of respondents expressing that they have changed the previous year's herbicide application scheme, having used on average three different MoA over the five-year period. However, on average, they apply less than two different herbicides per year, and nearly all apply ALS inhibitor herbicides. Regarding crop management practices, rice producers recognize their importance, particularly to mitigate the lower efficacy of herbicides, but the results show very low adherence to crop management practices. However, the Clearfield® technology was applied by 42% of farmers. This technology has proved to be an innovation and is associated with tolerance of rice varieties to imidazolinones (especially important for *O. sylvatica* control), but it is pesticide-using technology.

The survey results confirmed the low adoption of alternative physical and cultural measures, and the main reasons for this were exposed in the focus groups, namely in the cases of rotation and stale seedbed. These restrictions are especially related to climate and soil conditions: strong constraints on cultivating other crops due to saline and heavy soils, and the stale seedbed option is difficult to implement due to the climatic conditions for sowing and harvesting dates. Other constraints related to crop rotation are the learning process for cultivating a new crop (namely, regarding access to production factors and knowledge of production practices), the viability of crop, and the difficulties associated with the commercialization of new production (lack of commercial contacts, low market power, or low productivity of these rotation crops).

5. Conclusions

The results of the study lead to a conclusion of the existence of increased weed resistance to herbicides and problematic weed management in rice crops. Despite the increase in the phenomenon of resistance to herbicides, rice growers are looking for solutions within the framework of the use of herbicides without a predisposition to adopt other methods of control, such as stale seedbed and crop rotation. Rice growers' attitudes and practices are conditioned based on soil, climate, and economic factors, as well as technical competence.

The implementation of these alternative control methods cannot be generalized but must be considered on a case-by-case basis [10,34–37], and requires technical monitoring adapted to the region and to the plot (depending on the soil type, size and location of the bed, degree of infestation, and weeds present). These local specificities of the ecosystem, the farmers' lack of knowledge, and the complexity of the learning process for new crops or techniques make non-chemical alternatives very risky for farmers. Despite the costs and the risks of herbicide resistance, they are still following the path of pesticide use.

It will be crucial to act at the innovation ecosystem level, from the emergence of scientific and technical knowledge applicable to new solutions, to the evolution of social capital that can promote skills and relationships between economic agents, and to political measures that support and encourage innovation and the implementation of more ecological and sustainable practices. The problem of herbicide resistance is growing and may deteriorate with the reduction in the number of active substances, available MoA and even the use of Clearfield® technology. There is difficulty in adopting non-chemical weed control practices when we need to move in the opposite direction to reduce the high costs of herbicides and meet the requirements of the European Ecological Pact, particularly regarding reducing the use of herbicides.

Author Contributions: Conceptualization, I.C. and P.R.; methodology, I.C. and P.R.; validation, I.C., P.R. and M.d.F.O.; formal analysis and data curation, Isabel Calha, P.R. and M.d.F.O.; investigation, I.C. and P.R.; resources, I.C., P.R. and M.d.F.O. writing—original draft preparation and review and editing, I.C., P.R. and M.d.F.O.; visualization and supervision, I.C., P.R. and M.d.F.O.; project administration, I.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the study financed by the project Operational Group +ARROZ, PDR2020 program, grant number: PDR2020-101-031998.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Gonçalo Canha, (Lusosem), for support with sectorial organizations; Teresa Pereira, Rodrigo Capela and Jorge Zambujo (*Aparroz),* Joaquim Cabeça and Teresa Ribeiro (*Benagro)*, João Alegria (*Orivárzea)*, Patricia Lopes (*Portarroz)* and Tiago Salgado, for their valuable collaboration in the implementation of the survey to rice growers. We would like to thank António Jordão (*DRAP Centro)*, Ana Paula Nunes (*COTHN)* and Teresa Pereira (*Aparroz)* for their collaboration in organizing the focus groups and compiling the conclusions. The authors wish to thank Ana Bela Lopes (Agriculture School, Polytechnic Institute of Coimbra, CERNAS), for her improvement of the manuscript's English. A special thank you to the 82 producers who made possible the survey.

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

Appendix A

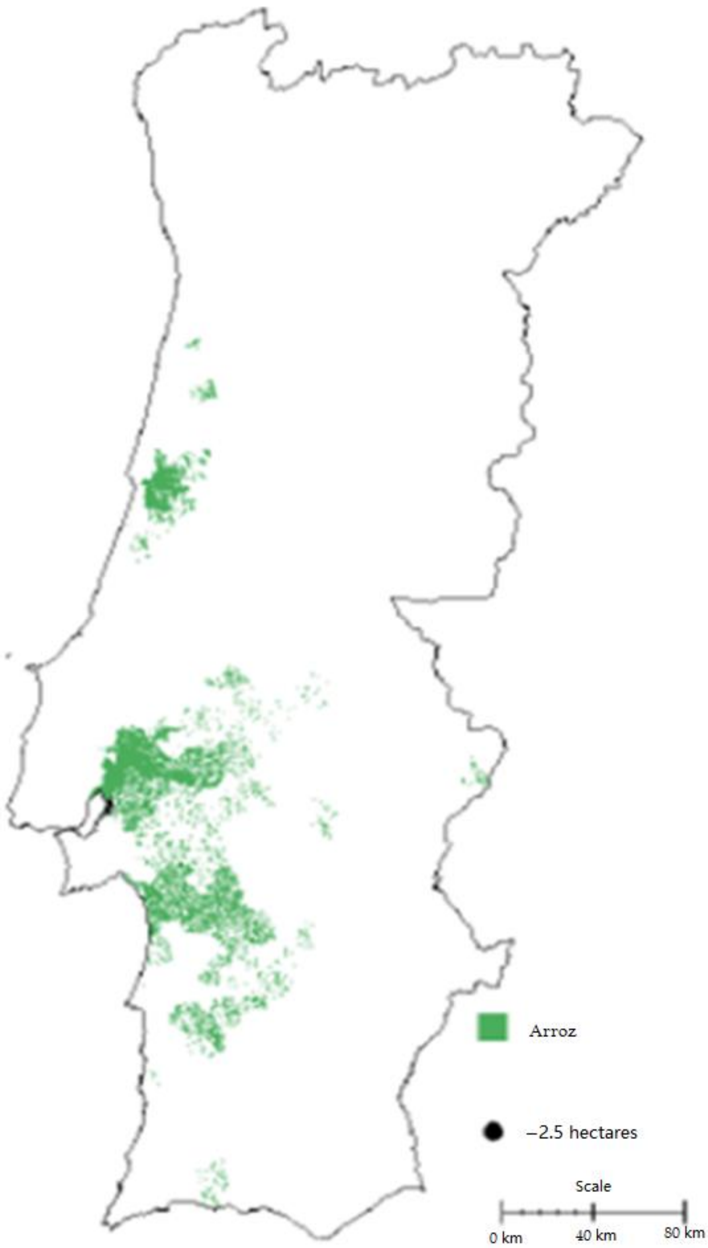

Figure A1. Rice regions in Portugal. **Source:** ARROZ A P O R I Z A [38].

Appendix B

Table A1. Scientific Name and EPPO/OEPP Code of rice weeds.

Scientific Name	EPPO/OEPP Code
Echinochloa spp.	ECHSS
Oryza sativa L. var. *sylvatica*	ORYSY
Alisma plantago-aquatica L.	ALSPA
Heteranthera spp.	HERSS
Leptochloa fusca ssp. *fascicularis* (Lam.) Gray	LEFFA
Cyperus rotundus L.	CYPRO
Cyperus esculentus L.	CYPES
Cyperus difformis L	CYPDI

Table A1. *Cont.*

Scientific Name	EPPO/OEPP Code
Schoenoplectus mucronatus (L.) Palla	SCPMU
Paspalum paspalodes (Michx.) Schribn.	PASDS
Cynodon dactylon (L.) Pers.	CYNDA
Leersia oryzoides (L.) Swartz	LEROR
Glyceria declinata Breb.	GLYDE
Echinochloa phyllopogon (Stapf) Koss./Vasc.	ECHPH

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