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Views of RNAi approaches for weed management in turfgrass systems

Sandra R. Ethridge[1], Khara Grieger[2], Anna M. Locke[3], Wesley J. Everman[4], David L. Jordan[5] and Ramon G. Leon[6]

[1]Graduate Research Assistant, Department of Crop and Soil Sciences, North Carolina State University, Raleigh, NC, USA; [2]Assistant Professor, Department of Applied Ecology, North Carolina State University, Raleigh, NC, USA; [3]Research Plant Physiologist, Soybean & Nitrogen Fixation Research, USDA Agricultural Research Service, Raleigh, NC, USA; [4]Associate Professor, Department of Crop and Soil Sciences, North Carolina State University, Raleigh, NC, USA; [5]William Neal Reynolds Distinguished Professor, Department of Crop and Soil Sciences, North Carolina State University, Raleigh, NC, USA and [6]Professor and University Faculty Scholar, Department of Crop and Soil Sciences, North Carolina State University, Raleigh, NC, USA

Research Article

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Corresponding author:
Ramon G. Leon; Email: rleon@ncsu.edu

Abstract

Public concern regarding the use of herbicides in urban areas (e.g., golf courses, parks, lawns) is increasing. Thus, there is a need for alternative methods for weed control that are safe for the public, effective against weeds, and yet selective to turfgrass and other desirable species. New molecular tools such as ribonucleic acid interference (RNAi) have the potential to meet all those requirements, but before these technologies can be implemented, it is critical to understand the perceptions of key stakeholders to facilitate adoption as well as regulatory processes. With this in mind, turfgrass system managers, such as golf course superintendents and lawn care providers, were surveyed to gain insight into the perception and potential adoption of RNAi technology for weed management. Based on survey results, turfgrass managers believe that cost of weed management and time spent managing weeds are the main challenges faced in their fields. When considering new weed management tools, survey respondents were most concerned about cost, efficacy, and efficiency of a new product. Survey respondents were also optimistic toward RNAi for weed management and would either use this technology in their own fields or be willing to conduct research to develop RNAi herbicides. Although respondents believed that the general public would have some concerns about this technology, they did not believe this to be the most important factor for them when choosing new weed management tools. The need for new herbicides to balance weed control challenges and public demands is a central factor for turfgrass managers' willingness to use RNAi-based weed control in turfgrass systems. They believe their clientele will be accepting of RNAi tools, although further research is needed to investigate how a wider range of stakeholders perceive RNAi tools for turfgrass management more broadly.

Introduction

Current estimates suggest that worldwide expenditures on pesticides were nearly $56 billion in 2012, with nearly half (i.e., 45%) related to herbicide costs and expenses (USEPA 2017). Weed control is an important component determining the economic and environmental impacts of vegetation management in the landscape; however, the efficacy and diversity of control tools have been decreasing at rapid rates due to the evolution of herbicide-resistant weeds and more stringent registration requirements (Heap 2023; Peters and Strek 2017; Powles and Yu 2010). In addition, there have been no new mechanisms of action (MOAs) introduced to the market in more than 30 yr, which creates major challenges for the future of herbicide-based weed management (Dayan 2019).

In the United States, managed turf area is estimated to be about 163,800 km^2, making this the single largest irrigated U.S. crop (Milesi et al. 2005). Turf includes residential, commercial, and institutional lawns, parks, athletic fields, and golf courses (Milesi et al. 2005). With this large expanse of land, evolution of herbicide resistance has become a major concern for many turfgrass managers (Brosnan et al. 2020a, 2020b), as herbicides are key for effective weed control at such large scales (Hull 1995). Weeds can cause dramatic changes in root and canopy microenvironments in turf, which can result in undesirable outcomes in turf quality (Schmidt and Blaser 1969). Species such as annual bluegrass (*Poa annua* L.) and goosegrass [*Eleusine indica* (L.) Gaertn.] have been confirmed to have resistance to multiple MOAs (Heap 2023), due to strong selection pressure and their high propensity to rapidly evolve resistance to herbicides (Brosnan et al. 2020b).

There has been an increase in public concern and perception of risk regarding the use of herbicides in turfgrass systems (Norgaard 2007), as people can come into direct contact with turf

herbicides, especially in urban areas (Hull 1995). For these reasons, it is expected that over time, there will be more restrictions for herbicide use in turfgrass. Therefore, there is a clear need to develop alternative tools that reduce reliance on traditional synthetic herbicides with undesirable toxicological profiles based on current public demands, yet provide effective weed control (Morgan 1992).

The increasing need for effective weed control in herbicide-resistant populations and public demands to reduce herbicide use have generated interest in using approaches based on gene technologies in weed management (Kumaran et al. 2020). One tool in particular, ribonucleic acid interference (RNAi), has been shown to effectively regulate biological processes in plants, such as leaf morphology and development (Palatnik et al. 2003), flowering time, floral organ identity (Aukerman and Sakai 2003), response to stress, and genome integrity (Carbonell 2019). For weed control, it has been shown that 21- to 200-bp double-stranded RNA (dsRNA) molecules can be applied topically to weeds to silence target genes. After foliar application, dsRNAs are absorbed, and once inside cells, they bind and act as guides to target homologous messenger RNA (mRNA) sequences for destruction by an RNA-induced silencing complex, a natural cellular mechanism. The result of mRNA degradation is the elimination of the biosynthesis of target proteins and the potential death of weeds (Sammons et al. 2011). Importantly, several operational aspects of RNA silencing can be species specific (Reinhart et al. 2002). Furthermore, it can prevent the production of enzymes resistant to herbicides and even of non-druggable proteins, which opens a wide range of possibilities to achieve selectivity, control weeds with target-site and non–target site herbicide resistance, and generate new MOAs.

Considering the rapid evolution of herbicide-resistant weeds and the consequent necessity for new solutions, it is necessary to understand the context in which RNAi should be developed and released for commercial use. In this regard, perceptions of this new technology by stakeholders must be a guiding criterion to identify the pathways or constraints for future adoption. In turf, aesthetics is an important factor to consider when landscaping decisions are made (Hayden et al. 2015), so it is imperative to consider the perception of risk in the decision-making process and implementation of a new technology for turf managers. However, new technologies, such as RNAi, face an additional challenge, because potential users have no or limited understanding of how the technology works and its potential benefits and unintended effects. Therefore, they must make decisions about adoption based on limited and frequently simplified introductory information that is possibly intentionally or unintentionally biased. This lack of knowledge of the new technology may result in either a reluctance to try it or, in contrast, an inclination to favor its use, depending on needs and concerns of the potential users.

For these reasons, we conducted a targeted survey to study the views of RNAi technology according to turfgrass managers in the context of herbicide resistant weed management. The hypothesis for this survey was that due to the intrinsic interaction between the public and turfgrass management activities and the increasing potential for herbicide-resistant weeds, turfgrass managers would be open to new tools for weed management but cautious about implementation of the technology. Therefore, the objectives of this study were to understand (1) current herbicide use and importance to turfgrass managers; (2) key challenges currently faced in their organizations regarding weed management; (3) considerations for adoption of new weed control tools; and (4) turfgrass managers' needs, perceptions, and likelihood of implementation of RNAi technology for weed management in turfgrass systems.

Materials and Methods

A survey was conducted at two turfgrass field days in 2022 in Jackson Springs and Raleigh, North Carolina, USA. Survey participants were given a short (5-min) talk describing RNAi systems, the status of the technology, and potential uses for weed control. They were also provided with a handout with details for them to have in hand when answering the survey (see Supplementary Material).

Next, the survey was distributed as paper copies to participants in attendance at the turfgrass field days, which included various positions/careers related to the turfgrass industry. The survey consisted of 13 questions (Table 1), including multiple-choice, Likert-scale, and fill-in-the-blank questions. Two questions were related to demographics (occupation and years of experience), and 11 were given to understand weed control considerations and the perception of implementing new weed control technologies. Before the survey's distribution, the questions were tested for clarity by a group of weed and turfgrass scientists and personnel with different levels of education involved in turfgrass management at the North Carolina State University campus. A total of 157 participants started the survey, while only 141 participants completed the survey. For a survey to be considered complete for this study, more than 75% (10 out of 13) of the questions had to be answered.

A frequency analysis was conducted to analyze the distribution of responses across surveys. For questions 3 and 4, stakeholders were split into three groups based on the level of interaction with end users (i.e., general public), and the results were analyzed using a chi-square test for differences in proportion of responses.

Results and Discussion

Survey Demographics

The vast majority of survey respondents (i.e., 80%) were individuals who represented diverse aspects of turfgrass management (Table 2). The remaining 20% of respondents were those who represented "other" areas of expertise, including individuals from parks and recreation management, Extension agents, crop consultants, government positions, landscaping directors, athletic field management, and industry and academic turf scientists. In addition, more than half of the respondents indicated that they had 0 to 10 yr of experience, with almost one-quarter having 11 to 20 yr, and the remaining quarter having more than 20 yr of experience in their field (Table 3).

Importance of Herbicides for Weed Management in Turf Systems

The vast majority of survey respondents (i.e., 95%) indicated that they currently use herbicides for weed control, while only 4.3% reported not using herbicides in their turfgrass operations. Less than 1% said they did not know or preferred not to answer. These findings indicate that the survey included respondents not only representing a comprehensive range of turfgrass systems but also with firsthand experience in weed control with herbicides. As nearly three-quarters of the respondents had more than 5 yr of experience, it was assumed that they had a clear understanding of the challenges associated with weed control and herbicide use.

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Table 1. Survey questions distributed to turfgrass managers at field days in 2022 in Jackson Springs and Raleigh, North Carolina, USA.

1. Do you currently use herbicides in turfgrass management?
   a. Yes
   b. No
   c. Don't know/prefer not to answer
2. In general, how important is weed management in your job or to your organization?
   a. Absolutely essential
   b. Very important
   c. Average importance
   d. Of little importance
   e. Not important
   f. Don't know/prefer not to answer
3. What are some of the key challenges that you face in your position or at your organization? [Select all that apply]
   a. Cost of weed management
   b. Time spent managing weeds
   c. Limited weed control options
   d. Herbicide-resistant weeds
   e. Environmentally safe weed management solutions
   f. Discussing weed management options with customers
   g. Other (Please specify):_____
4. In your opinion, what are some important factors when considering a new product for turfgrass management?
   a. Efficacy
   b. Cost
   c. Efficiency
   d. Public perception
   e. Environmental impacts
   f. Health impacts
   g. Other (Please specify):_____
5. Considering the description of RNAi technology provided earlier, your current knowledge of turfgrass management, and assuming EPA approval and registration, would you consider implementing this technology for weed management in the near future (i.e., in the next five years)?
   a. Yes
   b. No
   c. Maybe
   d. Don't know/prefer not to answer
6. Why or why not? Please elaborate on the response to the previous question:_____
7. To what degree (if any) is there a need for RNAi technology for weed management in your field of work?
   a. Not at all
   b. Very little
   c. Somewhat
   d. To a great extent
   e. Don't know/prefer not to answer
8. Considering the description of the RNAi technology provided earlier, how do the potential benefits and risks compare?
   a. Benefits greatly outweigh risks
   b. Benefits somewhat outweigh risks
   c. Benefits are equal to risks
   d. Risks somewhat outweigh benefits
   e. Risks greatly outweigh benefits
   f. Don't know/prefer not to answer
9. In your opinion, what do you think would be the level of concern (if any) in the general public regarding RNAi technology for weed control?
   a. Not at all concerned
   b. A little concerned
   c. Neither concerned or unconcerned
   d. Somewhat concerned
   e. Greatly concerned
   f. Don't know/prefer not to answer
10. Would you be willing to test or use a product with RNAi experimentally or participate in research for developing the technology within the near future (i.e., in the next two years)?
    a. No
    b. Maybe
    c. Yes
    d. Don't know/prefer not to answer
11. Do you have any additional comments or suggestions that you would like to share with our research team regarding RNAi technologies?
12. What is your occupation?
    a. Farm manager
    b. Golf course superintendent
    c. Lawn care provider
    d. Groundskeeper
    e. Herbicide applicator
    f. Other (Please specify):_____
13. How many years have you been working in your position?
    a. 0–5
    b. 6–10
    c. 11–15
    d. 16–20
    e. >20

Table 2. Responses to "What is your occupation?"

Occupation	Response[a]
	%
Farm manager	2.5
Golf course superintendent	2.5
Lawn care provider	35.0
Groundskeeper	23.6
Herbicide applicator	14.6
Other[b]	21.7
Total	100

[a]Total number of responses for this question is equal to 157, as some participants considered themselves to be a part of one or more occupation group.
[b]"Other" category consists of individuals from parks and recreation management, Extension agents, crop consultants, government positions, landscaping directors, athletic field management, and industry and academic turf scientists.

Table 3. Responses to "How many years have you been working in your position?"

Years	Response
	%
0–5	27.7
6–10	24.8
11–15	10.6
16–20	12.8
>20	24.1
Total	100

In addition, all respondents attributed some degree of importance to weed management. For instance, more than 80% of stakeholders reported that weed management in their current position is absolutely essential or very important (Figure 1). The remainder of the sample considered that weeds have an average importance or little importance in their operations. When asked to choose key challenges faced in their positions that involved weeds,

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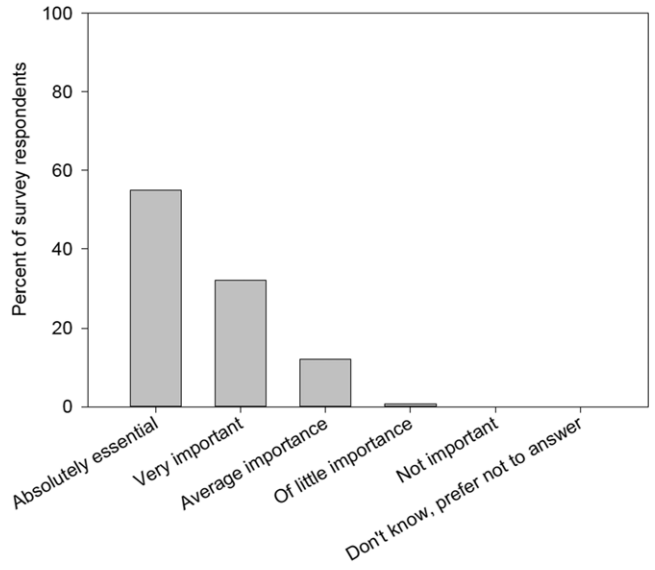

Figure 1. Responses to "In general, how important is weed management in your job or to your organization?"

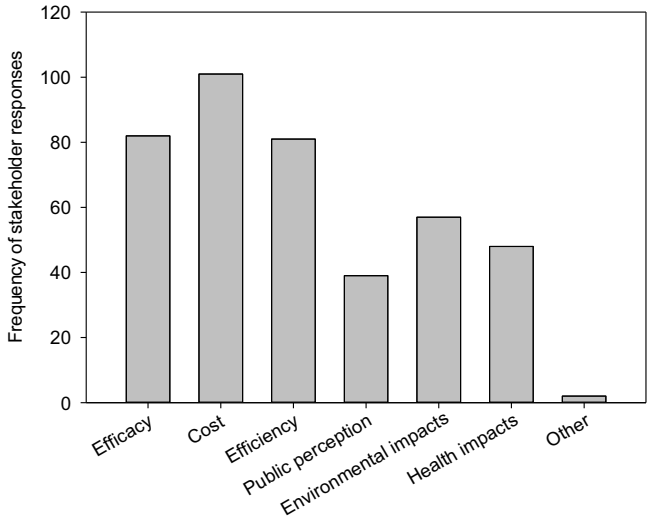

Figure 3. Responses to "In your opinion, what are some important factors when considering a new product for turfgrass management?"

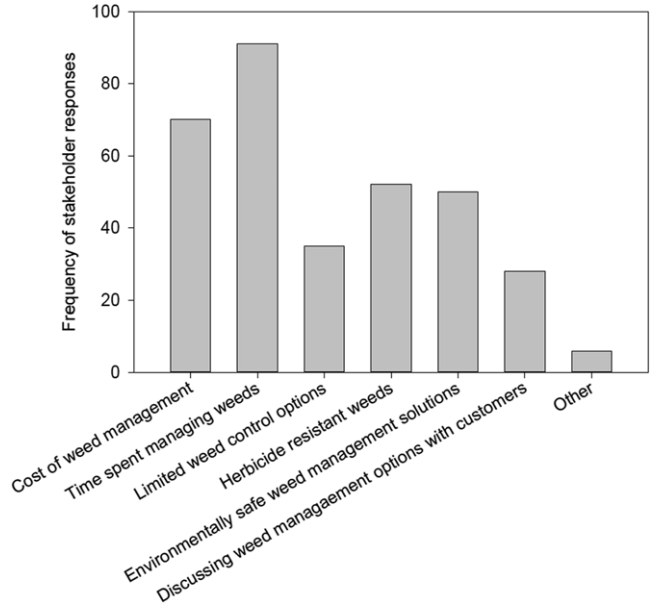

Figure 2. Responses to "What are some of the key challenges that you face in your position or at your organization involving weeds?"

stakeholders ranked time spent managing weeds and cost of weed management as the most important (Figure 2). Herbicide-resistant weeds and the need for environmentally safe weed management solutions represented the second tier of importance, while limited weed control options, discussing weed management options with customers, and other challenges were ranked lowest.

Current Challenges of Weed Management

The challenges associated with time and cost constraints for weed management (Figure 2) were reflected in the factors respondents identified as important when considering new weed products for turfgrass management (Figure 3). For instance, cost, efficacy, and efficiency were a priority for more than 80% of respondents. Interestingly, although around half of the respondents considered that environmental and health impacts were important considerations, only a third of the stakeholders were worried about public perception (Figure 3).

The tolerance for weeds in turfgrass systems is low (Alumai et al. 2008; Marshall et al. 2015). Therefore, weed management is an essential part of any profession in turf. Turfgrass systems, such as golf courses and urban lawns, are high-input systems that require a considerable amount of time, money, and chemicals to maintain aesthetics and functionality at the levels demanded by the clientele of each of those systems (Alumai et al. 2008; Brosnan et al. 2020a; Marshall et al. 2015; Robbins et al. 2001). For those reasons, we investigate how the level of interaction with the public (i.e., their clientele) could be affecting responses of survey participants to key challenges and factors and their decision making when choosing new weed control tools.

Public Interactions Influencing Management Practices

To understand how the public's perception drives decisions in each occupation, survey participants were divided into categories related to likelihood of interacting with the public. The public were defined as end users of turfgrass products, such as golfers, people who visit parks or other recreational sites, or homeowners with lawns. Professions with low likelihood of interaction with the public included sod farm managers, golf course superintendents, and herbicide applicators. Groundskeepers (e.g., parks and recreation, public athletic fields) were considered a profession with a moderate likelihood of interaction with the public, and the profession with a high likelihood of interaction with the public was composed of lawn care providers.

When asked about key challenges faced in their position (Table 1, question 3), differences were seen in the proportion of each group of survey respondent in regard to herbicide resistance, environmentally safe weed management solutions, and discussing weed management options with customers as key challenges at their organizations (Table 4). The proportion of respondents with high levels of interactions with the public, or lawn care providers,

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Table 4. Chi-square analysis of proportion of responses given by respondent groups, divided into low, moderate, and high level of interactions with the public for question 3: "What are some of the key challenges that you face in your position or at your organization?"

Response	Level of interaction[a]			P-value[b]
	Low	Moderate	High	
	——%——			
Cost of weed management	27.3	22.5	18.9	0.1892
Time spent managing weeds	27.3	32.4	27.4	0.7106
Limited weed control options	9.1	11.3	13.2	0.3094
Herbicide-resistant weeds	22.7	8.5	13.2	0.0050
Environmentally safe weed management solutions	4.5	23.9	11.3	<0.0001
Discussing weed management options with customers	4.5	1.4	12.3	0.0005
Other	4.5	0	3.8	0.1858

[a]The results are presented as the percentage of responses within each stakeholder group (low, moderate, or high level of interaction with the public). Survey respondents were separated into the three groups based upon their level of interaction with end users. Professions with low likelihood of interaction with the public included sod farm managers, golf course superintendents, and herbicide applicators. Groundskeepers (e.g., parks and recreation, public athletic fields) were considered a profession with a moderate likelihood of interaction with the public, and the profession with a high likelihood of interaction with the public was composed of lawn care providers.
[b]P-values lower than 0.05 indicate a significant difference between the respondent groups.

Table 5. Chi-square analysis of proportion of responses given by respondent groups, divided into low, moderate, and high level of interactions with the public for question 4: "In your opinion, what are some important factors when considering a new product for turfgrass management?"

Response	Level of interaction[a]			P-value[b]
	Low	Moderate	High	
	——%——			
Efficacy	26.8	11.8	19.7	0.0038
Cost	25.0	20.6	24.1	0.6571
Efficiency	10.7	20.6	19.7	<0.0001
Public perception	7.1	12.7	6.6	0.1030
Environmental impacts	12.5	15.7	13.9	0.5964
Health impacts	14.3	13.7	12.4	0.8352
Other	3.6	4.9	3.6	0.7757

[a]The results are presented as the percentage of responses within each respondent group (low, moderate, or high level of interaction with the public). Respondents were separated into the three groups based upon their level of interaction with end users. Professions with low likelihood of interaction with the public included sod farm managers, golf course superintendents, and herbicide applicators. Groundskeepers (e.g., parks and recreation, public athletic fields) were considered a profession with a moderate likelihood of interaction with the public, and the profession with a high likelihood of interaction with the public was composed of lawn care providers.
[b]P-values lower than 0.05 indicate a significant difference between the respondent groups.

were six times more likely to be concerned about the challenges associated with discussing weed management options with customers than respondents with low and moderate interactions with the public (Table 4). Despite these clear differences regarding interactions with the public, we did not find differences among groups of respondents when considering public perception about new weed control products (Table 5). The proportion of respondents with moderate to high levels of interaction with the public had higher concern for environmentally safe weed management solutions compared with the stakeholders with low public interaction (Table 4). When asked about important factors when considering a new product for turfgrass management, differences were seen in the proportion of each group prioritizing efficacy and efficiency (Table 5). The participants with low and high interactions with the public had a higher concern for efficacy of a new product (Table 5). Participants with high and moderate levels of interactions with the public had the highest concern for the efficiency of a product, followed by those with low public interactions (Table 5).

In this study, positions with low levels of interaction with the public had higher levels of autonomy in regard to weed management decisions in their fields. These individuals are tasked with identifying and diagnosing problems and then designing solutions to best fit the needs of their turf fields. For example, golf course superintendents use their knowledge and experience of their golf courses to implement accurate and efficient site-specific management (Winklerprins 1999). Discussing weed management options is more of a challenge for those professions that have frequent and close interactions with the public, as is the case of lawn care professionals interacting with homeowners. Those interactions are diverse and complex, because homeowners not only have their own preferences but also can be exposed to specific requirements from public policies, local housing regulations (Jenkins 1994), and peer pressure from neighbors (Byrne 2005). Therefore, it is understandable that lawn care professionals are more frequently involved in discussions with a diverse clientele, and they are more concerned about the nuances that drive those discussions.

Professions with moderate to high levels of interaction with the public also believed that finding environmentally safe weed management solutions was a challenge faced in their profession, as compared with professions with low interaction with the public. There is an increased concern from the public regarding the use of synthetic pesticides in urban lawns that have been associated with environmental pollution (Alumai et al. 2008). In addition, the impact of climate change, governmental regulations, and public perceptions have been noted to change the behavior of consumers and businesses toward their use of certain lawn care chemicals (Scotts Miracle-Gro Company 2022). Due to these rising concerns, synthetic pesticide use in these turf systems has been reduced, and the use of alternative lawn management strategies has become more available (Alumai et al. 2008).

The efficiency of a new product for weed control was considered an important factor for turfgrass management. However, the group with low likelihood of interacting with the public were less concerned than the group with a high likelihood of interacting with the public. This could be attributed to the lower number of herbicides registered for lawn care compared with golf courses and sod farms and the need of lawn care companies to have efficient products to manage larger areas and alleviate the labor burden associated with large-scale weed management (Robbins and Sharp 2003).

New Technologies in Weed Management

When considering a description of RNAi technology provided in the survey, their current knowledge of turfgrass management, and assuming U.S. Environmental Protection Agency (USEPA) approval and registration, almost two-thirds of respondents would consider implementing this technology for weed management in the next 5 yr (Table 6). About one-third of the respondents said "maybe" to this possibility, while only a single respondent opposed the use of RNAi. Respondents who answered "yes" to implementing RNAi technology in the future were also those who indicated the need for new, effective weed control tools, environmentally safe solutions, herbicide resistance, and safety (Table 7). Participants

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Table 6. Percentage of stakeholder responses to question 5: "Considering the description of RNAi technology provided earlier, your current knowledge of turfgrass management, and assuming EPA approval and registration, would you consider implementing this technology for weed management in the near future (i.e., in the next five years)?"

Answer	Response
	%
Yes	60.4
Maybe	34.5
No	0.7
Don't know, prefer not to answer	4.3
Total	100

who responded "maybe" were most concerned about needing more information, the cost, considerations of people involved, and weed control and technology (Table 7).

Two-thirds of respondents considered that there was somewhat of or to a great extent a need for RNAi technology for weed management in their field of work (Figure 4). Less than 20% respondents thought there was very little need or no need at all for RNAi technology for weed management (Figure 4). Also, there were almost three times more respondents not knowing or choosing not to answer about the need for RNAi than there were respondents who were uncertain about using this technology themselves. This indicated that a proportion of respondents were willing to try the technology despite of not being clear about the real need for RNAi tools.

After pondering the description of the RNAi technology, half of the respondents considered that the benefits outweigh the risks (Figure 5), while 20% stated the benefits were equal to the risks. There was also a high level of uncertainty surrounding this question, with more than 20% of participants responding: "Don't know, prefer not to answer" (Figure 5).

Next, the respondents were asked to rate a level of concern they think the public might have regarding RNAi technology for weed control. Approximately 40% believed that the public would be somewhat to greatly concerned about this technology (Figure 6), and half considered that the public would be neutral or would have little concern about the use of the technology (Figure 6).

Finally, we asked whether the respondents would be willing to test or use a product with RNAi experimentally or participate in research for developing the technology within the near future (i.e., 2 yr). Almost half of respondents (46%) said they would be willing to participate in research, 39% of respondents would consider this possibility, and 10% answered "no." Only 4.4% respondents said: "Don't know, prefer not to answer."

In turfgrass management, the most dominant form of weed management is the use of herbicides (Watschke et al. 2013). This reliance on herbicides is explained by the fact that turfgrass managers cannot use many methods of control common in other crop systems such as tillage or crop rotations (Brosnan et al. 2020a). However, there have been multiple examples where herbicides have been restricted due to the public's potential exposure, such as in athletic fields (Brosnan et al. 2014).

The necessity to keep many of the turf systems weed-free to maintain aesthetic and functional quality (Brosnan et al. 2020b), yet reduce the amount of herbicide used, makes RNAi a potential solution for both turfgrass managers and the concerned public. The turfgrass managers in our survey responded positively to potential use of RNAi technology for weed management, and many believed that the benefits of this technology would outweigh potential risks (Figure 5). It seems that turfgrass managers' response to the possibility of RNAi becoming a viable solution to their weed management problems was based on "techno-optimism." This is the belief that technology can solve current and future weed control issues, such as herbicide-resistance problems (Dentzman et al. 2016). This is similar to the drivers of adoption of genetically modified organisms. For example, the expectation that glyphosate-resistant crops could simplify and even increase weed control was enough to motivate farmers to try and adopt those crops (Lucht 2015). The perceived usefulness of the new technology has been demonstrated as the most critical factor for potential adoption by farmers (Caffaro et al. 2020; Lucht 2015). Although this techno-optimism can be seen as positive in terms of implementing this new technology, it is critical to properly determine its potential impacts, positive and negative, such as whether adoption is based on realistic expectations. If this new technology is implemented, it must be made clear to beneficiaries that it is not a "silver bullet" and is not intended to replace all other methods of weed control. Furthermore, stewardship of the technology is necessary to reduce the potential overuse and loss of an important new tool for weed management. Unlike farmers and managers, the public is rarely concerned with the benefits of the new tool to solve technical aspects of production. Instead, perception of potential risks is the main driver for public acceptance (Byrne 2006; Lucht 2015; Ruibal-Mendieta and Lints 1998). Therefore, a clear characterization and explanation of risk will likely be necessary to harmonize managers' adoption with public acceptance.

While many respondents were positive about the use of RNAi technology for weed management, there were also some that were more skeptical. Among those who responded "maybe" to the implementation of this new technology, the majority stated that they would need more information or data to decide whether or not this is a technology they would like to see in their fields (Table 7). This "decision delay" allows for respondents to wait and see instead of quickly accepting or rejecting this technology (Gardezi and Arbuckle 2020; McNeill et al. 2015; Morton et al. 2017). This skepticism is welcomed, as in the past new technologies or products, such as glyphosate- and dicamba-resistant crops, have been proven to require evaluations at incremental scales to understand not only the best way to use them for production purposes but also to make sure their benefits are long-lasting (Shaner et al. 2011).

The present study demonstrated that turfgrass managers rely on herbicides as an important tool for weed management. According to the turfgrass managers surveyed, time and cost constraints are a major challenge for weed management. Therefore, when presented with new weed control tools, such as RNAi technology, many were very optimistic about the potential of this new tool and were readily willing to use this product in their fields.

The current survey illustrates how potential users might approach the possibility of using RNAi technology for weed management in turfgrass. Overall, based on responses from 141 individuals who represent a range of turfgrass management, survey participants largely considered there to be a need for innovative technologies such as RNAi to address the multiple challenges associated with the loss of herbicides or the limitations in their use in many production systems. This willingness to try RNAi technology for weed control was accompanied by a lack of concern for the potential opposition that the general public might have to the use of this tool in their communities. However, at the same

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Table 7. Responses of turfgrass managers when asked "Why or why not? Please elaborate on your response to the previous question (i.e., question 5: "Considering the description of RNAi technology provided earlier, your current knowledge of turfgrass management, and assuming EPA approval and registration, would you consider implementing this technology for weed management in the near future [i.e., in the next five years]?")"

Answer	Category[a]	Responses
Yes	Need for new, effective weed control tools	• Always open to improved weed management • Anything to help us with weed control • Any opportunity to be more proactive in control and larger control of certain weeds is welcome. • I would use new herbicides if they are cost-effective and provide good control. • I'm willing to try anything to help. • I'll try anything to make my program better. • Lack of other management options • Need help • To promote a more efficient weed control management plan • Unique methods to solve long-standing issues • We need to be open for new technologies. • Yes, it would help me get more knowledge and learning more about technology for weed management. • Yes, willing to try new things if research shows it is a smart move • Support research studies • I don't know a lot about it but I am all for new technology/things that work well. • If it is effective and not too costly it would be good to use something new. • Good to have more products to choose from • If you can cut inputs and have them be more efficient and cost less • I believe that it could be a great solution, but I would need to do more research. • Always willing to try something new and different • Always interested in new technology • Advancement in the future of weed control needs to be helped/approved as much as possible. • Always looking for new tools for the tool box • Anything that is approved that makes my job easier is great. • To help build information on the subject
	Environmentally safe solutions	• Yes because my end goal is to keep lawns looking clear with little impact to the environment. • Environmentally friendly option • If it works and doesn't kill the planet, I'm good! • Always looking for most efficient, least toxic, and least environmental impact products
	Herbicide resistance	• Limiting resistance • It could reverse herbicide resistance. • Need for options in control and resistance • Need to explore all opportunities, especially in respect to resistance management
	Safety	• It's important to keep everyone safe. • Looking for the safest products • Open to anything safe/effective • Need to act responsibly • I am willing to try anything proven to be safe and effective.
	Other	• To address above issues • New technology • Evolution of industry
Maybe	Needing more information	• I would like more information to gain a better understanding of this technology. • I'm not a get on the boat first, I'll let others be trail blazers and evaluate their experiences before taking the plunge. • Need more information • Need more information, how does it fit into business model • Need more years of information and teaching • Needs a little more data • Not knowledgeable enough to know for sure
	Cost	• Cost • Depending on cost vs. traditional methods • Hope time spent spraying and cost will be worth the time
	Considerations of people involved	• All depends on customer preference • I am concerned about public perception. • This would have to be a discussion agreed upon by all the staff.
	Weed control and technology	• Anything to help with weed control • I will always consider new turf technology.
No[b]	—	None
Don't know, prefer not to answer		• Don't know RNAi well enough • Depending on cost, efficacy, and health impacts but reading about it now sounds good

[a]Categories were used to arrange write-in responses based upon the answer given in question 5.
[b]Those who responded "no" to question 5 did not respond to question 6.

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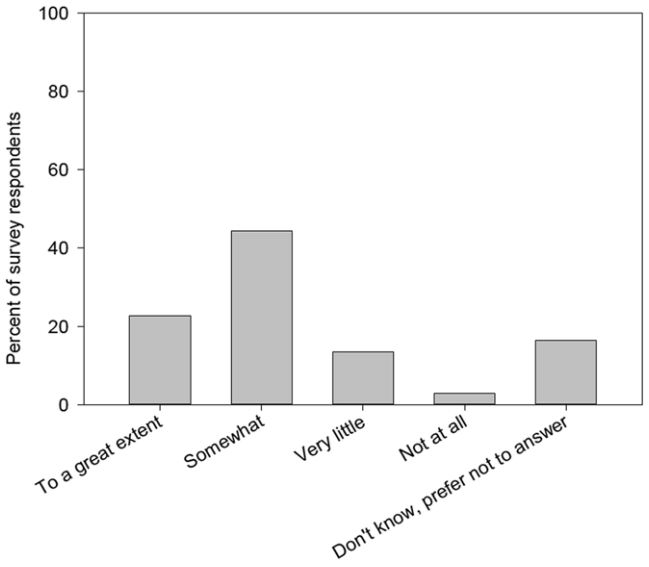

Figure 4. Responses to "To what degree (if any) is there a need for RNAi technology for weed management in your field of work?"

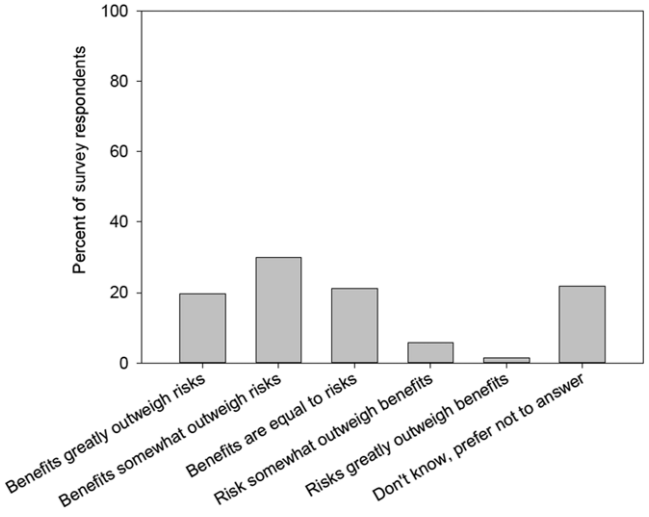

Figure 5. Responses to "Considering the description of the RNAi technology provided earlier, how do the potential benefits and risks compare?"

time, we recognize that the survey was distributed to individuals who attended turfgrass field day events and may not be representative of a broader range of stakeholders potentially impacted by new RNAi technologies for use in turfgrass systems. Additionally, it is likely that the explanation and handout provided to participants influenced their responses. Both were intended to provide an objective description of the technology. However, we recognize that the information provided might not be enough for respondents to make a fully informed decision. Furthermore, it is likely that under real situations, stakeholders would be exposed to both overly positive and overly negative information. From this perspective, exposure to biased information is an intrinsic part of the decision process. Therefore, future research should focus on determining how this technology should be introduced to both turfgrass managers as well as the various other stakeholder groups that could be impacted, including environmental groups, residents, and managers of homeowners associations, among others. This

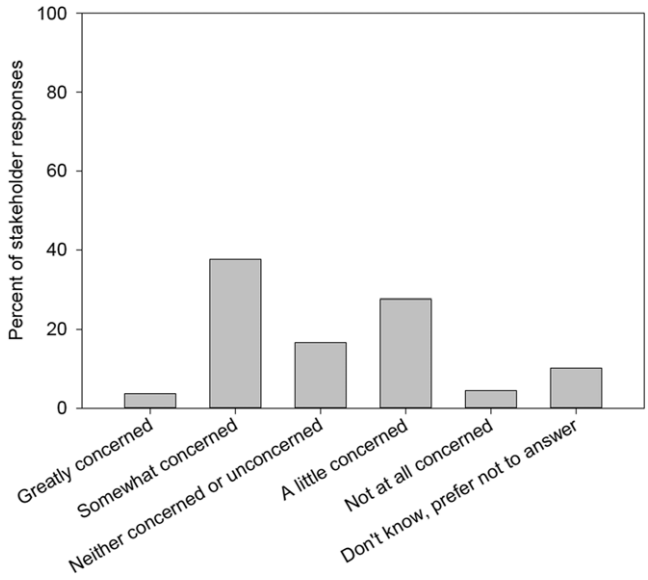

Figure 6. Responses to "In your opinion, what do you think would be the level of concern (if any) in the general public regarding RNAi technology for weed control?"

should be done in such a way that the development of the product is not circumscribed just to ensure control efficacy and efficiency but also encompasses strategies to inform the general public and incorporate their concerns before the technology is used at a large scale.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/wsc.2023.37

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